Jens Bennedsen, Aage Birkkjær Lauritsen,
Kristina Edström, Natha Kuptasthien, Janne
Roslöf & Robert Songer (eds.)

The 15th International CDIO Conference

Proceedings – Full Papers

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AARHUS UNIVERSITY

cdio

Editorial

The CDIO approach is an innovative educational framework for producing the next generation of engineers. The aim is an education that supports students in the acquisition of strong technical fundamentals while simultaneously developing the necessary professional skills required of a practising engineer. This is done by providing students with dual-impact learning experiences that are based upon the lifecycle of an engineering project, the Conceiving – Designing – Implementing – Operating (CDIO) of real-world products, processes, and systems. Throughout the world, more than 165 institutions have adopted CDIO as the framework of their curriculum development.

The Annual International Conference is the central meeting of the CDIO Initiative, and it includes presentations of papers as well as specialised seminars, workshops, roundtables, events and activities. The 15th International CDIO Conference takes place in Aarhus, Denmark, June 24-28, 2019, hosted by Aarhus University. The organisers together with the city of Aarhus welcome you to the event!

The theme of this year is Change. The theme is visible in the keynote presentations, paper presentations, roundtables and workshops. The rich topical program will facilitate lively discussion and contribute to the further advancement of engineering education.

The conference includes three types of contributions: Full Papers, Project in Progress contributions, and Extended Abstracts. The Full Papers fall into three tracks: Advances in CDIO, CDIO Implementation, and Engineering Education Research. All contributions have undergone a full single-blind peer-review process to meet scholarly standards. The Projects in Progress contributions describe current activities and initial developments that have not yet reached completion at the time of writing, and the Extended Abstracts summarise the Roundtable discussions and Workshops held at the event.

Initially, 226 abstracts were submitted to the conference. The authors of the accepted Full Paper and Projects in Progress abstracts submitted 142 manuscripts to the peer-review process. During the review, 458 review reports were filed by 104 members of the 2019 International Program Committee. Acceptance decisions were made based on these reviews. The reviewers' constructive remarks served as valuable support to the authors of the accepted papers when they prepared the final versions of their contributions. We want to address our warmest thanks to those who participated in the rigorous review process.

This publication contains the 75 accepted Full Paper contributions to be presented at the conference, of which 3 are Advances in CDIO, 60 are CDIO Implementation, and 12 are Engineering Education Research. These papers have been written by 234 different authors representing 25 countries. This book is available as an electronic publication only. In addition to the Full Papers, 28 Projects in Progress contributions, as well as 14 Extended Abstracts,

are to be presented at the conference and are not included in this publication. Two working groups have been working prior to the conference and the day before the conference.

We hope you find these contributions valuable for your own research, curriculum development, and teaching practice, ultimately furthering the engineering profession. We also hope that you benefit through the truly unique community of practice that exists within the CDIO Initiative. More than 140 institutions from 33 countries, representing 6 continents, will be present at the conference. Seize the opportunity to discuss and share with colleagues, as global awareness and partnerships are of significant importance in the education of the next generation of engineers.

Wishing all of you a wonderful CDIO 2019 experience!

Aarhus, 24 June 2019

Jens Bennedsen   *Kristina Edström*   *Natha Kuptasthien*

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Table of Contents

Advances in CDIO

CDIO Implementation

Engineering Education Reseacrh

Advances in CDIO

ENGINEERING EDUCATION: INSTITUTIONALIZATION, INTERNATIONALIZATION, AND GRADUATE ATTRIBUTES

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ABSTRACT

Internationalization is becoming an agenda of growing strategic importance to higher education institutions across the world driven by influences of globalization. Embedding the internationalization process within the CDIO context would certainly benefit the higher education institutions and the attributes of their graduates. This paper suggests embedding implicitly the internationalization process within the CDIO standards without the needfor creating additional mandatory or optional ones. The case of institutionalizing the internationalization process at the Australian College of Kuwait is then presented and discussed.

KEYWORDS

Internationalization, Globalization, Institutionalization, Graduate Attributes, CDIO, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

Due to the internationalization, liberalization, and globalization trends, there is an increase in interdependence, innovation and research, convergence of economies, and liberalization of trade and markets. Within the context of engineering education, changes in the nature of knowledge are imposing new requirements on the academic systems such as relevance, quality, accreditation, graduate's employability and mobility, innovation, and entrepreneurship (Stier, 2004).

Therefore, engineering colleges at the world-class universities are nowadays taking into account globalization and international dimensions in the various aspects of their activities including: teaching and learning, curriculum development, student services, and innovative assessment methods, etc. Internationalization is becoming a key institutional strategy in engineering education to support sustainable economic development (Knight, 1999, 2004, 2015).

Nowadays, internationalization of the curriculum is geared towards what students will experience rather than what they will learn and how they will demonstrate their learning. An internationalized curriculum should engage students with informed research and cultural and linguistic diversity and develop their perspectives as global citizens. It will also foster their ability to interpret local concerns within a global context.

To this end, the CDIO is introduced to contextualize engineering education. The concept of Conceiving, Designing, Implementing, and Operating engineering activities, offers an excellent structure for internationalizing engineering education. The CDIO standards capture in one framework the effective practices of successful engineering education, which were identified through benchmarking of programs worldwide (Crawley et Al., 2007). Consecutively, several studies were conducted to emphasize on the internationalization aspects and suggest formalizing this concept in the form of additional optional (Malmqvist et al., 2017) or mandatory CDIO standards (Campbell and Beck, 2010). However, these were addressed by updating the CDIO syllabus without amending its 12 standards.

In this paper, the concept of embedding the internationalization process implicitly within the available 12 CDIO standards is firstly addressed after a thorough investigation of the evolution of internationalization during the last two decades. Second, the steps adopted at the Australian College of Kuwait (ACK) to institutionalize the suggested concept are presented.

INTERNATIONALIZATION

Internationalization at the national sector and institutional levels were initially defined as: "the process of integrating an international or intercultural dimension into the teaching, research, and service functions of a higher education institution" (Knight, 1994, 1999, 2004). More recently, this definition had been generalized to: "the process of integrating an international, intercultural, or global dimension into the purpose, functions or delivery of postsecondary education" (Knight, 2015).

An internationalized higher education institution is associated with success in research funding, recruitment of international faculty and students, student mobility (inbound and outbound), availability of abundant resources to conduct advanced research, and a favorable governance structure.

The Evolution of Internationalization's Definition

By comparing the similarities and differences between the two definitions above, one would extract the evolution of internationalization in the past two decades. Starting with the first invariant, it is clear that internationalization is still regarded as a *process* in the sense that it keeps evolving according to the surrounding inputs and desired outputs. Although these inputs and outputs should be ideally common among nations and institutions in order to reach a positive convergence of the internationalization process towards a better world and future for humanity, it is an unfortunate fact that divergent concepts and ideologies about internationalization had emerged in the past few decades which made the possibility of unifying the implementation of internationalization questionable.

Three forms of ideologies about internationalization had been identified (Stier, 2004): idealism, instrumentalism and educationalism. Idealists regard higher education institutions that implement internationalization as the savior of humanity. From their perspective,

internationalized curricula would increase the awareness of global life-conditions and social injustice, thus spreading equity and eliminating social injustice. On the other hand, instrumentalism ideologists view internationalization as a mean of maximizing nations' and/or institutions' profits, economic growth and ideologies for the sake of sustainable development. As for educationalists, the role of internationalization is to enrich the individuals' (e.g. students' and academics') soft and technical skills by placing them in a broader internationalized study environment. As such, a better commitment to learning, personal growth and long-life learning are acquired.

The second invariant between the former and the updated definitions is the "integration of international and intercultural dimension" which is the core aspect of internationalization that opens the door for relationships between and among nations, cultures or countries. One should not confuse though such integration with the flow of people, capital, ideologies, media and cultural impulses across borders which is usually referred to as globalization (de Wit, 2001). Indeed, the internationalization of higher education is considered to be a response to, and even a product of, globalization. In other words, "internationalization is changing the world of education and globalization is changing the world of internationalization" (Knight, 2015). Therefore, it is not strange that the word "global dimension" is added to the new definition of internationalization as an indicator of its strong dependence on globalization.

Finally, the previously discussed dimensions are no more integrated solely into "the teaching, research, and service functions of a higher education institution", they are integrated into "the purpose, functions or delivery of postsecondary education" in the newer definition. Once again, as a response to globalization, it is nowadays required that internationalization is integrated as part of the higher education institutions' missions, visions and core values in addition to their other teaching, research and community service functions. Another important aspect is that internationalization is no more restricted to higher education institutions but also to any other post-secondary education sector (Knight, 2015).

CDIO

The CDIO defines the premise of conceive-design-implement-operate as the context of engineering education. As such, graduating engineers should be able to "conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment" (Crawley, Malmqvist, Lucas & Brodeur, 2011). In other words, graduating engineers should appreciate the engineering process by identifying and/or analyzing engineering problems, designing potential solutions and contributing to the development of these solutions in the form of engineering products, and do so while working in engineering organizations. Consequently, 12 standards were derived as a guideline for educational program reform and evaluation, create benchmarks and goals with the worldwide application, and provide a framework for continuous improvement (CDIO, 2010). They are a well-developed international model, a basis of common comparison of student learning outcomes, and a basis for common accreditation (Crawley, Malmqvist, Ostlund, Brodeur & Edstrom, 2014).

For a better understanding of its concept, the CDIO syllabus was developed as a complimentary detailed description of the knowledge, skills, and attitudes necessary to become successful young engineers (Crawley, Malmqvist, Lucas & Brodeur, 2011). The objectives of the syllabus are to create clear, complete, and consistent set of goals for engineering education in sufficient detail that could be understood and implemented by

engineering faculty (Crawley et al. 2014). The strength of the CDIO syllabus is in its international adaptability across all engineering schools.

INTERNATIONALIZATION & CDIO

Whereas internationalization is a process that requires the incorporation of international and intercultural, global dimensions into higher education systems, the CDIO provides a context of engineering education. Incorporating internationalization into the CDIO framework requires introducing the concepts and dimensions of internationalization within the CDIO standards and/or syllabus. It is here worth recalling the various benefits CDIO institutions would gain by implementing internationalization. Depending on the adopted ideology the advantages would be: economic growth, profit, exchange of know-how, larger labor force, cultural transmission, personal growth, commitment and long-life learning, respect, tolerance among people, social change, redistribution of wealth, personal commitment, etc. (Stier, 2004).

For the sake of the internationalization of CDIO based curriculum, Campbell and Beck (2010) suggested the addition of a 13th standard entitled "CDIO Internationalization and Mobility". This suggestion was not approved and was simply addressed by adding some concepts related to a global perspective, working in an international organization, foreign language, and international norms under the sections 4.1.6, 4.2.5, 3.3 and 2.5.2 in the CDIO syllabus respectively (Crawley, Malmqvist, Lucas & Brodeur, 2011). More recently, Malmqvist, Edström, and Hugo (2017) proposed the creation of optional CDIO standards, one of them being "Internationalization and Mobility" which was inspired from the previous standard proposal of Campbell and Beck (2010). Other 11 additional optional standards were also proposed at that time. Although this approach would look more convincing for the CDIO council, it is still looking into internationalization as a standard rather than a process. An internationalized CDIO curriculum should rather implicitly incorporate international, intercultural and global dimensions in each of the existing standards, rather than creating a separate core or optional standard.

Table 1 summarizes the actions that may be applied towards internationalization distributed over the existing CDIO standards. We here emphasize that all the actions listed as "evidences" in the 13th CDIO standard proposed by Campbell and Beck (2010) or in the optional standard proposed by Malmqvist, Edström, and Hugo (2017) are somehow related to the existing 12 standards as detailed in Table 1 below.

Table 1. Implicit incorporation of internationalization dimensions into CDIO standards

Standard	Highlights from the standard	Actions toward internationalization
1. The Context	Conceive stage includes defining customer needs considering technology, enterprise strategy, and regulations; and, developing conceptual, technical, and business plans	The customer can be a global/international customer located anywhere around the world, e.g. an international partner.
	The Design stage focuses on creating the design, that is, the plans, drawings, and algorithms that describe what will be implemented.	Usage of internationally recognized software tools and standards.

		The Implement stage refers to the transformation of the design into the product, process, or system, including manufacturing, coding, testing and validation	Mobility allows students to perform each of these processes in different places around the world.
2.	Learning Outcomes	Learning outcomes are reviewed and validated by key stakeholders, that is, groups who share an interest in the graduates of engineering programs, for consistency with program goals and relevance to engineering practice	International Accreditations. International Stakeholders.
3.	Integrated Curriculum	An integrated curriculum includes learning experiences that lead to the acquisition of personal and interpersonal skills, and product, process, and system building skills (Standard 2), interwoven with the learning of disciplinary knowledge and its application in professional engineering	Adoption of Project Based Learning, taking into account: International projects (or a portion of it). Multinational students working within the same group. International PBL facilitators.
4.	Introduction to Engineering	Students engage in the practice of engineering through problem-solving and simple design exercises, individually and in teams.	Multinational students working together within the same group. Adopting the multi-cultural aspects to the design.
5.	Design-Implement Experiences	Included are all of the activities described in Standard One at the Design and Implement stages, plus appropriate aspects of conceptual design from the Conceive stage.	The conceive stage does not have to solve national or governmental problems. It may tackle international engineering problems.
		Opportunities to conceive, design, implement, and operate products, processes, and systems may also be included in required co-curricular activities, for example, undergraduate research projects and internships	Involving students in International Research projects. Participating in international internship students exchange programs (e.g. IAESTE).
6.	Engineering Workspaces	The physical learning environment includes traditional learning spaces, for example, classrooms, lecture halls, and seminar rooms, as well as engineering workspaces and laboratories	Promote e-learning, remote access to software licenses across countries (mutual interest between international partners), remote access to e-libraries, mobility of students to allow for out-campus and abroad hands-on experience.
7.	Integrated Learning Experiences	Integrated learning experiences are pedagogical approaches that foster the learning of disciplinary knowledge simultaneously with personal and interpersonal skills, and	International partners to provide exercises that allow the students to analyze a product, its design, and the social responsibility of the designer of

		product, process, and system building skills	the product at an international level.
8.	Active Learning	Active learning in lecture-based courses can include such methods as partner and small-group discussions, demonstrations, debates, concept questions, and feedback from students about what they are learning.	Involvement of international faculty members in the same course. Creating multinational and multicultural students groups.
9.	Enhancement of Faculty Competence	Examples of actions that enhance faculty competence include: professional leave to work in industry, partnerships with industry colleagues in research and education projects, inclusion of engineering practice as a criterion for hiring and promotion, and appropriate professional development experiences at the university.	Partnerships with international industries which allow for abroad professional leave, international research projects. International speakers and professional development sessions for faculty members. Encouraging the participation to international conferences, seminars and workshops.
10.	Enhancement of Faculty Teaching Competence	Examples of actions that enhance faculty competence include: support for faculty participation in university and external faculty development programs, forums for sharing ideas and best practices, and emphasis in performance reviews and hiring on effective teaching methods.	External would refer to abroad professional development programs.
11.	Learning Assessment	These methods may include written and oral tests, observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.	Inviting international experts to assess the student learning. Conducting simultaneous assessments in different countries using the same assessment tool. Transparent credit transfer approach and policy.
12.	Program Evaluation	A CDIO program should be evaluated relative to these 12 CDIO Standards.	In an internationalized CDIO based institution, internationalization dimensions summarized in this table should be an important factor in evaluating the program.

INSTITUTIONALIZATION OF INTERNATIONALIZATION

Internationalization has become an indicator of quality in higher education (De Wit, 2011, p.39). Mainstreaming internationalization requires an integral process-based approach to be adopted by higher education institutions. This process is referred to as 'institutionalization" of internationalization. Institutionalization becomes a critical component of the internationalization process of engineering education. It is defined as the establishment of formal organizational

features and support with a level of permanence that extends further than the usual publishing or project cycles (Youtie, Li, Rogers & Shapira 2017).

To achieve the optimal outcomes of internationalization, there are specific institutionalization routes which must be adhered to by the institution. Curriculum, course development, faculty activities, scholarship with the pedagogy, and reward and recognition are clear evidence of the institutionalization of service-learning among faculty members. Meanwhile, courses, student culture, co-curricular transcripts documenting service and service-learning scholarships are demonstrations of the institutionalization of service learning among students.

The institutionalization process can be addressed from different dimensions: government policy, higher education institution level, and basic academic unit and individual professor level (Shin, 2013). However, when discussing institutionalizing internationalization, it is important to note that the process of internationalization is not a straightforward one, it is cyclical rather than linear (Qiang, 2003). Accordingly, institutionalization may be viewed along two dimensions: some higher education institutions will adopt international elements in a sporadic and irregular manner in terms of procedure and structure, and others will develop precise, strategic and systematic procedures (Qiang, 2003).

The institutionalization process within any higher education institution will vary. However, regardless of the differences, there are certain steps that seem inevitably common. These steps are summarized in Figure 1 below.

Pre-institutionalization Phase
- This phase involves all the necessary steps that should be adopted by the university before embarking on the process of internationalization. This entails:
- Studying the national/provincial policies
- Identifying university policies that favor this process
- Consulting with the necessary stakeholders
- Identifying funding channels (within the university or nationally) to sustain this process.

Institutionalization Phase
- This phase is one in which the university actually sets out to establish the necessary structure for internationalization:
- Creating the internationalization structure
- Establishing this structure
- Laying the activities of this structure
- Conducting research with external stakeholders
- Creating the mechanisms for monitoring the implementation

Post-Institutionalization
- This phase covers aspects related to sustainability of the process:
- Using the co-generated knowledge, sharing lessons and good practices
- Identifying best practices and efforts aimed at scaling up the positive outcomes so that the benefits accrued can be multiplied and replicated.

Figure 1. The institutionalization steps

INSTITUTIONALIZATION OF INTERNATIONALIZATION & CDIO: CASE OF THE AUSTRALIAN COLLEGE OF KUWAIT

To internationalize engineering education, the Australian College of Kuwait adopted the CDIO standards while meeting the Graduate Attributes specified by Engineers Australia. Institutionalizing the CDIO framework entailed changes to the College's overall structures, objectives, and curricula. This reform required the College to undergo pedagogical and institutional modifications in addition to changes to its policies and procedures.

Institutionalizing internationalization is a process of long-term change and was initiated at the level of the College's executive leaders with a clear vision. During the pre-institutionalization phase, the College assessed the level and requirements of internationalization in order to develop the institutional structures for its integration. Prior to the formation of internationalization strategies, the College conducted a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to produce information that aided in the strategic planning process. Through SWOT analysis, the College identified the internal and external factors which can and cannot be acted upon in order to strategize internationalization. The SWOT analysis aided the College in the identification of the required budget and resources for internationalization. In addition, it served as an important tool for benchmarking practices within the Gulf Region and internationally which resulted in modifications to policies and procedures. For instance, promotion and incentive schemes were enhanced to attract international high caliber faculty and retain existing ones. Conducting quality assurance processes such as SWOT analysis enabled the College to devise targeted strategies to implement the CDIO model and to develop the necessary institutional frameworks along with it.

During the institutionalization phase, the implementation of the CDIO framework resulted in the adoption of a new pedagogical framework based on experiential learning for engineering education. This implied a shift in engineering education to a more integrated curriculum, changes in the curricular structure, and benchmarking the existing curriculum from the perspective of the CDIO syllabus.

As a result, the College amended the Project Based Learning to match the CDIO standards requirements and incorporate the internationalization aspects as described in Table 1. At the moment, 20% of the engineering curriculum is based on this approach which facilitates the process of learning and retention through promoting deep knowledge of technical fundamentals and of practical skills. By following CDIO Standards 3 and 10 under actions towards internationalization, the College has set out agreements with Aalborg University for Project Based Learning (PBL) to enhance the faculty's competencies and share best practices. Furthermore, international workshops and symposiums related to PBL were attended by the College's faculty members. These workshops allowed faculty members to identify areas of similarities and differences between the PBL practiced in Europe and the way it is practiced at the College. "It is impressive how the PBL classrooms are organized in Aalborg, promoting students' collaboration while preserving the privacy and the confidentiality of their work", one of the attendees expressed after his visit to Aalborg. Another faculty member who attended the workshop stated, "the PBL at Aalborg went through several reforms until it reached its current state, which means that the concept of PBL needs to be reviewed and reformed from time to time".

The PBL center at ACK collected the feedback of the participants and implemented several changes to the PBL approach as a result of this international exposure. To this end, the PBL classrooms were enhanced to promote privacy and convenience of the students while working on their projects. In addition, the assessment framework of PBL units was enhanced and this resulted in a higher rate of student satisfaction. For instance, an ACK alumni stated when asked about the best learning experience, skill or knowledge acquired at ACK: "PBL is

incredibly useful in the workplace, it is very easy for me to identify what is professional and what is not, how to plan for a project, to design and implement it and more importantly to present and document its outcomes".

The College further invested in recruiting international faculty members. Currently, the College benefits from the presence of a high percentage (88%) of international faculty with diverse experiences and skills. This diversity exposes students to various teaching styles, projects and problems originating from different countries around the world. The College also has students from different countries and cultures which is an added contribution to the diversity of thought within the campus. "I learned to work with teammates each originated from a country and each tackles the problem from his or her own point of view. All these points of views were valid and this was really impressive and beneficial", one of the student's stated when asked about his group work during a PBL experience he had at the College.

To ensure the CDIO based pedagogy is penetrated into the teaching process as per Standards 2 and 11 under actions towards internationalization, the Graduate Attributes were developed in consultation with the international strategic learning partner universities (Central Queensland University in Australia and Cape Breton University in Canada), transnational professional accreditation agency (Engineers Australia), and locally with the ACK Industry Advisory Board. These combined inputs ensure that ACK engineering students acquire an international standard of education which is also tailored to meet workplace expectations within Kuwait and the MENA region. For the benefit of both faculty and students, the ACK graduate attributes were further divided into clusters of abilities and learning outcomes. This provided clarification to faculty in the preparation of individual course materials and assessments as well as guidelines to students regarding specific expectations and outcomes from the learning process.

To institutionalize internationalization as per CDIO standard 9 under actions towards internationalization, the College developed comprehensive strategies for research and development. As a result, since 2015, the College's publications have dramatically increased by 168%.

As stated in table 1 under actions towards internationalization within standards 2 and 7, sustaining the process of institutionalizing internationalization required the College to maintain strategic collaborations with Central Queensland University (CQU) and Cape Breton University (CBU) and expand its cooperation through academic activities, joint research cooperation, and funding. At the school level, the engineering program was accredited by Engineers Australia (EA), and at the institutional level, the College has attained the Quality Management System ISO 9001:2015 certification and became a proud member of the Association of Arab Universities (AARU).

Furthermore, to promote students' mobility and provide them with hands-on experience as elaborated in table 1 standard 5 and 6 under actions towards internationalization, an agreement was set-out with the International Association for the Exchange of Students for Technical Experience (IAESTE) to facilitate international internships for students. This association is connecting more than 80 countries by exchanging over 4000 traineeships each year. Furthermore, the College has introduced a local internship program where as of 2016, 384 engineering students have interned in different international and multinational worksites around Kuwait.

CONCLUSION

This paper has demonstrated the process of embedding internationalization within the CDIO standards without the requirement to create mandatory or optional standards. It has also explained the integrated multidimensional approach adopted by the Australian College of Kuwait to institutionalize internationalization for its engineering education.

The internationalization process at the College has resulted in significant improvements in the teaching practices and pedagogy methods. In addition, there have been tangible improvements in the students' performance. Overall, implementation is in its initial phases and there is still a lack of longitudinal data to assess the long-term outcomes. With that said, the short-term outcomes have been promising. The process of internationalizing education is long-term, multifaceted, and not straightforward. In addition, the involvement of many stakeholders such as the government and policymakers creates challenges that could potentially affect its impact and limit its implementation. Therefore, it is recommended that the impact and effectiveness of internationalization at the Australian College of Kuwait is assessed in 2-5 years and informed by data collected along the way.

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CDIO THAILAND: COMMUNITY OF GOOD PRACTICES FOR THAI ENGINEERING EDUCATION

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ABSTRACT

In order to strengthen the reformation of engineering education in Thailand, the faculty of engineering, Chulalongkorn University (CU) and Rajamangala University of Technology Thanyaburi (RMUTT) formed CDIO Thailand since 2014. For five years, both CU and RMUTT CDIO practitioners have reached out to more than 2,000 scholars from more than 20 institutions. This paper aims to share how CU and RMUTT implemented CDIO framework into their institutions. In addition, this paper describes how CDIO Thailand supports both engineering and non-engineering educators in the process of implementing CDIO framework at a course level, program level and institutional level. The objectives of this network are (1) to serve as a community of good practices and pedagogical competence towards the educational reform (2) to provide CDIO knowledge and guidelines for implementing CDIO, and (3) to contribute to CDIO Asian Region and CDIO Worldwide Initiatives. Furthermore, the benefits of program level CDIO implementations compared to piece-meal improvement were demonstrated, as well as the discussion of effectiveness of the accreditation requirement in providing motivation for educational changes in Thailand.

KEYWORDS

Faculty development, community of practices, pedagogical competent, standards: 1, 10, 12.

INTRODUCTION

CDIO has reached Thailand in 2013 when Singapore Polytechnic International, Faculty of Engineering, Chulalongkorn University (CU) and Rajamangala University of Technology Thanyaburi (RMUTT) launched a project titled "Temasek Foundation – Singapore Polytechnic: Conceive, Design, Implement, and Operate (CDIO) Framework for Re-Thinking Engineering Education Thailand", which was supported by Temasek Foundation. Faculty members of both institutes adopted and implemented the CDIO framework during a series of workshops that covered the CDIO Syllabus, in addition to 12 CDIO standards. The project ended in 2014 where 10 CDIO master trainers were titled. CU, the first Thai university, represents a research university, while RMUTT characterizes a more technical university. CDIO Thailand was founded in 2014 to assist in the reformation and strengthening of engineering education in Thailand. The platform embraces the CDIO standard 10, Community of Practices (CoP), and Adult Learning Model for Faculty Development.

This paper aims to share how CDIO Thailand:
(1) serve as a community of good practices and pedagogical competence towards the educational reform
(2) provide CDIO knowledge and guidelines for implementing CDIO, and
(3) contribute to the CDIO Community

LITERATURE REVIEW

CDIO Standard 10 (2010) encourages CDIO programs to enhance faculty competence by providing integrated learning experiences (Standard 7), using active and experiential learning (Standard 8), and assessing student learning (Standard 11). These faculty development practices may vary depending on the nature, scope, programs and institutions (Crawley et al., 2007). The visualizing 17 years of CDIO influences published by Meikleham et al. (2018) revealed that more discussions on faculty development and learning assessment are critically important factors that play a role in continuing the sustainability of CDIO initiatives. A development of holistic faculty development systems, continuous support from the senior management team, promoting a network for sharing and evidence-based approaches are recommended (Thompson and Clark, 2018). Leong et al. (2016) presented a well-structured approach for teaching competence development at Singapore Polytechnic (SP). This model consists of supporting the needs of newly-hired faculty members, implementing ongoing developments for teaching lecturers, encouraging teaching & learning Initiatives and providing the necessary platforms for sharing and learning. KTH Royal Institute of Technology initiated a systematic approach for faculty development where the pedagogical developers facilitate wider, effective co-operation and knowledge exchanges among faculty members (Berglund et al., 2016, 2017, 2018)

The community of Practice (CoP), developed by Wenger (1998) is widely used in higher education institutions. Wenger (2015) concludes CoP in a nutshell as follows:

"Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly."

A CoP has three characteristics:

(1) A shared domain of interest where members show commitment and possess a shared competence.
(2) A community where members participate in activities, discuss, support other members and share information.
(3) Practices where members share a repertoire of resources and practices.

The community of practice can lead to sustaining changes. It involves a group of educators/lecturers who meet regularly to share expertise and work collaboratively towards improving teaching skills and the academic performance of students. These specific activities and goals of learning community may vary depending on each institution (Lee et al., 2018)

Professional developers nowadays are facing a demand for incorporating technology into learning, a challenge of funding, a diversity of learners and educational settings and a paradigm shift from teaching-focus to learning-focus.

Lawler and King (2003) have presented an integrative approach to professional development involving adult education, learner-centered perspectives, transformative learning styles, needs towards motivation and technology learning.

A current trend in professional development programs is the Adult Learning Model for Faculty Development where faculty members are viewed as adult learners. Adult learners are considered a diverse group, with different lives, education experiences and perspectives. They expect personalized learning which is meaningful, adjusts to their physical and psychological attributes and is suitable for their social and cultural context. The 6 adult learning principles (Lawler and King, 2000) can be referred as guidelines for professional developers: creating a climate of respect, encouraging active participation, building up on experience, employing collaborative inquiry, learning for action, and empowering the participants.

With the knowledge of CDIO framework, CoP and the Adult Learning Model for Faculty Development, CU and RMUTT have implemented CDIO concept regarding their contexts as research and technical universities. CDIO Thailand provides a platform for two universities to learn and share their experiences. Each institution has established its own system of faculty development. Occasionally, CDIO master trainers co-organize and co-teach the participants in CDIO workshop and tutorials at various faculty development programs.

IMPLEMENTATION AT CHULALONGKORN UNIVERSITY

CDIO and Innovation society

The very first standard of 12 CDIO standards is the context. Standard 1 can be read as interpreting **engineering professions as an innovative process.** In recent years, the nature of innovation – its place in 21st century industry, its importance in the global socio-economic landscape and its effects on engineering professions raises more questions than answers in Thailand.

Innovation society is a global phenomenon and it affects global and Thai engineering landscape. As a result, despite such a quirky name (that Thai professors often ask about its meaning), the concept of dealing with the innovation process at its core is relevant to the development and implementation of engineering programs in response to changes in the industry. It should be noted that CU called its implementation of CDIO concept as CEE4.0 (Chula Engineering Education 4.0) since 2014, while the government dubbed its push for a new model of development based on creativity and innovation as Thailand 4.0 in 2016.

The biggest change from introducing the context of innovation comes in the form of **design thinking**. A new course, Creative Design for Community 2100-303 was initiated in 2015. Alumni with knowledge and experience in design thinking from Stanford University was invited to team up with faculty members to develop this course as a general education course. The course was developed to devote to experiential learning of design thinking in practice. The setting of this course is interdisciplinary with students from engineering as well as other disciplines such as economics, commerce, psychology and arts. In the same way that CEE4.0 preceded Thailand 4.0, the introduction of design thinking at the time preceded popular training on design thinking on offers everywhere today.

On the other hand, the very concept of innovation takes time to understand especially when it is described as engineering practices (that although well-founded is still regularly disrupted nowadays). **The first attempt** to deploy the CDIO framework school-wide (all 12 programs at CU) was not a success. These difficulties in understanding and working on program-level CDIO framework were well documented (Lee et al., 2015)

The renewed strategy for CU's implementation of CDIO is made up of two parts. The first part is to support and recognize existing programs that already support the policy. The second

part is to develop central facilities common to all programs. These facilities lessen the burden for the CDIO programs and demonstrate benefits to the programs not yet taken on CDIO. The facilities include common courses and common learning spaces.

Common facilities – instilling core competency for the entire class
In implementing the CDIO framework into existing curriculum, one of the key success factors in inviting changes from the faculty is to **involve key stakeholders** – the students and industry in this case.

To prepare students for the mindset-changing-concept of design thinking, the **introduction to engineering** course called *Exploring Engineering World* in the first year was revamped (Sripakagorn, 2014). The experiential learning of the design thinking was arranged in team learning in a period of 5 weeks. The learning was focused on 6 major problems that Thailand was facing which were shared by participations of faculty members from all programs in the style of multidisciplinary discussions. The course works with over 20 faculty members from 12 programs and handles about 400 students per semester.

Not only are mindsets need changing, **the professional skills** are also to be installed as well (as per CDIO standard 2). Apart from skills specifics to a particular program/discipline, certain skill sets were identified to be common to many programs. In an attempt to expedite rapid change and assure common outcomes, a course called *Engineering Essentials* was offered as a common core course for programs to choose from. It was managed by Engineering Education Initiative, EEi unit where different teams from various companies were invited to coach students in developing different skills. EEi co-developed the course outcomes as well as the assessment with interested programs. The results of the assessment were reported back to the programs accordingly. Later on, EEi arranged a train-the-trainers sessions which allowed faculty members to become more gradually engaged in skill developments with skills and confidence.

To wrap up the CDIO implementation, EEi lay out another course, **multidisciplinary senior project,** as a final year course focusing on the full implementation of C-D-I-O process in design and built projects. Active learning (CDIO Standard 8) was supported by a newly conceived learning space called iSCALE (denoted i-Student-centered-active-learning-experience). The CDIO workspace (CDIO Standard 6) was supported by a newly conceived Mi (denoted Making Innovatist) working space. All of these facilities are located in the Centennial building where EEi office also located. A major part of CDIO implementation activities being situated in one location makes it easier for visitors to become inspired and informed. Recently, EEi together with CDIO learning facilities received regular visits from engineering, as well as non-engineering schools such as medical, pharmaceutical, education and nursing.

CDIO – program level implementation – insight to inherent resistance
Although the concept of outcome-based education is not new to higher levels of Thai education, the concept of **program-level implementation** is surprisingly neglected. The improvements within educational practices are usually associated with correct documentation of program outcomes, assessments and the use of active learning along with educational technology. These efficient and temporary improvements are necessary with finding quick solutions but are not enough to scale up to university level curriculums. Incidentally, high-level management would find these elements in CDIO standards and might find it fulfilling. Nevertheless, in order to apply sustainable and profound changes in a program reform, the program-level implementation is needed.

The CDIO framework provides 3 crucial ingredients for the full awareness of program-level implementations. The first ingredient is the 12 CDIO standards, the 5 Standards (1, 3, 7, 11 and 12) which are specific to these program-level implementations. This provides awareness

for top management to act on the effectiveness of the program level implementation. The second ingredient is the availability of rubrics for each of the standards. This allows the use of an effective tool for easy adoptions and adaptations. On the other hand, the rubrics all benchmarking that reveals the ineffectiveness of the implementation for future action. The last ingredient is the global community of knowledge and experience. When the program committee decides to proceed with a program-level implementation (sometimes after **negligence and/or denial**), support units such as EEi can provide extra assistance with local as well as international knowledge from the outside.

Although a major challenge in CDIO implementation is usually attributed to buy-in from faculty members, the experience at CU pointed to another aspect – the nature of the program committee. It makes a lot of sense to say, it is best to work on one thing with people with motivation on. And once it is clear that CDIO is always about program-level, effective implementation needs to go through the program committee. From many reasons, it is usually found that the members of the program committee are either senior faculty members that are rather detached from innovation/changes/21st century skills or junior faculty members that are full of energy but have full workload from academic and research works. Between the two groups of people, the junior faculty members are more passionate about educational reform and try to have some experience of their own in practicing teaching technique or educational technology. As a result, with such business-as-usual scenario, educational reform at the program level – with or without CDIO framework – is not possible. Recommendations are; employ a Professional Standards Framework (Higher Education Academy, 2011) to nurture future program committee and reward the program committee to reflect its importance in educational reform regarding time, budget and recognition.

EEi - Local Ed Tech Influencer

Although the concept of program-level implementation takes time to catch on, active participation of EEi in the local community of practitioners allows EEi to influence the policy and the funding from the university in supporting education improvement in other schools within Chulalongkorn University. Working in partnership with the Learning Innovation Center, EEi expands and deepens interest in active learning, flipped classroom and a new style of learning space (iSCALE) that is usually called a smart classroom. Activities include arranging workshop and visit, issuing calls for classroom-action-research proposal and providing co-funding to schools to develop its own smart classroom. Until recently, the partnership resulted in smart classroom development in 10 faculties in CU.

IMPLEMENTATION AT RMUTT

RMUTT has fully adopted and implemented CDIO Framework at three levels: (1) Course/Subject Level, (2) Program Level, and (3) Institutional Level. At course/subject level, the lecturer can apply CDIO standard 4, 5, 7, 8 to improve student's learning outcomes. For the program level, the program committee plays a vital role in designing a student's university experience with full implementation of CDIO Syllabus and CDIO standard 1-12. The institutional level requires a full commitment of top management such as deans, directors, president, as well as, financial supports.

To achieve educational change at RMUTT, the top management realize the important of mindset change of the faculty members. Since CDIO project in 2013, the university set annual budget approximately 15 million Thai Baht (equivalent approximately to 500,000 US dollars) for faculty development. Table 1 summarizes the numbers of faculty members who attended the CDIO training. Currently, 46% of the total number of RMUTT faculty members understand CDIO-based education knowledge.

At the same time, there are other models that RMUTT also explore and support the training, namely, Competency-based education, STEM Education, Design Thinking, University Pedagogy, and Thai Meister. One faculty member can belong to more than 1 CoP regarding their interests. Until now, there are 5 CoPs at RMUTT running by trainers of each faculty development models. Different titles are awarded to the trainers; namely, CDIO master trainer, STEM ambassador, University Pedagogy mentor, Design Thinking facilitator, and Thai Meister. Flarup and Wivel (2018) stated that the trainers as change agents who drive cultural change of mindset in implementing CDIO. RMUTT, too, value these key persons to sustain the change at their faculties. RMUTT strongly commits in establishing a community of pedagogical competent of the community. To provide a good quality of higher education, three features are reviewed and implement related to CDIO standards.

Excellent Curriculum

As stated in the author's previous work (Lee et al., 2018), now RMUTT is using Design Thinking in Curriculum Design and Development along with four phases of Advancing CDIO Curriculum Development: Mapping – Enhancing – Innovating – Sustaining. CDIO Syllabus and CDIO Standards 1 – 3 provide a key concept of how to identify future competencies, set program outcomes, and outline student attributes. An implementation of CDIO Standards 4 – 5 resulted in two new mandatory courses; namely, Introduction to Profession and Multi-disciplinary Project (MDP) courses to all programs reviewed and redesigned in the 2018 cycle. In 2018, RMUTT organized two workshops for program committees from 40 programs. CDIO master trainers act as a facilitator for extra explanation, discussing and sharing their experiences with the participants. Table 2 shows programs in which using CDIO-based Education as a guideline for developing a curriculum. The event was noticed as a remarkable change in the curriculum development process at the institutional level. These re-designed programs will be active in the academic year 2020. The participating programs have a clearer view of their graduate attributes and program outcomes. With the long-term vision to be an Innovative University, the introductory to profession and MDP courses provide a design-build-test learning experiences to the students. Professional competencies, personal and interpersonal skills are integrated into the program systematically.

Table 1. Number of Faculty Members Participated in CDIO Workshop at RMUTT

Year	Faculty / College												Total
	AGT	ARC	BA	ENG	FA	HET	LA	MCT	N	ST	TED	TMC	
2013				30							4		34
2014	2		5	15			1	32		6	7		48
2015	3	8	11	11		3	5			1	2	17	61
2016		24	12	40	11	13	25	5		9	7	9	155
2017	10	10		18	5	5	10	15	5	6	5	7	91
Total number of participants	15	34	21	111	16	21	41	52	5	22	25	33	396
Total number of faculty members	63	54	93	195	83	48	106	52	14	118	92	33	951
%	24	63	23	57	19	44	39	100	4	19	27	100	42

Note: AGT – Agricultural Technology, ARC – Architecture, BA – Business Administration, FA – Fine and Applied Arts, HET – Home Economics Technology, N – Nursing, ST – Science and Technology, TED – Technical Education, TMS – Thai Traditional Medicine College

Learning Environment and Processes

To raise student's motivation, learning environment and learning processes are essential. CDIO Standard 6, 7, 8 and 11 are implemented. RMUTT has received a series of budget to innovate learning and workspaces, for example, maker spaces at the faculty of Mass

Communication Technology, STEM lab at Faculty of Science and Technology, FabLab at the main library and at the faculty of Engineering. For pedagogical development, lecturers who attended the CDIO workshops and University Pedagogy training programs continue improving their teaching courses through pedagogical projects. Theories that are widely adopted for pedagogical projects are motivation, constructive alignment, flipped classroom, problem-based learning, project-based learning, and blended learning, formative and summative assessment. To provide students with integrated experience, every program offers work-integrated learning, 4-month cooperative education or 2-month on-the-job training with partner industries.

High Quality of Learning Outcomes

To assure a high quality of learning outcomes, CDIO standard 12 is utilized for program evaluation. Currently, the early CDIO-adopted programs; Industrial Engineering, Multimedia, Digital Media, Television and Radio Broadcasting, Photography and Cinematography, Advertisement and Public Relations, and Digital Printing and Packaging Technologies have performed self-assessment using CDIO-assessment-rubric annually. The review data has been utilized to set the next fiscal year action plan, budgeting, and goals for continuous improvement.

Table 2. RMUTT Programs using CDIO-based Education for Curriculum Development

Faculty / College	No. of Programs	Program Names
Agricultural Technology	3	Fisheries, Food Science and Technology, Landscape Technology
Business Administration	8	Business English, Computer Business, Economics, Finance, International Business, Logistics and Supply Chain Management, Marketing, Management
Engineering	9	Agricultural Machinery Engineering, Computer Engineering, Industrial Engineering, Electronics and Telecommunication Engineering, Environmental Engineering, Food Engineering, Irrigation Engineering and Water Management, Material Engineering, Textile Chemical and Fiber
Fined and Applied Arts	9	Innovation Contemporary Product Design, Interior Design, Graphic Arts, Music, Painting, Product Design, Sculpture, Thai Arts, Visual Communication Design
Home Economics Technology	3	Food Industry and Services, Food and Nutrition, Fashion Design and Clothing
Mass Communication Technology	6	Photography and Cinematography Technology, Digital Printing and Packaging Technology, Radio and Television Broadcasting Technology, Advertising and Public Relations Technology, Multimedia Technology, Digital Media Technology
Liberal Arts	2	Tourism, Hotel Management
Total	40	

CONTRIBUTIONS TO CDIO COMMUNITY

With permission from CDIO founder, Professor Johan Malmqvist, CDIO Thailand has translated CDIO Syllabus and CDIO Standards in Thai language for deeper understandings for CDIO practitioners in Thailand. Table 3 shows CDIO Thailand activities from 2014-2018 reaching to thousands of lecturers in Thailand and some other countries. There are several types of how CDIO Thailand share their knowledge and guidelines to the participants with selected successful cases. Note that this variety of activities offer CDIO practitioner 3 types of activities that are knowledge, values and activities from different levels of participation. This is consistent to UK PSF professional standard framework (Higher Education Academy, 2011)

CDIO IMPLEMENTATION AND ACCREDITATIONS

Among threats or motivations for a program-level development, accreditation is the first priority for many programs. In Thailand, the council of engineering, COE holds the responsibility to push for international accreditation with the goal to get a substantial equivalent accreditation to the Washington Accord (WA). The framework that has been set up is TABEE (Thailand Accreditation Body for Engineering Education). Accreditation is promoted as a tool to enhance the educational standard and allow workforce mobility among APEC and ASEAN regions. Some programs have targeted ABET initially but were tempted to TABEE due to the cost as well as the burden to translate a large number of documents from Thai.

At the first phase, programs are invited to voluntarily apply for TABEE accreditation with the aim to bring TABEE accredited programs to WA equivalent status in a later date. The process of TABEE accreditation involves: application; training (organized by COE) and consulting; submitting self-study report; site visit and assessment by TABEE's certified examiner. Programs from the two founding members of CDIO Thailand applied for the TABEE accreditation. CDIO Thailand's member from both CU and RMUTT were invited to share experience in implementing curriculum reform using CDIO framework for participants of TABEE.

The provision of Quality Education is based on the interaction between Program Design, Quality Assurance and Program Accreditation (Cheah, 2013). The experience at CU in applying for TABEE accreditation see the effectiveness of CDIO framework in support of such quality education (see Figure 1).

Table 3. CDIO Activities 2014 – 2018

Types of Sharing	University and Organization	No. of Participants
Seminar and Special Talk	1. Faculty of Engineering, Chulalongkorn University	60
	2. Faculty of Engineering, King Mongkut Institute of Technology Ladkrabang	65
	3. Faculty of Science, Mahidol University	82
	4. Faculty of Engineering, Burapha University	40
	5. Council of Dean of Engineering Annual Meeting and Conference	150
	6. Hui Chiew University	30
	7. RMUTL (Lanna)	58
	8. RMUTP (Phra Nakorn)	53
	9. Faculty of Engineering, Rangsit Unviersity	60
	10. Faculty of Engineering, Suranaree Unviersity of Technology	30
	11. Chiang Mai University	65
	12. Faculty of Mass Communication, Chiang Mai University	28
	13. Inje University, Korea	44
	14. RMTC	84
	15. RMUTKM+2	500
	16. Faculty of Business Administration and Liberal Arts, RMUTL	64
	17. Ministry of Education and Sports, People's Democratic Republic of Laos	12
	18. Postgraduate Institute of Management, Sri Lanka	44
Tutorial Session	1. iSTEM-Edu International Conference, Thailand	50
	2. International and National Conference of Engineering Education Thailand	34
	3. Thai Professional Organization Development (Thai POD)	30
Workshop Introduction to CDIO	1. Faculty of Liberal Arts, RMUTK (Krung Thep)	73
	2. RMUTP (Phra Nakorn)	60
	3. RMUTI (Isan)	120
	4. Faculty of Engineering, RMUTI (Isan)	80
	5. Hokkaido Information University, Japan	22
	6. Faculty of Engineering, Suranaree University of Technology	28
	7. Faculty of Engineering, Naresuan University	26
	8. Faculty to Allied Health Science, Walailuk University	14
	9. Faculty of Mass Communication, Chiang Mai University	28
	10. Camarine Sur Polytechnic College, Philippines	44
	11. RMUTSB (Suvarnnaphumi)	64
	12. Network of Printing Society Institute	16
	13. Faculty of Business Administration, RMUTI (Isan)	64
	Total	2,192
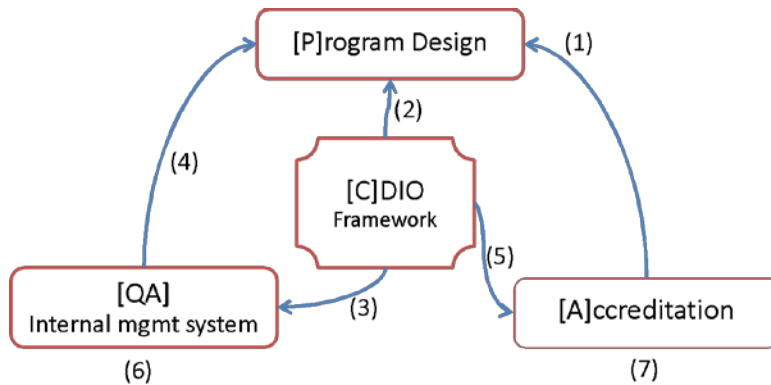
Figure 1: Synergy between Program Design, Quality Assurance and Program Accreditation provided by CDIO framework.

At first, the standard prescribed by accreditation body [A] influence the attribute for students documented in the program design [P]. Program proceeds to improve the quality of teaching and learning by using CDIO framework [C] as a guideline for curriculum redesign. During such processes, it is important to map out CDIO implementation with the quality assurance system [QA]. This way, the continuous quality improvement can be done according to the CDIO framework while relaying key quality indicator to the internal quality management system with ease. Even with accreditation body looking in from the outside to give an independent recognition of quality, a school still needs a QA system to answer its own need in ensuring uniqueness in attributes from a program in that school. The QA system can be internal or even external providing unbiased reflection to the operations of the program. At the same time, the systematic and holistic nature of CDIO framework allows the demonstration of the quality education process to the accreditation body without added or repetitive work. It was confirmed by experience in TABEE that the CDIO programs benefit from the synergy between the CDIO framework and the Program Design, Quality Assurance and Accreditation processes.

CONCLUDING REMARKS

Education reform is hard. It is even harder to start. CDIO Thailand is described as a unique way to start by having non-competing yet inspiring relationship coming from two universities with different background yet focusing on the same goal – Thailand's educational reform. Indeed, there are a lot of educational improvements made by practitioners nation-wide. Yet, it is more about holistic development that different parts of the hard work fit together. This is where the program-level development such as CDIO framework bring effectiveness to the educational reform. Indeed, it was the program-level implementation that is missed out from general considerations. CDIO Thailand believes that the unique proposition of CDIO framework is that, it is one, if not the only one, of education framework that brings holistic framework of curriculum reform to engineering programs. CDIO framework provides key focus in the form of CDIO standards for a program to focus and prioritize. Equally important is the CoP local and outside of a school that provides strength as well as continues motion towards education reform.

With the innovation society in full bloom, it is no surprise that programs other than engineering found CDIO framework entirely applicable and equally effective. A program focusing on the innovative/creative industry will find CDIO applicable in rather full form. Other programs will find many elements such as active learning or faculty development useful.

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TOWARDS CDIO STANDARDS 3.0

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ABSTRACT

The topic of this paper is the CDIO Standards, specifically the formulation of CDIO Standards version 3.0. The paper first reviews the potential change drivers that motivate a revision of the Standards. Such change drivers are identified both externally (i.e., from outside of the CDIO community) and internally. It is found that external change drivers have affected the perceptions of what problems engineers should address, what knowledge future engineers should possess and what are the most effective teaching practices in engineering education. Internally, the paper identifies criticism of the Standards, as well as ideas for development, that have been codified as proposed additional CDIO Standards. With references to these change drivers, five areas are identified for the revision: sustainability, digitalization of teaching and learning; service; and faculty competence. A revised version of the Standards is presented. In addition, it is proposed that a new category of Standards is established, "optional standards". Optional Standards are a complement to the twelve "basic" Standards,

and serve to guide educational development and profiling beyond the current Standards. A selected set of proposed optional Standards are recommended for further evaluation and possibly acceptance by the CDIO community.

KEYWORDS

Sustainable development, Digitalization, Learning environments, Faculty competence, Standards 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

The CDIO Standards were introduced in 2005, with the main aims to (a) clearly describe the key features of CDIO programs and (b) to support the continuous improvement of CDIO programs through the use of a capability maturity-based self-evaluation process. The creation of CDIO Syllabus version 2.0 and of CDIO Standards user experience influenced the development of CDIO Standards 2.0 and 2.1, although the updates were minor.

In recent years, a number of educational change drivers have emerged, including the recognition that engineering education plays a critical role in creating a sustainable society and the abundance of digital learning tools. In addition, a number of CDIO schools have developed approaches that go beyond the original scope of the CDIO Standards. Considering these developments, there is a need to review and update the CDIO Standards. This paper thus aims to argue and propose modifications and additions to the CDIO Standards, accommodating the needs of the CDIO community on two levels:

We first discuss and propose general updates to the Standards 2.1 on a level that reflects widely shared and recognised needs. These changes should be generally acceptable, and of such nature that CDIO will otherwise be seen as incomplete or falling behind. Second, in order to serve the needs of more progressive institutions, and to keep the position as thought-leaders in engineering education, other changes are addressed in new optional standards.

The general update addresses Standards 1-12 and considers the following topics:

- Sustainable development
- Digitalisation & learning environments
- Services
- Faculty competence

In the second part of the paper, we summarize what some progressive institutions are doing. These developments reflect educational components beyond what can presently fit in CDIO as a general framework. It is proposed that introducing a new category of Standards, called "optional" Standards is a way to address this issue. However, the formulation of new optional standards must keep the interplay with the existing standards in mind, and the proposition and acceptance by the CDIO community of new (optional) standards need to be carried out in an open, transparent and structured way.

ORIGIN AND EVOLUTION OF THE CDIO STANDARDS

The CDIO Standards are a key part of the CDIO framework by defining the distinguishing features of a CDIO program, by serving as guidelines for educational reform, and by providing a tool for continuous improvement (Crawley *et al.,* 2014).

The CDIO Standards were initially presented in 2005 (Brodeur & Crawley, 2005) and described more fully by Crawley *et al.* (2014). Rubrics for evaluating programs according to the Standards were introduced in 2010. The CDIO Standards have since been updated to version 2.0 (Crawley *et al.*, 2014) and the rubrics have been further modified (Bennedsen *et al.*, 2016). These modifications have been relatively minor and have not changed the scope or the main contents of the Standards.

While the CDIO Standards have been stable during this time period the internal and external context of engineering education has evolved.

External change drivers

Three types of external factors that drive changes to the CDIO framework can be identified, stemming from changes to the **context**, the **what** and the **how** of engineering education: First, new characterizations of the context that future engineers will operate in are constantly being published. If the context changes, engineering education will need to follow and adapt. The need context for engineering is often summarized by the term "VUCA", an acronym for Volatility, Uncertainty, Complexity and Ambiguity (Wikipedia, 2019b). An engineering education that prepares for a VUCA world will likely have a much stronger emphasis on multidisciplinary projects, addressing real-world, open-ended design problems. A second change driver comes in the form of updated notions about what the goal or what of engineering practice is. The UN goals for sustainable development (United Nations, 2015) challenge engineering programs to broaden the taught goals for engineering, i.e., from optimizing technical and economic performance to the simultaneous achievement of goals for economic, environmental and social sustainability. Addressing this challenge requires updates to disciplinary knowledge, skills and attitudes to be learnt in engineering education. A third category of external change drivers is rooted in descriptions of current and emerging best practices for engineering education ("how"). According to Graham (2018), future leaders in engineering education offer programmes with four key characteristics: a combination of digital and student activating learning forms, educational arrangements with a high degree of flexibility and diversity, global and multidisciplinary elements, as well as design projects that at the same time offer opportunities for reflection on technology development and own learning.

Internal change drivers

In addition to external change drivers, the CDIO framework is also subject to challenges initiated from within the CDIO community, either as criticism resulting from theoretical analysis or practical experience of the framework or as developments of novel education approaches or tools. Criticism includes observations that while the CDIO framework supports many of the activities that are required to prepare for a EUR-ACE accreditation, there are also some missing elements, for example concerning standards for student support (Malmqvist, 2012). Respondents to the global CDIO survey (Malmqvist *et al.*, 2015) identified faculty competence as a major barrier to successful CDIO implementation and mentioned insights into internal motivation and gender and sexual diversity as poorly treated in the
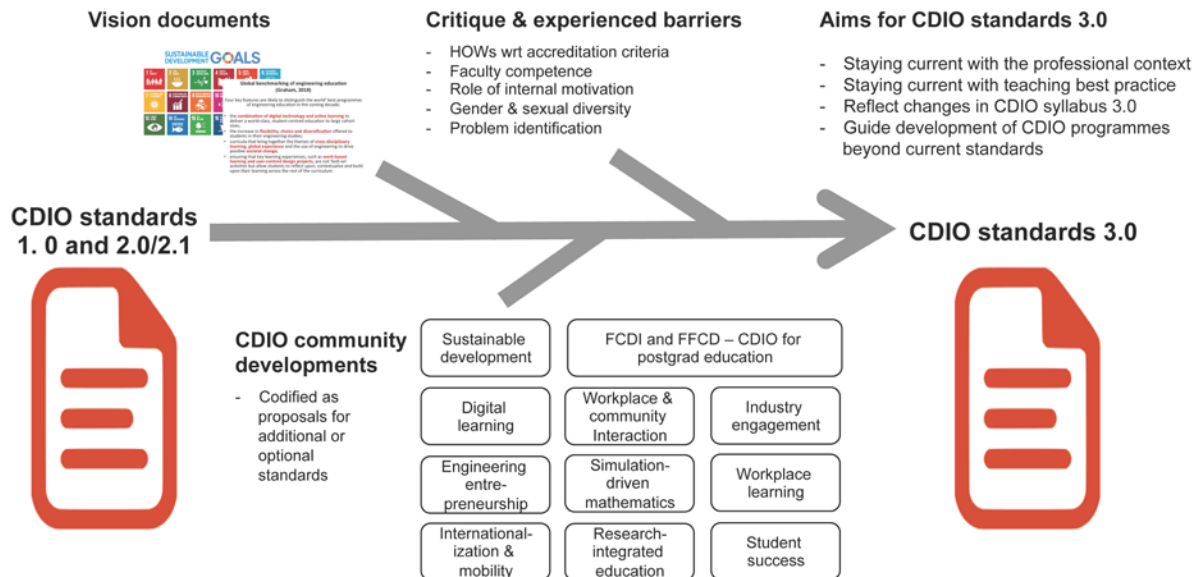
Figure 1. Revision of the CDIO Standards to version 3.0.

CDIO Syllabus. Taajamaa *et al.* (2016) and Kohn Rådberg *et al.* (2018) argue that CDIO should put a stronger emphasis on problem identification, not only on problem-solving. The second type of internal change drivers is constituted by proposals for additional or optional standards. The first proposal for an additional standard was the "Internationalization & mobility" standard (Campbell & Beck, 2010). Malmqvist *et al.* (2017) introduced the concept of optional standards along with six candidates for such standards. In 2018, proposals for optional standards related to workplace learning and industry engagement (Cheah and Leong, 2018); for student support (Gonzales *et al.*, 2018), and for master and doctoral level CDIO programs (Chuchalin, 2018) were published.

The inputs to the process of revising the CDIO Standards are summarized in Figure 1

REVISING THE STANDARDS TO CREATE VERSION 3.0

In this section, we outline and motivate the modifications proposed to evolve the CDIO standards from version 2.1 to version 3.0. A statement of the aims for the revisions, and analysis of some challenges that need to be considered precede the discussion. The modifications are then summarized. The modified standards are found in the appendix.

Aims for revision

There are three main aims for this proposal for revision of the Standards to version 3.0:

- To accommodate changes in the external context of engineering education, as interpreted in the updates of the CDIO Syllabus
- To stay current with the developments of teaching best practice
- To provide guidance for the development of CDIO programmes beyond current Standards

Further, the intent is to carry out a transparent revision process through the publication and presentations of proposals (such as this one) in open CDIO meetings, while at the same time making sure that the evolving standards build on the original intent and do not grow in an uncontrolled fashion.

Challenges & considerations when updating the Standards

Below, we will discuss specific proposed changes to the CDIO Standards. However, let us first outline some challenges and pre-requisites that have been considered.

The Standards are formulated rather broadly and generically. This allows flexibility for how something is carried out, but also makes it more complicated to add or evolve the Standards. When it comes to changes in **what** the education addresses, it is relatively easy to make the argument that "X is already covered" if it is included in the Syllabus. However, not all readers simultaneously access the Syllabus and the Standards hence may get the impression that the Standards do not address certain current topics. In the proposal below, this is reflected in two ways: Some moderate changes to the standards to reflect the evolving context of engineering education is proposed, whilst no additional basic standards are proposed. The concept of optional standards is suggested as a way to explicitly accommodate more specific topics.

As noted, some Standards refer back to the Syllabus, indicating a need to revise the Syllabus rather than the Standards. This principle is adhered to here as well. In some cases, however, changes apply to both documents. For example, the stronger emphasis on sustainability in the Standards is aligned to corresponding revisions of the Syllabus (see Rosén *et al.*, 2019).

The Standards are organized in a flat structure, as a list. In principle, adding elements to standards or new standards could be done expanding the scope of some current Standards, by breadth (introducing Standard 13, 14, …) or by depth (introducing Standard 5.1, 5.2, …). In the proposals below, some Standards (6, 9) are expanded, whilst the concept of optional standards can be viewed as an addition by breadth. The introduction of a hierarchy is a possibility but is not pursued here.

The original scope of the CDIO Syllabus and Standards essentially focused on common denominators for learning outcomes for a first degree in engineering (bachelor or master, depending on country). Later proposals (e.g., internationalization, leadership, student support) have been associated with expansions on that scope. Below, it is argued that such proposals should be accommodated as optional standards.

Suggested revisions

Sustainable development

The CDIO Syllabus 1.0 received some criticism for not incorporating sustainability adequately. Competences for sustainable development were in fact included in CDIO Syllabus 1.0, but did not appear explicitly in the higher levels of the Syllabus. In the CDIO Syllabus 2.0 development, sustainability was nevertheless reconsidered, with a strengthening of topics and clearer visibility of sustainability on the top levels on the CDIO Syllabus. For example, a new section 4.1.7 Sustainability and the Need for Sustainable

Development was added, and the term "environment" was included in the headings on section 4 and 4.1 (Crawley *et al*., 2014).

However, the overarching goals of engineering products and systems (e.g. high quality, low cost, efficiency etc.) are, with the exception of one use of the word "value-added", not embedded in the CDIO Standards, neither in version 1.0 nor 2.0/2.1. The reason is that the Standards describe **how** the CDIO Syllabus learning outcomes can be achieved. Hence, since goal statements are considered as **whats**, the inclusion in the CDIO Syllabus would lead to a follow on-effect: If sustainability topics are more strongly featured in the CDIO Syllabus, then it would follow that achievement of Standards 2 and 3 would also require a more extensive coverage of sustainability in the curriculum. This content-focused argument does, however, not address the visibility aspect. A reader who does a stand-alone reading of the CDIO Standards 2.0/2.1 may not fully comprehend the Syllabus-Standards coupling. In light of the importance of the topic, we, therefore, argue that it is motivated to revise the CDIO Standards in order to bring forward the terms "sustainability" and "sustainable development".

In the appended proposal for CDIO Standards, these revisions have affected Standards 1, 3, 4, 5 and 9.

Sustainable development has also been proposed as an optional standard (Malmqvist *et al*., 2017). For this topic and some others, including entrepreneurship, it has been argued that an optional standard is unnecessary. The argument is either that the topic is already covered in the CDIO Syllabus and, hence, although not explicitly, also addressed by the CDIO Standards. The appropriate approach would then be to first revise the CDIO Syllabus and then the core CDIO Standards to accommodate the topic. However, an optional standard offers an additional level of concretion in terms of guidelines for learning experiences and for evidence of fulfilment that can be helpful in curriculum design and when marketing the profile of the programme. We, therefore, suggest that some elements of the proposed sustainable development standard are integrated into Standards 1 and 3, but also that the sustainable development standard be kept among the proposal for optional standards.

Digitalisation & learning environments

While sustainability can be understood to be the central objective and constraint for future engineering activities, digitalization can be argued to be the major enabler for reforming both engineering work and ways of learning how to engineer.

The CDIO Standard 6 "Engineering workspaces" focuses explicitly on physical workspaces, emphasizing hands-on and social learning. Such learning spaces are essential for CDIO learning but tended to be threatened or even lacking during the early 2000s. The recent emergence of Makerspaces and FabLabs as a distinctive feature of "current leaders" in engineering education (Graham, 2018) has again established the importance of such spaces. However, Graham (op. cit.) also observes that learning environments at "emerging leaders" in engineering education are based on a purposeful combination of digital learning and physical learning environments that support work-based learning and user-centred design projects.

We, therefore, propose a significant revision of CDIO Standard 6. The name is modified to "Engineering learning workspaces" in order to emphasize that these spaces, physical and digital, support both student engineering work and learning in a broader sense. The

description and rationale of Standard 6 can be constructively complemented with elements adapted from the previously proposed optional standard "Digital learning" (Malmqvist *et al.*, 2017), which we further propose to be integrated into Standard 6, *i.e.*, not pursued as an optional standard.

Services

According to Crawley *et al.* (2014) page 50, the goal of engineering education is that every graduating engineer should be able to:

Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.

This formulation can be used as a "working definition" of what engineers do, and it forms the basis for the entire CDIO framework. However*,* during the last decade or so, the development and operation of services have emerged as an important aim for engineering. Service has a very wide interpretation, and e.g. the explanation in Wikipedia says "*A 'service' can be described as: all intangible effects that result from a client interaction that creates and captures value".* For simplicity, the discussion here will be restricted to services where engineering is involved in some way. It should be stressed that engineering work to provide services of various types has existed for many years in terms of e.g. professional services (engineering consulting), or supply of electricity with stable voltage and frequency and water of sufficiently high quality. More recently an important driver for the growing importance of services is the rapid development within information and communication technology (ICT), and services such as bandwidth, computational capacity, and data storage are parts of the daily life. The arrival of the smartphone with the possibility to download applications (apps) for different purposes has enabled a tremendous growth of ICT based services. A parallel to the service bandwidth, but within another field, is for a customer to buy transportation capacity (mass times distance per time unit) instead of purchasing a new heavy truck. Thus, in addition to the words product, process, and system in the definition, the word *service* has become more and more common and relevant for engineering and engineering education in various ways. The impact is also visible in mechanical product development textbooks, such as Ulrich & Eppinger (2015), which now include chapters on service design.

The main implication for the CDIO Standards of the growing importance of the service area is to append the word *services* in the definition above and hence also in Standard 1 which contains a similar formulation. Such a change will then have implications for e.g. Standard 5, which talks about the development of products and processes, and here the scope needs to be widened to include services. In addition, services should be added to the sequence product, process, and system also in Standard 9 and others. In summary, the Standards 1-7, 9, and 11 are affected by this modification.

Faculty competence

Standards 9 and 10 address enhancement of faculty competence, with regards to the same *engineering skills* that they should help students develop (**what**) and the *teaching competence* to enable the development of education according to the CDIO standards (**how**). Edström (2017, p. 81-82) pointed out that this leaves CDIO silent on the matter of faculty competence regarding the theoretical content, despite the fact that *deeper working understanding of technical fundamentals* is the first aim of CDIO (Crawley *et al.*, 2014, p. 7). Adding to this, faculty members are increasingly tasked to integrate learning of sustainability and ethics with learning subject matter content. Edström further argues that it is not enough

that the faculty should know the subject for themselves, but they must also be able to guide others into understanding it. Shulman (1987) coined the concept pedagogical content knowledge, "*the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction*" (p. 8).

A complete conceptualisation of faculty competence contains two aspects related to the **what** – one aligned to the professional preparation and one to the disciplinary knowledge. We do not propose adding a standard but suggest that faculty competence in advanced disciplinary knowledge, by which is meant pedagogical content knowledge, is added to Standard 9.

OPTIONAL STANDARDS

The concept of "optional CDIO Standards" was introduced by Malmqvist *et al.* (2017). Malmqvist *et al.* (*op. cit.*) argued that while the original twelve Standards (referred to as "basic" Standards) have shown to be a robust and still relevant benchmark for the core of a first engineering degree, emerging and evolving expectation on the competences of graduating engineers as well as new pedagogical approaches and tools motivate the extension of the CDIO framework, in the form of additional Standards. The basic CDIO standards form a core to which optional CDIO standards can be added to indicate a particular profile or development direction for a program, but the optional standards do not replace any of the basic standards.

An optional CDIO Standard will be used for the same purpose as a basic, i.e., as a support for program design, for period program review and for benchmarking. Malmqvist *et al.* (*op. cit.*) further put forward a number of requirements that an optional Standard should fulfil. An optional CDIO Standards should:

- Address an important, typically emerging, need in engineering education.
- Be based on a novel, yet well codified, pedagogical approach, developed within or outside of the CDIO community.
- Be widely applicable, i.e. not be specific to a single discipline (e.g., civil engineering).
- Not be sufficiently addressed by interpretation of a current standard (such as integrated learning).
- Reflect a program-level approach, and not be obtainable by implementation in a single course
- Be evident in a substantial number of CDIO programs as a distinguishing feature.
- Support the definition of a distinct program profile, beyond basic CDIO.
- Be assessable by the CDIO standards rubrics.

Current proposals

Table 1 summarizes the current set of proposed optional Standards, 11 in total. Roughly, they can be divided into three groups: Some proposals are linked to major societal trends that are high on the strategic agendas of many universities and companies: Sustainable development, Digital learning (we include Simulation-based mathematics here) and Engineering entrepreneurship. Another group has the common trait of outreach and collaboration: internationally, with research, with companies or the local public sector. Some

proposals also aim to expand the scope of the Standards, either towards student services and support or towards graduate education.

Table 1: Proposed optional standards

	Title	Short description	Source
Strategic trends	Sustainable development	A program that identifies the ability to contribute to sustainable development as a key competence of its graduates. The program is rich with sustainability learning experiences, developing the knowledge, skills and attitudes required to address sustainability challenges	Malmqvist *et al.*, 2017
	Digital learning	Engineering programs that support and enhance the quality of student learning, and teaching, through digital learning tools and environments	Malmqvist *et al.*, 2017
	Simulation-based mathematics	Engineering programs for which the mathematics curriculum is infused with programming, numerical modeling and simulation from the start	Malmqvist *et al.*, 2017
	Engineering entrepren-eurship	Engineering programs that actively develop their graduate's abilities to, in addition to conceive, design, implement and operate complex products, systems and processes, to commercialize technology and to create business ventures based on new technology	Malmqvist *et al.*, 2017
Outreach & collaboration	International-ization & mobility	Programs and organizational commitment which exposes students to foreign cultures, and promotes and enables transportability of curriculum, portability of qualifications, joint awards, transparent recognition and international mobility	Campbell & Beck, 2010
	Research-integrated education	Engineering programs that include one or more research experiences as part of student learning	Malmqvist *et al.*, 2017
	Industry engagement	Actions that education institutions undertake to actively engage industry partners to improve its curriculum.	Cheah & Leong, 2018
	Workplace learning	A curriculum that includes students working in a real-world work environment with the aims of strengthening in-campus learning and developing their professional identity.	Cheah & Leong, 2018
	Workplace and community integration	Engineering programs that actively develop their graduates' abilities to identify and address authentic and open-ended problems, in authentic settings, interacting with stakeholders	Malmqvist *et al.*, 2017
Expanding scope / coverage	Student success	A curriculum supported in the analysis and synthesis of information allowing taking effective actions to mitigate the risk and vulnerability in the student population; with strategies focused on the prevention of drop out and that guarantee student success.	Gonzales *et al.*, 2018
	Foresight – Forecast – CD(IO)	Revision of all CDIO Standards to fit frame of master and PhD programmes. This implies elaborating on product (etc) lifecycle stages prior to Conceiving, referred to as Foresighting and Forecasting	Chuchalin, 2018

Process for evaluating and approving proposals for optional Standards

Figure 2 outlines a process by which a proposal for an optional CDIO Standard can be evaluated and possibly approved.

The starting point is that a proposal for a new optional Standard has been formulated by one (or several in collaboration) CDIO universities. The proposal should be documented in a paper that is submitted to the annual international CDIO conference, be presented there, and published in the conference proceedings.

In conjunction with the international conference, the CDIO Council will review proposals for new Standards. They can give three different recommendations:

- "Reject", implying that the proposal is not assessed as suitable for the status of an approved CDIO Standard.
- "Approval for potential revision of basic Standard", indicating that the proposal is assessed to have merit, but that it is positioned too close to an existing Standard in order to motivate the addition of a new Standard. Therefore, the proposers are tasked with creating a revised version of an existing Standard, in which their ideas are integrated.
- "Approval for evaluation as new optional Standard", meaning that the proposal is of sufficient distinction and quality that it may potentially be accepted as a new official CDIO Standard.

If the Council recommendation is "Approval for potential revision of basic Standard", then the next step is that the proposers are tasked with authoring a revision of an existing Standards, in which their ideas are incorporated.

If the Council recommendation is "Approval for evaluation as new optional Standard", the proposal will be distributed to all CDIO member universities for evaluation and feedback. The Council will summarize the feedback and provide instructions to the proposers on how the proposal should be revised in order to address the feedback.

The CDIO Council will review the revised proposals during the following year's international conference. If accepted, the new or revised Standards will be included in the official CDIO framework and published on www.cdio.org.
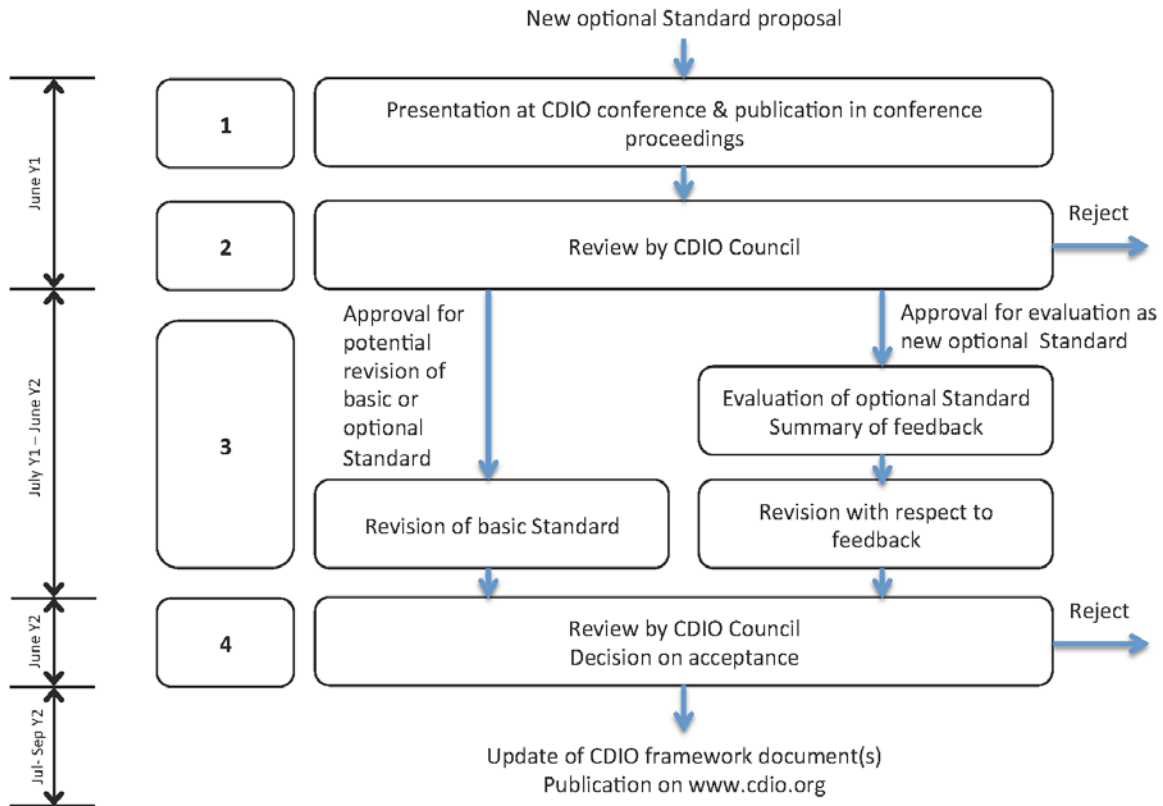
Figure 2. Optional Standards evaluation and approval process.

CONCLUSIONS

Changed perceptions of the role of engineering and education development efforts motivate a revision of the CDIO Standards from version 2.1 to 3.0. The revisions should address sustainability, digitalization of learning, service engineering, faculty competence and the attitudes that students are expected to develop during their studies. As a consequence, many of the CDIO Standards should be updated. However, the most significant changes affect Standard 1 – The Context, Standard 6 – Engineering Learning Workspaces (new name) and Standard 9 – Faculty Competence. The mentioned modifications are to a high degree driven by external factors.

Internally, many development efforts undertaken by CDIO universities have been codified in the same format as the original Standards. The dissemination and wider adoption of these proposals warrant the introduction of a new category of Standards, referred to as "optional" Standards. The optional Standards serve to guide educational development beyond the scope of the original, "basic" Standards. A number of such optional Standards can be identified. A suitable next step is to evaluate these through an open review in the CDIO community. Given a positive evaluation and possibly some adjustments, an optional Standard can be approved by the CDIO council and officially included in the CDIO framework, as available on www.cdio.org.

During the development of the proposal for revised standards, it was also observed that fosterage of values and attitudes have become more prominent goals for engineering education. Indeed, the CDIO syllabus identifies many desirable values and attitudes, including, e.g., self-awareness, perseverance, and integrity. However, there are to date no CDIO standards that suggest how to develop such values or attitudes, neither specifically nor in a general sense. An investigation into the feasibility of creating standards for how to form engineering values and attitudes is an interesting area for future work. Another needed future effort is the revision of the rubrics for the basic standards along with the elaboration of new rubrics for accepted optional standards.

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APPENDIX: PROPOSAL FOR CDIO STANDARDS 3.0

The proposal for revised standards follows below. The revisions are yellow-marked. The intent is to facilitate discussion and feedback on the proposed changes, prior to the ultimate decision by the CDIO council on the acceptance of the proposals.

STANDARD 1 — THE CONTEXT*

Adoption of the principle that sustainable product, process, system and service lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education

Description

A CDIO program is based on the principle that product, process, system and service lifecycle development and deployment are the appropriate context for engineering education. Conceiving--Designing--Implementing--Operating is a model of the entire product, process, system, and service lifecycle. A CDIO education further identifies the ability to contribute to a sustainable development as a key competence of its graduates. The Conceive stage includes defining customer and societal needs; considering technology, enterprise strategy, and regulations; and, developing conceptual, technical, and business plans. The Design stage focuses on creating the design, that is, the plans, drawings, and algorithms that describe what will be implemented. The Implement stage refers to the transformation of the design into the product, process, or system, including manufacturing, coding, testing and validation. The final stage, Operate, uses the implemented product or process to deliver the intended value, including maintaining, evolving, recycling and retiring the system.

The product, process, system and service lifecycle is considered the context for engineering education in that it is part of the cultural framework, or environment, in which technical knowledge and other skills are taught, practiced and learned. The principle is adopted by a program when there is an explicit agreement of faculty to transition to a CDIO program, and support from program leaders to sustain reform initiatives.

Rationale

Beginning engineers should be able to Conceive--Design--Implement--Operate complex value-added engineering products, processes, systems and services in modern team-based environments. They should be able to participate in engineering processes, contribute to the development of engineering products, and do so while working to professional standards in any organization. This is the essence of the engineering profession. To address the issues of sustainability is a key challenge for humankind. Engineers need to understand the implications of technology on social, economic and environmental sustainability factors, in order to develop appropriate technical solutions as well as to collaborate with other actors in addressing sociotechnical issues.

STANDARD 2 — LEARNING OUTCOMES*

Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, system and ==service== building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders

Description

The knowledge, skills, and attitudes intended as a result of engineering education, that is, the learning outcomes, are codified in the CDIO Syllabus. These learning outcomes detail what students should know and be able to do at the conclusion of their engineering programs. In addition to learning outcomes for technical disciplinary knowledge (Section 1), the CDIO Syllabus specifies learning outcomes as personal and interpersonal skills, and product, process, system and ==service== building. Personal learning outcomes (Section 2) focus on individual students' cognitive and affective development, for example, engineering reasoning and problem-solving, experimentation and knowledge discovery, system thinking, creative thinking, critical thinking, and professional ethics. Interpersonal learning outcomes (Section 3) focus on individual and group interactions, such as teamwork, leadership, communication, and communication in foreign languages. Product, process, system and ==service== building skills (Section 4) focus on conceiving, designing, implementing, and operating systems in enterprise, business, and societal contexts.

Learning outcomes are reviewed and validated by key stakeholders, that is, groups who share an interest in the graduates of engineering programs, for consistency with program goals and relevance to engineering practice. Programs are encouraged to customize the CDIO Syllabus to their respective programs. In addition, stakeholders help to determine the expected level of proficiency, or standard of achievement, for each learning outcome.

Rationale

Setting specific learning outcomes helps to ensure that students acquire the appropriate foundation for their future. Professional engineering organizations and industry representatives identified key attributes of beginning engineers both in technical and professional areas. Moreover, many evaluation and accreditation bodies expect engineering programs to identify program outcomes in terms of their graduates' knowledge, skills, and attitudes.

STANDARD 3 — INTEGRATED CURRICULUM*

A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, competences for sustainable development==,== and product, process, system and ==service== building skills.

Description

An integrated curriculum includes learning experiences that lead to the acquisition of personal and interpersonal skills, competences for sustainable development==,== and product, process, system and ==service== building skills (Standard 2), interwoven with the learning of disciplinary knowledge and its application in professional engineering. Disciplinary courses are mutually supporting when they make explicit connections among related and supporting

content and learning outcomes. An explicit plan identifies ways in which the integration of skills and multidisciplinary connections are to be made, for example, by mapping the specified learning outcomes to courses and co-curricular activities that make up the curriculum.

Rationale

The teaching of personal, interpersonal, and professional skills, and product, process, system, and <mark>service</mark> building skills should not be considered an addition to an already full curriculum, but an integral part of it. To reach the intended learning outcomes in disciplinary knowledge and skills, the curriculum and learning experiences have to make dual use of available time. Faculty play an active role in designing the integrated curriculum by suggesting appropriate disciplinary linkages, as well as opportunities to address specific skills in their respective teaching areas.

STANDARD 4 — INTRODUCTION TO ENGINEERING

An introductory course that provides the framework for engineering practice in product, process, system, and <mark>service</mark> building, and introduces essential personal and interpersonal skills and the rationale of sustainability in the context of engineering.

Description

The introductory course, usually one of the first required courses in a program, provides a framework for the practice of engineering. This framework is a broad outline of the tasks and responsibilities of an engineer, and the use of disciplinary knowledge in executing those tasks. Students engage in the practice of engineering through problem solving and simple design exercises, individually and in teams. The course also includes personal and interpersonal skills knowledge, skills, and attitudes that are essential at the start of a program to prepare students for more advanced product, process, system, and <mark>service</mark> building experiences. For example, students can participate in small team exercises to prepare them for larger development teams.

Rationale

Introductory courses aim to stimulate students' interest in, and strengthen their motivation for, the field of engineering by focusing on the application of relevant core engineering disciplines. Students usually select engineering programs because they want to build things, and introductory courses can capitalize on this interest. In addition, introductory courses provide an early start to the development of the essential skills described in the CDIO Syllabus.

STANDARD 5 — DESIGN-IMPLEMENT EXPERIENCES*

A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level

Description

The term design-implement experience denotes a range of engineering activities central to the process of developing new products and systems.   Included are all of the activities

described in Standard One at the Design and Implement stages, plus appropriate aspects of conceptual design from the Conceive stage. Students develop product, process, system, and ==service== building skills, as well as the ability to apply engineering science ==while considering aspects of sustainability,== in design-implement experiences integrated into the curriculum. Design-implement experiences are considered basic or advanced in terms of their scope, complexity, and sequence in the program. For example, simpler products and systems are included earlier in the program, while more complex design-implement experiences appear in later courses designed to help students integrate knowledge and skills acquired in preceding courses and learning activities. Opportunities to conceive, design, implement and operate products, processes, and systems may also be included in required co-curricular activities, for example, undergraduate research projects and internships.

Rationale

Design-implement experiences are structured and sequenced to promote early success in engineering practice. Iteration of design-implement experiences and increasing levels of design complexity reinforce students' understanding of the product, process, system, and ==service== development process. Design-implement experiences also provide a solid foundation upon which to build deeper conceptual understanding of disciplinary skills ==as well as appreciation of ethical and sustainability aspects==. The emphasis on building products and implementing processes in real-world contexts gives students opportunities to make connections between the technical content they are learning and their professional and career interests.

STANDARD 6 — ==ENGINEERING LEARNING WORKSPACES==

==A combination of== a physical learning environment with engineering workspaces and laboratories that support and encourage hands-on learning of product, process, system, and ==service== building, disciplinary knowledge, and social learning, ==with a digital learning environment with on-line tools and environments that support and enhance the quality of teaching and student learning.==

Description

The physical learning environment includes traditional learning spaces, for example, classrooms, lecture halls, and seminar rooms, as well as engineering workspaces and laboratories. Workspaces and laboratories support the learning of product, process, system, and service building skills concurrently with disciplinary knowledge. They emphasize hands-on learning in which students are directly engaged in their own learning and provide opportunities for social learning, that is, settings where students can learn from each other and interact with several groups. The creation of new workspaces, or remodeling of existing laboratories, will vary with the size of the program and resources of the institution. ==The digital learning environment employs digital learning technology to enhance the student learning experience as well as teaching effectiveness. Course development and delivery are assisted using appropriate e-learning development infrastructure. Program and course development is assisted by staff familiar with the CDIO framework for engineering education development, as well as expertise in instructional design, multimedia content development (recording, editing, and distribution), assessment and learning analytics.==

Rationale

Workspaces and other learning environments that support hands-on learning are fundamental resources for learning to design, implement, and operate products, processes, systems and services. Students who have access to modern engineering tools, software, and laboratories have opportunities to develop the knowledge, skills, and attitudes that support product, process, and system building competencies. These competencies are best developed in workspaces that are student-centered, user-friendly, accessible, and interactive. The ability to augment learning activities through digital tools and resources provides instructors, program designers, and students with increased flexibility. Digital content repositories from prerequisite courses enable the efficient reactivation of knowledge, facilitating scaffolding across the curriculum. Program designers can structure student learning in a manner that provides increased learning flexibility including student mobility and personalized learning experience.

STANDARD 7 — INTEGRATED LEARNING EXPERIENCES*

Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, system, and service building skills.

Description

Integrated learning experiences are pedagogical approaches that foster the learning of disciplinary knowledge simultaneously with personal and interpersonal skills, and product, process, system, and service building skills. They incorporate professional engineering issues in contexts where they coexist with disciplinary issues. For example, students might consider the analysis of a product, the design of the product, as well as the social or societal responsibility of the designer of the product, all in one learning experience. Industrial partners, alumni, and other key stakeholders are often helpful in providing examples of such ~~exercises~~ cases.

Rationale

The curriculum design and learning outcomes, prescribed in Standards 2 and 3 respectively, can be realized only if there are corresponding pedagogical approaches that make dual use of student learning time. Furthermore, it is important that students recognize engineering faculty as role models of professional engineers, instructing them in disciplinary knowledge, personal and interpersonal skills, and product, process, and system building skills. With integrated learning experiences, faculty can be more effective in helping students apply disciplinary knowledge to engineering practice and better prepare them to meet the demands of the engineering profession.

STANDARD 8 — ACTIVE LEARNING

Teaching and learning based on active experiential learning methods

Description

Active learning methods engage students directly in thinking and problem-solving activities. There is less emphasis on passive transmission of information, and more on engaging students in manipulating, applying, analyzing, and evaluating ideas. Active learning in lecture-based courses can include such methods as a partner and small-group discussions, demonstrations, debates, concept questions, and feedback from students about what they are learning. Active learning is considered experiential when students take on roles that simulate professional engineering practice, for example, design-implement projects, simulations, and case studies.

Rationale

By engaging students in thinking about concepts, particularly new ideas, and requiring them to make an overt response, students not only learn more, they recognize for themselves what and how they learn. This process aims to increase students' motivation to achieve program learning outcomes and form habits of lifelong learning. With active learning methods, instructors can help students make connections among key concepts and facilitate the application of this knowledge to new settings.

STANDARD 9 — ENHANCEMENT OF FACULTY COMPETENCE*

Actions that enhance faculty competence in what to teach, including personal and interpersonal skills, product, process, system, and service building skills, competences for sustainable development, as well as disciplinary fundamentals.

Description

CDIO programs provide support for the collective engineering faculty to improve its competence in what to teach, according to program goals as described in Standard 2. This includes personal and interpersonal skills, product, process, system, and service building skills, as well as competences for sustainable development. Some of these skills are developed best in contexts of professional engineering practice. Faculty competence also includes the ability to support students to achieve a deeper working understanding of the relevant disciplinary fundamentals. The nature and scope of faculty development vary with the resources and intentions of different programs and institutions. Examples of actions that enhance faculty competence include: professional leave to work in industry, partnerships with industry colleagues in research and education projects, inclusion of engineering practice as a criterion for hiring and promotion, and appropriate professional development experiences at the university.

Rationale

If engineering faculty are expected to teach a curriculum of personal and interpersonal skills, and product, process, system, and service building skills integrated with disciplinary knowledge, as described in Standards 3, 4, 5, and 7, they as a group need to be competent in those skills. Engineering professors tend to be experts in the research and knowledge base of their respective disciplines, with only limited experience in the practice of engineering in business and industrial settings, and its role in sustainable development. A key aspect of expertise is pedagogical content knowledge, which refers to the ability to effectively support

==students in learning the subject.== Moreover, the rapid pace of technological innovation requires continuous updating of engineering skills. The collective faculty needs to enhance its engineering knowledge and skills so that it can provide relevant examples to students and also serve as individual role models of contemporary engineers.

STANDARD 10 — ENHANCEMENT OF FACULTY TEACHING COMPETENCE

Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning

Description

A CDIO program provides support for faculty to improve their competence in integrated learning experiences (Standard 7), active and experiential learning (Standard 8), and assessing student learning (Standard 11). The nature and scope of faculty development practices will vary with programs and institutions. Examples of actions that enhance faculty competence include: support for faculty participation in university and external faculty development programs, forums for sharing ideas and best practices, and emphasis in performance reviews and hiring on effective teaching methods.

Rationale

If faculty members are expected to teach and assess in new ways, as described in ==the CDIO== Standards, they need opportunities to develop and improve these competencies. Many universities have faculty development programs and services that might be eager to collaborate with faculty in CDIO programs. In addition, if CDIO programs want to emphasize the importance of teaching, learning, and assessment, they must commit adequate resources for faculty development in these areas.

STANDARD 11 — LEARNING ASSESSMENT*

Assessment of student learning in personal and interpersonal skills, and product, process, system, and ==service== building skills, as well as in disciplinary knowledge

Description

Assessment of student learning is the measure of the extent to which each student achieves ==the intended== ~~specified~~ learning outcomes. Instructors usually conduct this assessment within their respective courses. Effective learning assessment uses a variety of methods matched appropriately to learning outcomes that address disciplinary knowledge, as well as personal and interpersonal skills, and product, process, system, and service building skills, as described in Standard ==2, 3 and 7==. These methods may include written, ==online== and oral tests, observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.

Rationale

If we value personal and interpersonal skills, and product, process, system, and ==service== building skills, and incorporate them into curriculum and learning experiences, then we must

have effective assessment processes for measuring them. Different categories of learning outcomes require different assessment methods. For example, learning outcomes related to disciplinary knowledge may be assessed with oral, ==online== and written tests, while those related to design-implement skills may be better measured with recorded observations. Using a variety of assessment methods accommodates a broader range of learning styles, and increases the reliability and validity of the assessment data. As a result, determinations of students' achievement of the intended learning outcomes can be made with greater confidence.

STANDARD 12 — PROGRAM EVALUATION

A system that evaluates programs against these twelve standards ==and any optional standards adopted==, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

Description

Program evaluation is a judgment of the overall value of a program based on evidence of a program's progress toward attaining its goals. A CDIO program should be evaluated relative to these 12 CDIO Standards ==and any optional standards that it has adopted==. Evidence of overall program value can be collected with course evaluations, instructor reflections, entry and exit interviews, reports of external reviewers, and follow-up studies with graduates and employers. The evidence ==should== be regularly reported back to instructors, students, program administrators, alumni, and other key stakeholders. This feedback forms the basis of decisions about the program and its plans for continuous improvement.

Rationale

A key function of program evaluation is to determine the program's effectiveness and efficiency in reaching its intended goals. Evidence collected during the program evaluation process also serves as the basis of continuous program improvement. For example, if in an exit interview, a majority of students reported that they were not able to meet some specific learning outcome, a plan could be initiated to identify root causes and implement changes. Moreover, many external evaluators and accreditation bodies require regular and consistent program evaluation.

MAPPING THE CDIO SYLLABUS TO THE UNESCO KEY COMPETENCIES FOR SUSTAINABILITY

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ABSTRACT

In this paper, a framework of key competencies for sustainability defined by UNESCO is used to evaluate the relevance of the CDIO Syllabus for promoting engineering education for sustainable development. The evaluation is performed in two steps. First, topics, terms and concepts in the CDIO Syllabus that corresponds to the different UNESCO key competencies are identified. The second step is a qualitative discussion where areas of strong mapping are highlighted and aspects that could be better visualized or strengthened in or added to, the Syllabus is identified. Differences in definitions of various concepts between the CDIO Syllabus and the UNESCO key competencies and the overall relation between the two frameworks are discussed. It is concluded that the CDIO Syllabus is rather well aligned with the UNESCO framework, however several opportunities (not to say needs) for strengthening the Syllabus in relation to the key competencies are identified. The UNESCO key competencies are found to be useful instruments for scrutinizing and updating the CDIO Syllabus. Other opportunities for knowledge and methods transfer between the Education for Sustainable Development (ESD) domain and the Engineering Education domain are identified. The paper is proposed to be used as basis for updating the CDIO Syllabus into a version 3.0 for maintaining its relevance in a changing world.

KEYWORDS

CDIO Syllabus, key competencies, sustainable development, ESD, Standards 1-3, 5, 7-9.

INTRODUCTION

Through the adoption of the UN 2030 Agenda (UN 2015), the global society and governments all over the world have agreed on the urgent need for change and formulated common Sustainable Development Goals (SDG). One of the seventeen SDGs considers education. To further promote the role of education for achieving the SDGs, UNESCO has issued guidelines for formulating learning objectives for each of the SDGs (UNESCO 2017). These learning objectives are based on eight key competencies for sustainability, which are derived by synthesising current research on education for sustainable development (e.g. de Haan 2010; Wiek et al. 2011; Rieckmann 2012).

The CDIO Syllabus aims to set consistent and generalizable goals for undergraduate engineering education addressing the conceiving-designing-implementing-operating (CDIO) context. The first version of the Syllabus, formulated in 2001, showed limited explicit attention to sustainability and sustainable development (Crawley 2001). In 2011, the Syllabus was reviewed and updated into Version 2.0 (Crawley et al. 2011). The review was based on comparison with the UNESCO Four Pillars of Learning (Delores 1996), different national accreditation and evaluation standards, and other forms of input received over the decade since the Syllabus was originally written. The major focus of the review was the formulation of two additional Syllabus sections concerning leadership (4.7) and entrepreneurship (4.8). With reference to Knutson-Wedel et al. (2008), it was concluded that while the Syllabus can support the development of engineering education to address sustainability, the visibility of the concept of sustainability could be strengthened. This resulted in the addition of terms such as environmental, sustainability, sustainable, and safe, mainly in section 4 of the Syllabus where also a new sub-section 4.1.7 *Sustainability and the Need for Sustainable* Development was added. Similar small modifications were also made concerning innovation, invention, internationalization and mobility.

The prospect of further developing the CDIO Syllabus and Standards in the context of the Sustainable Development Goals is now being considered in a joint effort by the Nordic Five Tech Universities (Aalto University, Chalmers University of Technology, Technical University of Denmark, KTH Royal Institute of Technology, and Norwegian University of Science and Technology). As part of this endeavour, the objective of this paper is to evaluate to what extent the current version of the CDIO Syllabus reflects the key competencies for sustainability outlined in UNESCO (2017). The aim is to contribute to the bridging of the two domains *Engineering Education* and *Education for Sustainable Development* (ESD) and to the development of the CDIO Syllabus for maintaining its relevance in a changing world. A parallel paper by Malmqvist et al. (2019) considers related revisions of the CDIO Standards.

CDIO SYLLABUS AND STANDARDS

The starting point of the CDIO Initiative was to consider what knowledge, skills, and attitudes that engineering students should learn to prepare for engineering practice. The resulting document was called the *CDIO Syllabus* (Crawley, 2001). It is structured in four sections according to Figure 1: The first is a placeholder for the subject knowledge relevant for a particular educational programme, the second section lists personal and professional skills, while the third contains interpersonal skills. The fourth overarching section contains the ability to conceive, design, implement and operate products, processes, and systems, in the enterprise and societal context – or what could be called the CDIO shorthand for engineering competencies. Since the CDIO Syllabus is a very extensive set of goals, it must be emphasised that it is intended to be comprehensive but not prescriptive; no program could be expected to address all topics.
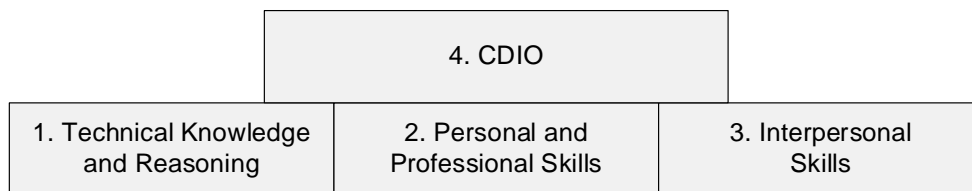
Figure 1. The four sections of the CDIO Syllabus (Crawley 2001).

It is not the CDIO Syllabus that defines the CDIO approach. Instead, the working definition is expressed in the CDIO Standards, formulated in 2004 to *define the distinguishing features of a CDIO program, serve as guidelines for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement* (CDIO 2004). Simply put, if the CDIO Syllabus defines what students should learn, the CDIO Standards are a set of aligned strategies for developing programs to address these learning goals. They focus on program aims (Standard 1), curriculum development (Standards 2, 3, 4), engineering projects and workspaces (Standards 5, 6), teaching and learning methods (Standards 7, 8), faculty development (Standards 9, 10), and assessment and evaluation (Standards 11, 12). The structure of the Syllabus can be clearly recognised when it is stated in the Standards that a program should set *specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders* (Standard 2). Hence, the main aim of the CDIO Syllabus is to be an instrument to guide the formulation of intended learning outcomes for a specific program, making priorities based on a particular context, conditions, ambitions, and stakeholder needs. As a comprehensive framework, it has been used for defining, analysing or comparing learning objectives in curriculum development – on program or course level, as well as in national and international quality assurance schemes.

KEY COMPETENCIES FOR SUSTAINABILITY

The consideration and implementation of *competencies* in educational systems have been an integral part of the shift from input-oriented knowledge-based educations to outcome-oriented competence-based educations, driven by the CDIO initiative, the Bologna process, and similar activities around the world. Such a shift builds on the idea that education should not only aim to provide knowledge in itself, but also foster the development of competencies as an interplay between knowledge, skills, and attitudes among the learners.

Key competencies for sustainability are competencies that, within the Education for Sustainable Development (ESD) domain, are considered necessary for all learners to cope with the increasingly diverse and interconnected world and to enable them to contribute to the urgently needed transformations towards a sustainable society. For example, the OECD DeSeCo project (OECD 2005) resulted in the definition of a set of nine key competencies. de Haan (2010) presented a set of twelve competencies subsumed under the term *Gestaltungskompetenz*, noting that those possessing these competencies *can help, through active participation, to modify and shape the future of the society, and to guide social, economic, technological and ecological changes along the lines of sustainable development*. Wiek et al. (2011) performed an extensive literature review, identifying various definitions of competencies related to sustainability, which were then clustered into a compiled set of five key competencies for sustainability. Here, critical thinking and basic communication skills were not included with the motivation that they should be considered as general competencies rather than key competencies. Rieckmann (2012) performed an empirical study among experts on higher education for sustainable development in a number of countries in Europe and South America, identifying a set of twelve key competencies, where critical thinking, systemic thinking and handling of complexity, and anticipatory thinking, were concluded to be the most important.

The key competencies in the above mentioned references have significant overlaps but also some differences, with several other definitions found in the literature as well. Hence, there is no general consensus on the specific definitions of key competencies for sustainability and the concept is still under development (e.g. Shephard et al. 2018). Some sort of convergence can, however, be seen, where key competencies are generally considered to represent cross-cutting, multifunctional, context- and domain-independent competencies.

In this paper, we use the eight key competencies for sustainability outlined by UNESCO (2017) as a reference when evaluating the CDIO Syllabus. Our motivation for choosing this particular set of competencies is two-fold: firstly, they connect directly to the SDGs in the UN 2030 Agenda, and secondly, they are well founded in other related literature (e.g. de Haan 2010; Wiek et al. 2011; Rieckmann 2012; OECD 2005) and can thereby be considered as a compilation of these. The UNESCO key competencies are here reproduced in Table 1, with each competency defined, or rather exemplified, in terms of a number of abilities according to UNESCO (2017). It should be noted that the UNESCO descriptions of the different competencies in Table 1 are rather limited, not least for the strategic competency, and that our analysis thereby will contain corresponding limitations.

Table 1. The eight key competencies for sustainability in UNESCO (2017).

Competency	Ability to…
1. Systems thinking competency	– recognize and understand relationships; – analyse complex systems; – think of how systems are embedded within different domains and different scales; – deal with uncertainty.
2. Anticipatory competency	– understand and evaluate multiple futures – possible, probable and desirable; – create one's own visions for the future; – apply the precautionary principle; – assess the consequences of actions; – deal with risks and changes.
3. Normative competency	– understand and reflect on the norms and values that underlie one's actions; – negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
4. Strategic competency	– collectively develop and implement innovative actions that further sustainability at the local level and further afield.
5. Collaboration competency	– learn from others; – understand and respect the needs, perspectives and actions of others (empathy); – understand, relate to and be sensitive to others (empathic leadership); – deal with conflicts in a group; – facilitate collaborative and participatory problem solving.
6. Critical thinking competency	– question norms, practices and opinions; – reflect on own one's values, perceptions and actions; – take a position in the sustainability discourse.
7. Self-awareness competency	– reflect on one's own role in the local community and (global) society; – continually evaluate and further motivate one's actions; – deal with one's feelings and desires.
8. Integrated problem-solving competency	– apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the abovementioned competences.
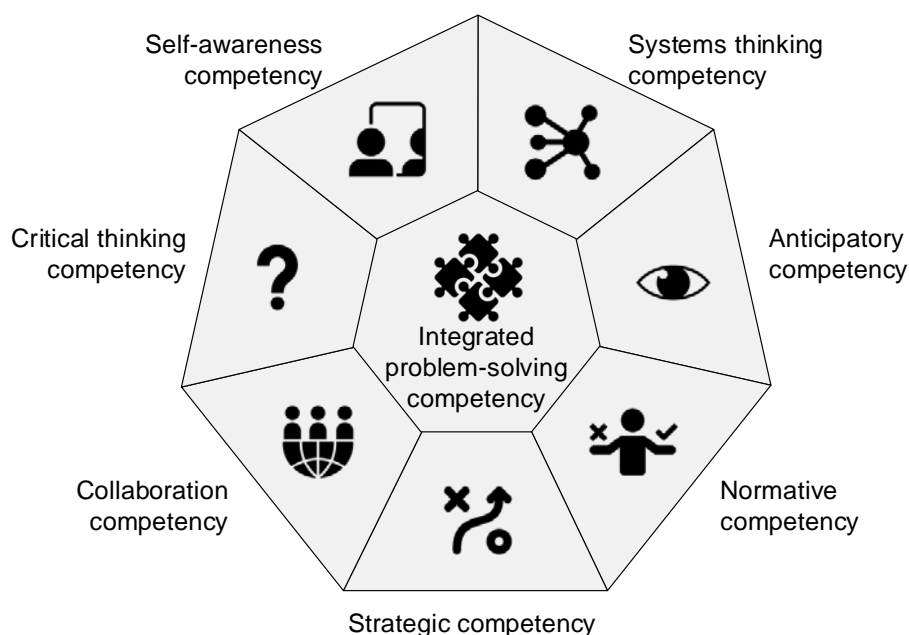
Figure 2. Our schematic illustration of the UNESCO key competencies framework.

METHOD

The objective of this paper is to evaluate to what extent the UNESCO key competencies for sustainability are reflected in the current version of the CDIO Syllabus as basis for further revision of the Syllabus. The evaluation is performed in two steps.

The first step is an analysis identifying topics, terms and concepts in the CDIO Syllabus that correspond to the different abilities of the UNESCO key competencies (as in Table 1). We use the current CDIO Syllabus version 2.0 (see Appendix B in Crawley et al. 2011) including sub-titles and explanatory keywords under the X.X.X level. The identified mapping is categorized on two levels: either i) explicit or otherwise strong mapping or ii) implicit or partial mapping.

Since the Syllabus section 1 is a placeholder for the subject knowledge relevant for a particular education programme, this mapping analysis only considers Syllabus sections 2-4. Further, it has become obvious through the process of this analysis that the 8th UNESCO key competency, *integrated problem-solving*, has a different character and role than the other competencies. As seen in Table 1, UNESCO defines this 8th competency as integrating the other seven key competencies. Similarly, Wiek et al. (2011) describe the incorporation of some of the key competencies in an integrated problem solving framework. Based on these observations we are here only addressing competencies 1-7 in the first step of the analysis, leaving *integrated problem-solving* for consideration in the second step.

The second step of the evaluation is a qualitative discussion where areas of strong mapping are highlighted and aspects that could be better visualized or strengthened in or added to, the Syllabus are identified. Differences in definitions of various concepts between the CDIO Syllabus and the UNESCO key competencies and the overall relation between the two frameworks are discussed.

The different key competencies have here been analysed by different working groups consisting of three to four of the co-authors of this paper representing different universities, disciplines and experiences. Several video conference discussions have provided further negotiation of our interpretation of the differences, providing a broad view and more valid understanding of the Syllabus and the key competencies. The analysis has hence been an interpretive process guided by conceptual reasoning and discussions between colleagues.

MAPPING

Overview

An overview of the identified mapping between the CDIO Syllabus and the UNESCO key competencies 1-7 is given in Table 2. Here dark coloured fields indicate explicit or otherwise strong mapping whereas light coloured fields indicate implicit or partial mapping. Fields marked with an asterisk indicates where we identified the potential for development. More details about the mapping analysis are provided in the appendix.

Strong mappings with basically all key competencies are identified for the Syllabus section 4.1 *External, Societal and Environmental Context*. This could be expected, not least since this is the section that was most updated regarding sustainability in the Syllabus 2.0 revision (Crawley et al 2011). Considering the nature of the sustainability concepts and concerns it is also expected that strong mapping with several of the key competencies is identified for the Syllabus sections 2.4 *Attitudes, Thought and Learning* and 2.5 *Ethics, Equity and Other Responsibilities*. On the other hand, rather weak mapping is identified between the key

competencies and the Syllabus sections 4.2 *Enterprise and Business Context*; 4.4 *Designing*; 4.5 *Implementing*; 4.7 *Leading Engineering Endeavors*; and 4.8 *Entrepreneurship*.

2 Personal & Professional Skills & Attributes

Key competency:
1. Systems thinking
2. Anticipatory
3. Normative
4. Strategic
5. Collaboration
6. Critical thinking
7. Self-awareness

3 Interpersonal Skills

Key competency:
1. Systems thinking
2. Anticipatory
3. Normative
4. Strategic
5. Collaboration
6. Critical thinking
7. Self-awareness

4 CDIO

Key competency:
1. Systems thinking
2. Anticipatory
3. Normative
4. Strategic
5. Collaboration
6. Critical thinking
7. Self-awareness

4 CDIO (cont)

Key competency:
1. Systems thinking
2. Anticipatory
3. Normative
4. Strategic
5. Collaboration
6. Critical thinking
7. Self-awareness

Considering the individual key competencies, particularly strong mapping is found for the *systems thinking* competency basically all through Syllabus sections 2 and 4. Strong mapping is also found between the *collaboration competency* and the Syllabus section 3.1 *Teamwork* and quite strong also with 3.2 *Communication*. Quite some mapping is also found for the *anticipatory*, *normative*, and *critical thinking* competencies, whereas the mapping is weaker regarding the *strategic* and *self-awareness* competencies. Some further observations and opportunities for strengthening the CDIO Syllabus in relation to the UNESCO key competencies are discussed in the following sub-sections.

Systems thinking

The identified strong mapping with the *systems thinking* competency all through the Syllabus sections 2 and 4 and the fact that there is a particular Syllabus section dedicated for *System Thinking* (2.3), on one hand indicates that the CDIO notion of systems thinking is more narrowly defined than the UNESCO *systems thinking* competency. On the other hand, this reflects that *systems thinking* in a broader sense, also including practical "*systems doing*", is a core aspect of engineering. This is particularly strongly expressed in the Syllabus section 4. It can also be seen in the CDIO Standard 1, citing the *principle that product, process, and system lifecycle development and deployment – Conceiving, Designing, Implementing and Operating – are the context for engineering education*.

Temporal and spatial perspectives

The mapping analysis indicates opportunities for strengthening the CDIO Syllabus in relation to both the *systems thinking* and *anticipatory* key competencies regarding the consideration of different scales, in time as well as space, and future scenarios. Although CDIO certainly advocates broadening the view on technology and engineering, global perspectives, temporal perspectives, and future-oriented thinking are more narrowly expressed and could be emphasized for example in the Syllabus sections 2.3.1, 2.3.4, 2.5.1, 4.1.4 and 4.1.6. Abilities to apply the precautionary principle could be more emphasized, for example in 2.4.2 and 2.5.1. The Syllabus considers various visionary aspects, however, limited to one's own personal future and visions for products and enterprises. Abilities to create one's own vision for the future could be strengthened in 2.5.3.

Personal value-related aspects

The UNESCO description of *normative* competency emphasizes the understanding of norms and values that form the basis for one's actions, and the ability to reflect upon those. It also stresses the importance of the ability to negotiate trade-offs among complex conflicts of interest about values, principles and goals, where information may be uncertain or contradictory, i.e., to handle complex value added systems. The UNESCO description for *critical thinking* competency is closely related to *normative* competency and together they illustrate some of the overall differences between the CDIO Syllabus and the UNESCO key competencies. While there is a good match for *critical thinking* with respect to particulars, there are differences in the overall view of the nature of the competency. The CDIO Syllabus does not explicitly address norms based on specific interests, ideology or belief systems in the same way that the UNESCO description does. Instead, the CDIO Syllabus takes prevailing systems more as given, and emphasises familiarity with current practices (2.5.4). The focus is rather on understanding important contemporary values more generally (4.1.5). Both these abilities, addressing norms and reflecting, seem to be missing from the current CDIO Syllabus, and could be added under to section 2.4 *Attitudes, Thought and Learning*, with *question norms, practices and opinions* included into 2.4.5 or even meriting its own, new, goal (a suggested 2.4.8). The ability to reflect on one's own values, perceptions and actions could be added as part of 2.4.2 or 2.4.5.

It is clear that UNESCO links both *normative* competency and *critical thinking* to one's ability to take a position in the sustainability discourse (rather than, for example, plan and implement actions for sustainability, which is part of *strategic* competency). The UNESCO descriptions view both these competencies as personal, value-related competencies of questioning prevailing norms and practices, including the ability to reflect on one's own values and actions. There is a distinction between, on the one hand, norms and standards based on engineering practices and calculations, which should be challenged on scientific grounds, and, on the other hand, norms founded in specific interests, ideology or belief systems. The latter may form boundary conditions for which solutions or actions are acceptable in a given situation. An understanding of this distinction is central to the ability to negotiate trade-offs among conflicting interests. While the UNESCO description conflates the two aspects, the CDIO Syllabus could clarify the distinction by distinguishing between them, most profitably in the syllabus sections indicated above.

This difference can also be seen in relation to the *self-awareness* competency. The CDIO Syllabus seems to connect self-awareness mainly to the cognitive domain of learning and metacognition, while the UNESCO approach emphasizes self-reflection regarding one's own role, feelings and desires. The Syllabus could be strengthened in relation to the *self-awareness* competency by adding abilities to reflect also one's own role locally and globally, and the ability to recognize and deal with one's feelings and desires in sections 2.4.5, 4.1.1 and 4.1.6. The ability to recognize and deal with one's feelings and desires, and also the ability to understand how they influence one's behaviour, willingness, effectivity, flexibility and motivation, could be added to 2.4.1, 2.4.2, and 4.7.5. The ability to continually evaluate and further motivate one's actions could be emphasized more in 2.5.3, 4.7.6, and 4.7.5. Finally, the collective abilities for self-awareness competency could be included in 4.7.7. With these developments, the CDIO Syllabus would actually go beyond the UNESCO key competency also including self-awareness for others and not just for one self.

Learning from others, participatory and empathic approaches

Collaboration is an important part of the CDIO framework and the Syllabus matches the collaborative competency to a very high degree. We found that the CDIO Syllabus focus to a high degree on teamwork primarily among engineers, and less so on collaboration across disciplines. The latter aspect is consistent with our findings with respect to *normative* competency and *critical thinking*, where we noted an absence in the CDIO Syllabus of an explicit mention of how to deal with values. Also, we found that the Syllabus could better emphasise the ability to learn from others (2.4.6), the need to consider collaborative and participatory problem-solving (3.1.4), and empathic leadership (4.7.5 or 4.8.7). At the same time, the CDIO Syllabus goes beyond the UNESCO competency when it comes to encouraging and inspiring others, and supporting their learning.

A note on the structures of the frameworks

This mapping process helped us see interconnections and dimensional qualities, making it clear that neither framework is a straight list. In the UNESCO framework, *integrated problem solving* integrates the other seven competencies. We illustrate this by placing it in the centre of the heptagon in Figure 2. Similarly, the CDIO Syllabus also has dimensions, as shown in Figure 1. In the CDIO framework it is *engineering* – or conceiving, designing, implementing and operating – that is the overarching and integrating competency, with 4.1 and 4.2 representing the context. If the CDIO Syllabus is further updated with respect to sustainability, as outlined in this paper, it could show a way for *practical* integrated problem-solving, well aligned with the UNESCO key competencies framework.

TOWARDS CDIO SYLLABUS 3.0

This study has shown that the current version of the CDIO Syllabus is already to quite some extent aligned with the UNESCO key competencies for sustainability. This can partly be explained by the previous enhancements regarding sustainability in the Syllabus 2.0 revision (Crawley et al. 2011) but even more by the strong emphasis on generic engineering skills as one of the core aspects of the CDIO Syllabus and the obvious correspondence between those skills and some of the key competencies such as collaboration, systems thinking and problem solving. Still, several opportunities (not to say needs) for strengthening the Syllabus in relation to the key competencies have been identified.

Just like we reason with regards to the generic engineering skills, sustainable development and therewith related competencies should not be treated as an add-on in isolated courses, but instead, be thoroughly integrated into education program curricula in line with the CDIO philosophy of integrated learning. Enhanced integration of sustainable development will contribute to improving the relevance and future compliance of engineering educations and could also contribute to students' and teachers' motivation. This study has shown that the UNESCO key competencies, and the underlying research literature, are useful instruments for scrutinizing and updating the CDIO Syllabus. In the other way around, implementations in the Engineering Education domain could also contribute to developing further understanding of the key competencies within the Education for Sustainable Development domain. Also regarding pedagogical approaches and learning activities there are opportunities for knowledge and methods transfer between these two educational domains (see for instance chapter 2 in UNESCO (2017) and Lozano et al. (2017) in relation to the CDIO Standards 7 and 8).

We propose that the results from this study are used as a basis for a structured process for updating the CDIO Syllabus into a version 3.0. As demonstrated and discussed in this paper such updating would partly be about adding words and expressions and partly about broadening and deepening the current conceptions of generic skills for better alignment with the key competencies.

Somewhat outside the scope of this paper, but still worth stating in the context of Syllabus updating, is the opportunity (not to say need) to add generic sustainability knowledge as an element in the Syllabus section 1. This section was deliberately excluded from our mapping analysis since it is mainly a placeholder for fundamental scientific and engineering knowledge that has to be defined for each education programme. However, as highlighted by Knutson-Wedel et al. (2008), in addition to domain-specific sustainability knowledge to be considered for each education program, there also exists a common domain- and program-independent core of sustainability knowledge that is crucial for all engineers and therefore would be motivated to include in section 1. This, for example, concerns knowledge of fundamental sustainability concepts, international policies, and possibilities and limitations of the use of different natural resources from a sustainability point of view.

Neither the CDIO Syllabus nor the UNESCO key competencies are prescriptive and they only address what students should learn. Enhanced integration of sustainable development in the CDIO framework will, therefore, require parallel revisions of the CDIO Syllabus and the CDIO Standards. Further background to and proposals of revisions of the CDIO Standards is considered in the parallel paper by Malmqvist et al. (2019).

With these changes, we suggest that the CDIO community can adopt the aim to educate students to *conceive, design, implement and operate complex value-added engineering products, processes, systems and services **for a sustainable society***.

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Martin E. Vigild is Professor at the Technical University of Denmark, DTU, and former president of the European Society for Engineering Education, www.sefi.be. For 10 years he has been responsible for undergraduate education and student environment at DTU. During this period CDIO – in general – and the imperative of sustainability – in particular – was implemented at DTU for the overall purpose of improving engineering education and making it challenging and attractive for students.

Thomas Fruergaard Astrup is Professor at DTU Environment at the Technical University of Denmark. He carries out research within waste and resources, in particular in relation to sustainable recycling and utilization of resources in waste from households and industry. The research focuses on environmental aspects of resource recovery and management in society.

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APPENDIX – MAPPING ANALYSIS DETAILS

Systems thinking competency

Systems thinking is a central concept within the CDIO framework and in the CDIO Syllabus we find a very strong match with the Systems thinking competency. It is covered by the sections *2.1 Analytic Reasoning and Problem Solving, 2.3 System Thinking* and *4.1 External, Societal and Environmental Context.* The four abilities that are explicitly mentioned (see Table 1; underlined below) correspond to the following items in the CDIO Syllabus: The ability to recognize and understand relationships is present throughout *2.3 System Thinking*, most directly in *2.3.2 emergence and interactio*ns which specifies *abstractions necessary to define and model the entities or elements of the system*, and the *important relationships, interactions and interfaces among elements.* The ability to analyse complex systems is fully addressed by a combination of *2.1 Analytic Reasoning and Problem Solving* and *2.3 System Thinking*. The former lists *problem identification and formulation* (2.1.1), *modeling* (2.1.2), *estimations* (2.1.3), *analysis with uncertainty* (2.1.4) and *recommendations* (2.1.5), while the latter lists *thinking holistically* (2.3.1), *prioritization and focus* (2.3.3), and *trade-offs, judgment and balance* (2.3.4). Arguably, this requires *creative thinking* (2.4.3), with keywords such as *conceptualization, abstraction, synthesis and generalization*, as well as *critical thinking* (2.4.4) with *purpose and statement of the problem or issue, logical arguments, supporting evidence, points of view and theories, conclusions and implications*. The ability to think of how systems are embedded within different domains and different scales matches *thinking holistically* (2.3.1), explicitly mentioning *transdisciplinary approaches that ensure the system is understood from all relevant perspectives*, and the *societal, enterprise and technical context of the system.* Another relevant aspect is *willingness to consider and embrace various viewpoints* (2.4.2). Also *4.1 External, Societal and Environmental Context* is relevant, as seen in phrases such as the *impact of engineering on the environmental, social, knowledge and economic systems in modern culture* (4.1.2) *historical and cultural context* (4.1.4), *contemporary issues and values* (4.1.5), *global perspective* (4.1.6) and *sustainability* (4.1.7). The ability to deal with uncertainty is addressed in *2.1 Analytic Reasoning and Problem Solving*, for instance in relation to estimations and assumptions in *problem formulation* (2.1.1) and *modeling* (2.1.2), and also in *analysis with uncertainty* (2.1.4) An associated attitudinal component is the *willingness to make decisions in the face of uncertainty* (2.4.1).

In the comparison, some aspects emerge that could be expressed more explicitly in the Syllabus. There are cases where the heading (on x.x.x level) is highly appropriate, but the sub-items listed suggest a narrower scope or understanding of a topic. For instance:
1) In *the historical and cultural context* (4.1.4), we miss items such as "Interpreting problems and issues in a historical and cultural context" and "Applying a historical and cultural perspective in creating and evaluating potential solutions".
2) In *developing a global perspective* (4.1.6), we suggest adding "Assessing the consequences of technical systems in a global perspective"
3) While *system improvement and evolution* (4.6.4) is highly relevant, the given examples seemingly refer to commercial handling of product generations. A more general bullet could be added, such as "Continuous improvement and evolution based on observations of system performance, changing needs or new opportunities".

Anticipatory competency

The ability to create one's own vision for the future is to some extent considered under *proactive vision and intention in life* (2.5.3) and *leadership and entrepreneurship* (4.7.2, 4.7.3, 4.7.7). Future perspectives are further considered in terms of: *needs and opportunities* in general (2.4.1, 4.7.1, 4.8.2) and particularly regarding sustainability (4.1.7, 4.3.1); *goals and trade-offs* (2.3.4, 4.3.3); and various *life-cycle considerations* (4.3.3, 4.4.6). Life-cycle

considerations can also be related to the ability to <u>assess the consequences of actions</u>, which is also addressed in terms of *new technology development and assessment* (4.2.6), *implications* and *impact* of engineering and technology on social, environmental, and economic systems (2.5.4, 4.1.2, 4.8.5), and *modeling* (2.1.2, 2.1.3). The ability to <u>deal with risks and changes</u> is explicitly considered in the contexts of *2.1 Analytical Reasoning and Problem Solving* and *2.4 Attitudes, Thought and Learning* in terms of *analysis with uncertainty*, *probabilistic and statistical models*, *cost-benefit and risk analysis* (2.1.4, 2.4.1), and also in the context of *leadership and entrepreneurship* (4.7.7). The ability to <u>understand and evaluate multiple futures – possible, probable and desirable</u> and to <u>apply the precautionary principle</u> are to some extent considered in 2.2.3 and 4.7.7 and by the above identified vision and future related elements. Anticipatory competency could also be considered as implicitly included in all considerations of *sustainability* related to conceiving, designing, implementing and operating (4.1.7, 4.4.6, 4.5.1). There could however be options for strengthening these formulations in the syllabus, for example by adding 'sustainable' (e.g. in 4.8.5) and by emphasizing societal needs and how legal and political systems do and could regulate and influence engineering in a sustainable direction (in 4.1.3).

Some aspects that could be expressed more explicitly in the Syllabus are the importance of different time scales and the abilities to evaluate different future scenarios. These could be emphasized for example in *thinking holistically* (2.3.1) and in *trade-offs, judgment and balance in resolution* (2.3.4). Further, *historical and cultural context* (4.1.4) and *developing a global perspective* (4.1.6), could be complemented to also include influences on future conditions and opportunities. The Syllabus considers various visionary aspects, however, limited to one's own personal future and visions for products and enterprises. Abilities to "create one's own vision for <u>the</u> future" could be added in (2.5.3). Abilities to apply the precautionary principle could be more emphasized, for example in 2.4.2 and 2.5.1.

Normative competency

The ability to <u>understand and reflect on the norms and values that underlie one's actions</u> is explicitly addressed in *ethics, integrity and social responsibility* (2.5.1), which is about ethical standards and principles, and the possibility of conflicts between ethical imperatives. With respect to sustainability it is further addressed in *contemporary issues and values* (4.1.5) which specifies the processes by which contemporary values are set, and in *sustainability and the need for sustainable development* (4.1.7). Other Syllabus items specify aspects that implicitly address and support the same ability, such as *problem identification and formulation* (2.1.1) that addresses assumptions and sources of bias, *thinking holistically* (2.3.1) that stresses the societal, enterprise and technical context of the system, and *self-awareness, metacognition and knowledge integration* (2.4.5). Other relevant sections are *roles and responsibilities of the engineers* (4.1.1), *the impact of engineering on society and the environment* (4.1.2), *developing a global perspective* (4.1.6), together with *understanding needs and setting goals* (4.3.1). The ability to <u>negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions</u> corresponds to *trade-offs, judgment and balance in resolution* (2.3.4), and *negotiation, compromise and conflict resolution* (3.2.8). The ability is also implicitly addressed and supported through *analysis with uncertainty* (2.1.4), *inquiry, listening and dialog* (3.2.7) addressing aspects supporting negotiation skills, and *system engineering, modelling and interfaces* (4.3.3) where trade-offs and iteration are identified as desired aspects. Finally, the need to identify all aspects of a problem at hand, including underlying paradoxes is addressed in *identifying the issue, problem or paradox* (4.7.1).

Strategic competency

The strategic competency is by UNESCO described as the ability to collectively develop and implement innovative actions that further sustainability at the local level and further afield. The CDIO syllabus reflects the components of this ability in several places. The collective dimension is emphasised in various ways in *team leadership* (3.1.4) and *technical and multidisciplinary teaming* (3.1.5). It could further be argued that development and implementation of innovative actions is done through the familiar process of 4.3 - 4.6, *Conceiving, Designing, Implementing and Operating*. Dimensions of furthering sustainability at the local level and further afield is covered in different parts of the syllabus including the *impact of engineering on society and the environment* (4.1.2), where the impact of engineering on the environmental, social, knowledge and economic systems in modern culture is addressed. The need to apply sustainability principles in engineering endeavours is part of *sustainability and the need for sustainable development* (4.1.7). Also, the awareness of the the responsibilities of engineers to society and a sustainable future is identified in *roles and responsibility of engineers* (4.1.1). *Understanding needs and setting goals* (4.3.1) addresses environmental needs as well as ethical, social, environmental, legal and regulatory influences, which must be furthering sustainability. Finally, *design for sustainability, safety, aesthetics, operability and other objectives* (4.4.6) and *designing a sustainable implementation process* (4.5.1) addresses important aspects of the furthering dimension. To conclude, we find a good match in the CDIO syllabus for every element of the strategic competency. We still hold that the strategic competency, as described by UNESCO, could be made to stand out more clearly in the syllabus.

Collaboration competency

The collaborative competency is directly addressed, and mostly covered, by the sections *2.5 Ethics, Equity and other Responsibilities, 3.1 Teamwork* and *3.2 Communications*. The ability to learn from others is somewhat present in *perseverance, urgency and will to deliver, resourcefulness and flexibility* (2.4.2), *lifelong learning and educating* (2.4.6), *team growth and evolution* (3.1.3), *inquiry, listening and dialog* (3.2.7) and *building and leading an organization and extended organization* (4.7.5). The ability to understand and respect the need, perspectives and actions of others (empathy) is addressed by a combination of *2.5 Ethics, Equity and other Responsibilities and 3.1 Teamwork*. It directly matches *ethics, integrity and social responsibility* (2.5.1), *equity and diversity* (2.5.5), *trust and loyalty* (2.5.6), *forming effective teams* (3.1.1), and *establishing diverse connections and networking* (3.2.10). It is furthermore to some extent included in *professional behavior* (2.5.2), *roles and responsibility of engineers* (4.1.1), *sustainability and the need for sustainable development* (4.1.7), *working in organizations* (4.2.4), *working in international organizations* (4.2.5). The ability to understand, relate to and be sensitive to others (empathic leadership) matches *trust and loyalty* (2.5.6), *working in organizations* (4.2.4) *and working in international organizations* (4.2.5). The ability to deal with conflicts in a group is highly present in *team operation with a focus on conflict mediation, negotiation and resolution* (3.1.2), and in *negotiation, compromise and conflict resolution* (3.2.8). Finally, the ability to facilitate collaborative and participatory problem solving is present throughout *3.1 Teamwork*, for instance in *forming effective teams* (3.1.1), *team operation* (3.1.2), *team growth and evolution* (3.1.3), *team leadership* (3.1.4) and *technical and multidisciplinary teaming* (3.1.5).

When considering the extent to which the CDIO Syllabus addresses the collaborative competency, we find some parts are missing in the syllabus. There is far more emphasis on communicating to others, than on learning from others. There is also a lack of empathic leadership. We, therefore, propose adding the following three abilities to the Syllabus:
1) "Facilitate collaborative and participatory problem-solving" into *team leadership* (3.1.4),
2) "Ability to learn from others" into *lifelong learning and education* (2.4.6), and

3) "Developing empathic leadership" into *building and leading an organization and extended organization* (4.7.5) or into *building the team and initiating engineering processes* (4.8.7).

On the other hand, the Syllabus emphasizes another point of view that is absent from the UNESCO definition: how one is able to affect and encourage others. To mention but a few examples, the ability to *enable learning in others* can be found in *lifelong learning and educating* (2.4.6), the commitment to *help others* is mentioned in *2.5 Ethics, Equity and other Responsibilities*, and *inspiring others* is part of *proactive vision and intention in life* (2.5.3).

Critical thinking competency

Critical thinking (as described by UNESCO) is visible in CDIO Syllabus particularly in relation to *self-awareness, metacognition and knowledge integration* (2.4.5), *ethics, integrity and social responsibility* (2.5.1) and *contemporary issues and values* (4.1.5) that all emphasise personal abilities for responsible, value-based actions and reflective thinking, and therefore link directly to the first two abilities of UNESCO's definition, <u>question norms, practices and opinions</u> and <u>reflect on own one's values, perceptions and actions</u>. These abilities are also to lesser extent visible in a number of other places, including *2.4 Attitudes, Thought and Learning* (particularly 2.4.4 and 2.4.6), *2.5 Ethics, Equity and other Responsibilities* (particularly 2.5.2, 2.5.3 and 2.5.5) and *3.2 Communications* (particularly 3.2.7 and 3.2.8). The ability to <u>take a position in the sustainability discourse</u>) is most directly visible as *the impact of engineering on society and the environment* (4.1.2) and *sustainability and the need for sustainable development* (4.1.7). This ability is naturally related also to *4.1 External, Societal, and Environmental Context* (especially sub-goals 4.1.1, 4.1.4, 4.1.5 and 4.1.6). It can also be seen to match other Syllabus items related to sustainability (including 4.3.1, 4.4.6, 4.6.1 and 4.7.1).

Self-awareness competency

Self-awareness is explicit in the heading *self-awareness, metacognition and knowledge integration* (2.4.5). This ability to <u>reflect on one's own role in the local community and (global) society</u> is addressed in the Syllabus by: *sense of responsibility for outcomes* (in 2.4.2), *a personal vision for one's future* and *considering one's contributions to society* (in 2.5.3), *roles and responsibility of engineers* (4.1.1) and *the Impact of engineering on society and the environment* (4.1.2). The ability to <u>continually evaluate and further motivate one's actions</u> can be recognized in: *decisions, based on the information at hand* and *the potential benefits and risks of an action or decision* (both in 2.4.1), and in *sense of responsibility for outcomes* and *adaptation to change* (both in 2.4.2). The ability to <u>deal with one's feelings and desires</u> is to some extent addressed by *determination to accomplish objectives, a readiness, willingness and ability to work independently, a willingness to work with others, and to consider and embrace various viewpoints, the balance between personal and professional life, self-confidence, courage and enthusiasm*, and *an acceptance of feedback, criticism and willingness to reflect and respond* (all in 2.4.2).

The content in section *self-awareness, metacognition and knowledge integration* (2.4.5) could be made more relevant for the self-awareness competency by adding points that reflect also one's own role locally and globally, and the ability to recognize and deal with one's feelings and desires. One's own role could be further strengthened also in the *roles and responsibility of engineers* (4.1.1) and *developing a global perspective* (4.1.6). The ability to recognize and deal with one's feelings and desires, and also the ability to understand how they influence one's behavior, willingness, effectivity, flexibility and motivation, could be added to *Initiative and willingness to make decisions in the face of uncertainty* (2.4.1), *perseverance, urgency and will to deliver, resourcefulness and flexibility* (2.4.2), and *building and leading an organization and extended organization*) (4.7.5). The ability to continually evaluate and further motivate one's actions could be emphasized more in *proactive vision and intention in life* (2.5.3) as well as in *managing a project and its human resources* (4.7.6), and could be strengthened

even more by adding *continuous self-evaluation in relation to teamwork and leadership* (to 4.7.5). Finally, the collective abilities for self-awareness competency, could be included in *exercising project/solution judgment and critical reasoning* (4.7.7).

The suggestions above to add self-awareness competency associated to leadership (in 4.7) would imply that the Syllabus would go beyond the UNESCO key competency, since this also includes self-awareness for others and not just for one self.

CDIO Implementation

A MODEL TO EXPLICITLY TEACH SELF-DIRECTED LEARNING TO CHEMICAL ENGINEERING STUDENTS

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ABSTRACT

The 3-year Diploma in Chemical Engineering (DCHE) curriculum had undergone a major redesign to transition to a spiral curriculum so as to better meet the learning outcomes mandated by SkillsFuture, the Singapore Government's national initiative. One of the outcomes is the development of a lifelong learning culture. In response, Singapore Polytechnic came up with several initiatives to enhance the competencies of its students, one of which is self-directed learning (SDL). This is achieved via the progressive nature of learning afforded by the spiral curriculum course structure by explicitly teaching a SDL model to students. This will be done over 4 semesters through 4 practical modules, beginning in Semester 1 of Year 1 when students first joined the polytechnic. There will be 1 practical module per semester where various learning tasks are designed to engage students to develop their knowledge, skills and attitudes as process technicians or future chemical engineers (with further studies). Using the spiral curriculum design, each concept is revisited again and again in later modules with increasing level of difficulty. It is notable that all learning tasks are designed to anchor to a typical chemical plant found in the oil and refining industry, to provide context and continuity required in a spiral curriculum. The 4 practical modules are also supported by other core chemical engineering modules within the same semester and across different semesters as part of the spiral curriculum. Using constructive alignment, students are assessed appropriately using a combination of formative and summative assessment over the 4 semesters. Preliminary findings showed that majority of students in general are receptive to the use of SDL model, but more research is needed to address the effectiveness of the SDL workshop, and improve the students' learning experience. This paper concludes with a discussion of our plans to move forward.

KEYWORDS

Chemical Engineering, Spiral Curriculum, Self-Directed Learning, CDIO Standards 1, 2, 3, 4, 7 and 11

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to as "faculty" in the universities.

INTRODUCTION

The 3-year Diploma in Chemical Engineering (DCHE) curriculum from Singapore Polytechnic (SP) had undergone a major redesign to transition to a spiral curriculum so as to better meet the learning outcomes mandated by SkillsFuture, the Singapore Government's national initiative (Cheah & Yang, 2018). The initiative was launched in 2015 aimed at helping Singapore manufacturers improve their operations to remain competitive in the global marketplace, promoting lifelong learning by providing workers with avenues to deepen their existing skills and acquire new ones, so that they can stay relevant amid ever-changing

workplace demands. As an educational institution, one of our key roles is therefore preparing students to be lifelong learners. Self-directed learning (SDL) has been identified as the key approach for becoming a lifelong learner (Candy, 1991; Alexander, et al, 2004; Tunney & Bell, 2011). A meta-analytic review by Boyer et al (2014) on SDL research over 30 years, five countries, and across multiple academic disciplines provided a strong case for using SDL to promote lifelong learning skills in students. This paper shares how we use the spiral curriculum (Bruner, 1960) to explicitly teach students skills in becoming a self-directed learner.

WHAT IS SELF-DIRECTED LEARNING?

The term self-directed learning is widely attributed to Knowles (1975) who described it broadly as "a process in which individuals take the initiative, with or without the help of others, to diagnose their learning needs, formulate learning goals, identify resources for learning, select and implement learning strategies, and evaluate learning outcomes". However, in today's adult learning literature, it had been reported that there exist a number of terminologies related to self-directed learning such as autonomous learning, independent learning, self-managed learning, self-organized learning, self-regulated learning, self-determined learning, self-planned learning, self-initiated learning, etc (Cosnefroy & Carré, 2014). According to Carré & Cosnefroy (2011), the 2 most commonly used are self-directed learning (hereafter SDL) and self-regulated learning (hereafter SRL). As noted by Loyens, et al (2008), even scholars in educational psychology have suggested that the 2 terms be used interchangeably in the literature. This is perhaps due to the similarity of the two concepts: both aimed at describing the various dimensions of independent, agentic management of one's learning efforts. For example, overall both SDL and SRL involve active engagement and goal-directed behaviour (Loyens, et al, 2008) and both address issues of responsibility and control in learning (Pilling-Cormick & Garrison, 2007). Saks & Leijen (2013) noted that the terms are not clearly distinguished in the literature thus leading to "tangled understandings and complications" in measuring SDL and SRL.

For this work, we adopted the position taken by Loyens, et al (2008) that SDL is considered as a broader construct encompassing SRL as a narrower and more specific one. SDL has also been treated as a broader concept in the sense of learner's freedom to manage his learning activities and the degree of control the learner has. According to Jossberger, et al (2010), the constructs of SDL skills and SRL skills are ascribed to different levels. The SDL is suggested to be situated at the macro level, where it refers to the planning of the learning trajectory – a self-directed learner is able to decide what needs to be learned next and how his learning is best accomplished. A skilful self-directed learner diagnoses his learning needs, formulates learning goals, finds suitable resources for learning and monitors his learning activities. SRL as the micro-level concept concerns with processes within task execution. SDL may include SRL but not the opposite (Jossberger *et al,* 2010). In other words, a self-directed learner is supposed to self-regulate, but a self-regulated learner may not self-direct.

THE DCHE SPIRAL CURRICULUM MODEL

Cheah & Yang (2018) had earlier presented the work done to redesign the DCHE curriculum in response to the SkillsFuture Initiative using the CDIO approach. One of the key features of our spiral curriculum is the introduction of 4 new practical modules, one for each semester in Year 1 and Year 2. Figure 1 shows the DCHE spiral curriculum model, highlighting progressive learning in the 4 practical modules, namely *Laboratory & Process Skills 1 & 2*, and *Process Operations Skills 1 & 2*. For each module, various learning tasks are designed using CDIO to engage students in learning how process technicians and chemical engineers work in the real world (Standard 1). Using the spiral curriculum design, each concept is revisited again and again in later lessons with increasing level of difficulty (Standard 2). The hands-on activities in

each practical module are supported with key concepts covered in core modules within the same semester of study. All learning tasks are anchored to a typical chemical plant found in the oil and refining industry, to provide context, and continuity in competency build-up required in a spiral curriculum (Standard 3).
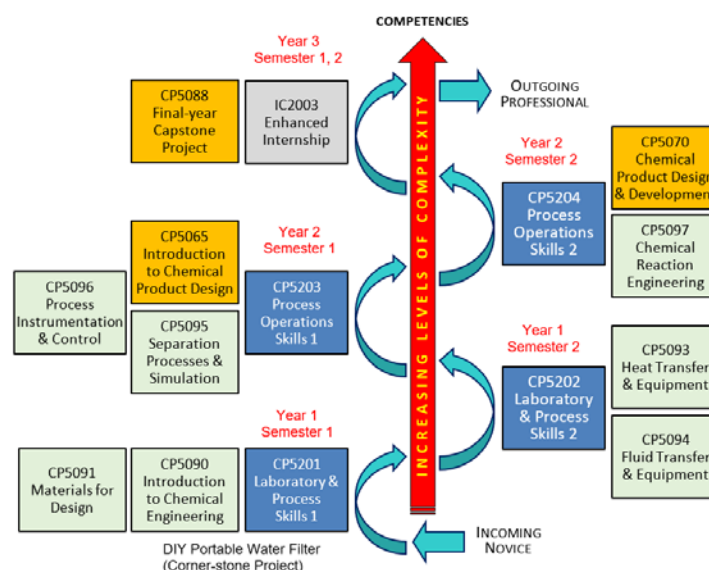
Figure 1. The DCHE Spiral Curriculum Model

Key CDIO skills such as teamwork, communication, critical thinking, hypothesis testing, etc are explicitly covered in the 4 practical modules (Standard 7). In the same vein, SDL will be deliberately taught to students, starting in Year 1. Here students will be introduced to a SDL model, with the necessary tools and scaffolding (Ley, et al, 2010), with feedback (Embo, et al, 2010) provided to help them use the model and monitor their learning metacognitively. Later in Year 2, the scaffolds will be gradually removed, and students are expected to be able to use the model without explicitly being told to do so. Students are also required to be able to transfer the skills acquired to new learning tasks, and to new contexts, especially during their final-year capstone project. This approach is consistent with that advocated by McCauley & McClelland (2004), who called for the teaching of SDL be included throughout the whole course.

THE DCHE-SDL MODEL

Although there are several models of SDL available in the literature, such as the 4-Stage Self-Directed Learning Model (Grow, 1991), Personal Responsibility Orientation (PRO) Model (Brockett & Hiemstra, 1991; Heimstra & Brockett, 2012) and the Comprehensive Model of Self-directed Learning (Garrison, 1997), Cycle of Self-directed Learning (Ambrose, et al, 2010), SP management had decided to formulate its own SDL model for adoption by the courses. In DCHE, we therefore use the SDL model (see Figure 2, left side) so that it can be *explicitly taught* to our students. In a nutshell, the model is built on students having a growth mindset and intrinsic motivation to learn on their own, as well as being able to metacognitively reflect on their learning process.

It is important to note here that we are not advocating the preferred use of our model over the existing ones, as we are not making comparisons over the relative advantages or disadvantages of the different models. What we are emphasizing in this paper is how it is being implemented using the CDIO approach, making reference to applicable CDIO Standard(s) as appropriate. The desired outcome is we hope to see is that students are able to transfer their

learning from one context to another, as shown by the large arrow (Figure 2, left side). The subsequent section will address our experience with the model to-date.

Growth mindset (Dweck, 2006) refers to the belief that intelligence can be developed. Students with a growth mindset understand they can get smarter through hard work, use of effective strategies, and help from others when needed. It is contrasted with a fixed mindset where the belief that intelligence is a fixed trait that is set in stone at birth. Research has shown that educating students about the growth mindset and how they can improve their learning experience is a key step towards increased intrinsic motivation (Ng, 2018; Colouri, 2014).
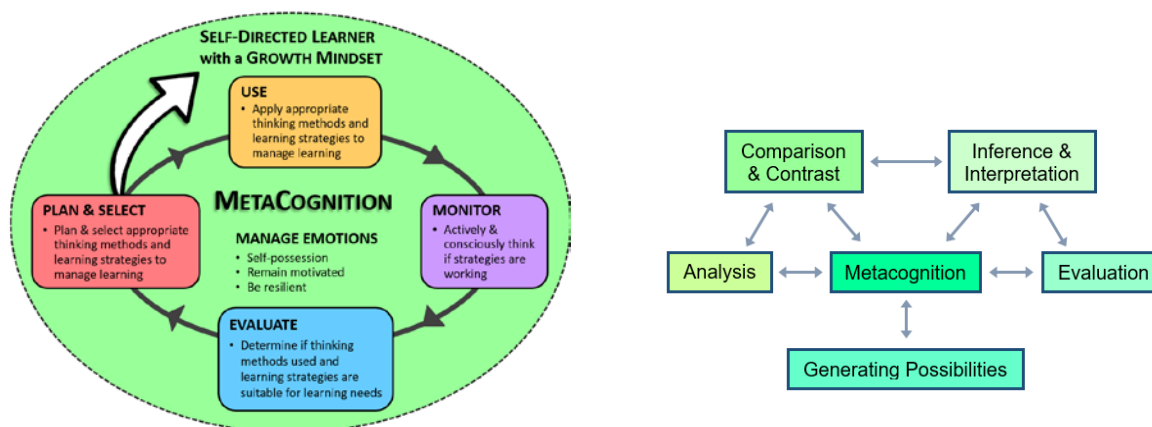
Figure 2. DCHE SDL Model (left) supported by Sale's Model of Thinking (right)

Metacognition (Schraw, 1998) refers to the awareness and understanding of one's own thought processes. Being metacognitive means to be aware of one's thinking, emotion/feeling and behaviour, evaluating how well one is using the range of specific thinking skills, and taking necessary corrective action to plan, monitor, and assess one's learning process and performance. Metacognition can therefore nurture students' learning and self-awareness of the learning process, as well as facilitate the transfer of understanding across disciplines. Metacognition can be taught through deliberately designed activities (Mills, 2016; Veenman, et al, 2006). We also introduce the use of reflective practice in learning so that students can reflect on their learning in order to discover new insights and a more sophisticated understanding (Kaplan, et al, 2013). We also require students to acknowledge the roles played by one's emotions in influencing the learning process (Bower, 1992; Rager, 2009) when they reflect on their own learning experience. Lastly, we leveraged on Sale's Model of Thinking (Sale & Cheah, 2011) to support the development of metacognition (Figure 2, right side). We explicitly teach students to discern between the different thinking heuristics so that they become aware of such "language of thinking" when we facilitate the learning in class, including modelling the thinking process in developing metacognitive competency. The 2-headed arrows indicate that mutually supportive nature of each thinking heuristic, with different combinations of which are often used simultaneously.

IMPLEMENTATION OF THE DCHE SDL MODEL

We start by introducing students to the growth mindset in Year 1 Semester 1 (i.e. Stage 1A) in an activity in the practical module *Laboratory & Process Skills 1* (Figure 4) where they are tasked to produce a prototype portable water filter kit using limited resources. Students are encouraged to go ahead and built a prototype without having first learnt about the engineering principles behind water filtration. This activity constitutes the DCHE corner-stone design-built experience for students in the *Introduction to Chemical Engineering* module (Standard 4).

The Model of Thinking and DCHE-SDL Model are next taught in Year 1 Semester 2 (i.e. Stage 1B), via a series of 3 workshops (P04 to P06 in Figure 4, conducted sequentially) in the practical module *Laboratory & Process Skills 2*. Students need to complete 3 practicals (P01 to P03) in the module prior to attending the workshops. These practicals are similar to those that students had done in *Laboratory & Process Skills 1*, but with a higher level of difficulty. Growth mindset is also reinforced these 3 practicals where students are required to come up with their own experimental procedures to carry out various scientific investigations as part of acquiring laboratory skills such as experimentation, investigation and knowledge discovery (SP-CDIO Syllabus Part 2.2, not included in this paper).
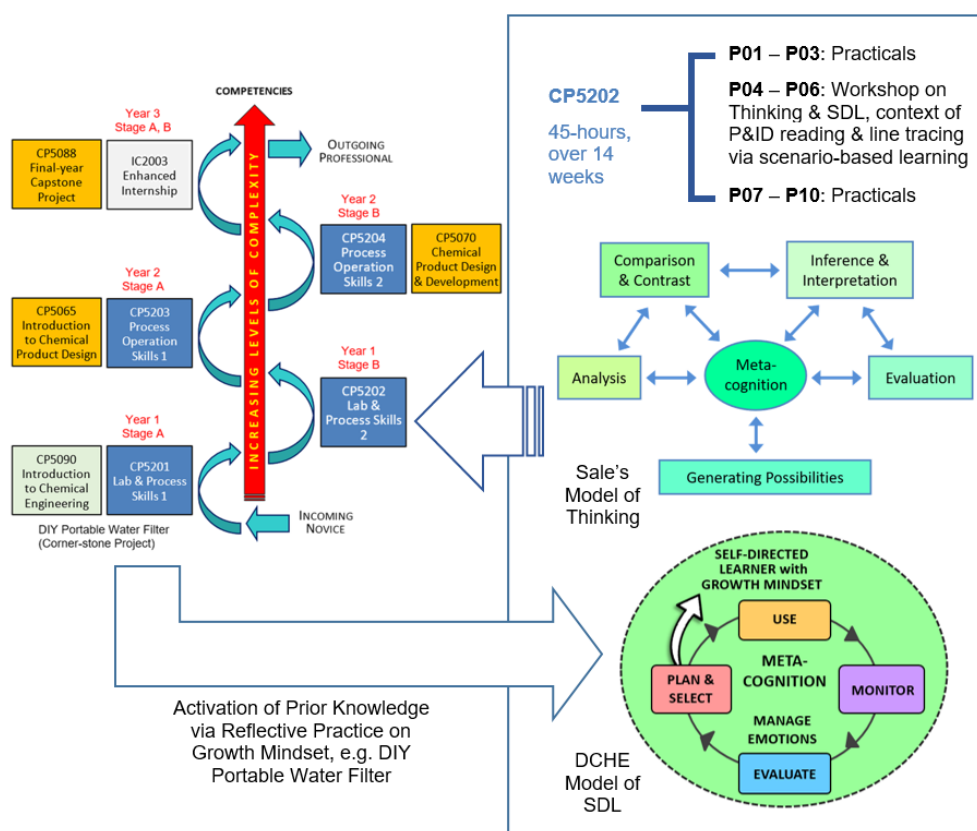
Figure 4. Integrating SDL into DCHE Spiral Curriculum

The first workshop starts (P04) with the rationale of why SDL is needed and how students can benefit from it, followed by Sale's Model of Thinking, using the corner-stone portable water filter project to demonstrate the various thinking processes employed in the building, testing and evaluating of the portable water filter. The workshop then introduces the SDL model, using the 3 practicals that students completed prior to the workshop, to bring out key challenges faced during their conduct of these practicals. The first 2 authors, serving as facilitators, demonstrate to students how a self-directed learner manages his/her own learning when addressing the challenges. Students are then asked to reflect on their own learning experiences for these practicals and are given the opportunity to resubmit their work.

The next 2 workshops (P05 and P06) then focused on getting students to apply the Model of Thinking and SDL model via various learning tasks designed to develop core competencies in chemical engineering, namely P&ID (piping and instrumentation diagram) reading and line tracing. Various thinking processes (including metacognition) and skills in SDL are explicitly taught in the context of developing these core competencies. Workshops are interactive in nature, with small group discussions to respond to scenarios presented. Some scenarios require students to obtain additional information on their own, and the lecturers (as facilitators) guide students in the discussion, and reinforce the practices of a self-directed learner, e.g.

explaining what can one do to monitor his/her own learning progress. The in-class activities are intentionally designed to be incomplete, and students are required to complete their own learning after class, using the SDL model. Students also get the opportunity to carry out line-tracing and sketch their own P&IDs from scratch, for selected pilot plants in the workshop. These P&IDs will be used for the remaining practicals (P07 to P10) in the modules. Lastly, students are required to reflect on their learning experience by submitting reflection journals. These journals are marked, commented on and returned to students. They are part of the formative assessment process, hence not graded (Standard 11).

As shown in Figure 4, there will be a continuation in the integration of SDL beyond the introduction in *Laboratory & Process Skills 2* in Stage 1B. Students will be expected to transfer these skills to more challenging process skills to further enhancing the core competencies next academic year, namely in *Process Operations Skills 1 & 2*, in Year 2 Semester 1 (i.e. Stage 2A) and Semester 2 (i.e. Stage 2B) respectively. In addition, students are also expected to use the SDL skills to manage their own learning in 2 chemical product design modules, one in each semester in Year 2 (*Introduction to Chemical Product Design*, *Chemical Product Design & Development*). The latter will be interesting as the context for which the SDL skills are applied will be quite different – namely in terms of skills in conceiving, designing, implementing and operating a chemical product, service or system. Lastly in Year 3, students are expected to be able to transfer (Scharff, et al, 2017) their SDL skills gained and apply to new challenges presented in the *Final-Year Capstone Project* and *Enhanced Internship* program.

PRELIMINARY EVALUATION TO DATE

We carried out a short survey in December 2018 to obtain a "feel" of the students' experience with the approach thus far. At the time of this submission, we are still analysing the results. For the purpose of this paper, the following are some of the questions posed:
A. Name one or more parts of the Self-Directed Learning Model you remember.
B. Did the workshops for P05 and P06 help you to appreciate the use of the Self-Directed Learning Model in gaining new knowledge? Why?
C. Which one of the following best describes your learning experience with the Self-Directed Learning Model so far?

Questions A and B are open-ended. For Question C, students are required to select 1 of 8 responses from a drop-down list, comprising the following:
- It helps me to work out how to learn in a systematic manner
- It is useful when I need to learn something new/ complex
- I am not too sure yet as I do not have sufficient practice using it at this moment in time
- I think only some parts of it are useful to me
- It is too complex to make use of
- I do not see how it can be applied
- I have my own way of learning, which I think is good enough for me
- I do not see its relevance in helping me learn

The survey was administered to all 7 classes of Year 1 DCHE students who took the module, totalling 130. A total of 81 responses were received. However, some responses were not accepted as they are deemed invalid. For example, for Question A, some students provided key competencies of chemical engineers (such as to conduct line tracing, sketching P&IDs) which were technical learning outcomes from the workshops. Likewise, some students left the field blank (i.e. unanswered, as we do not design the survey to require respondents to answer a question before they can proceed to the next question), and these too are deemed invalid. As such, the number of respondents to each question can vary. The findings relevant to these questions are presented below in Figures 5 to 7.
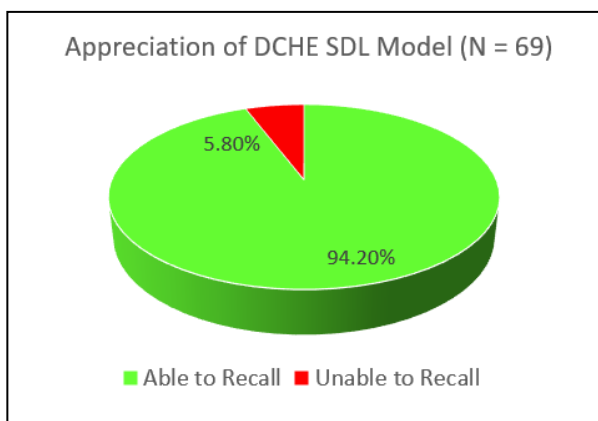
Figure 5. Responses to Question A
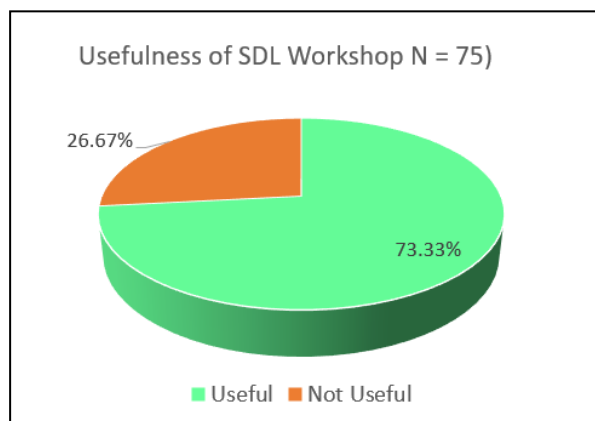
Figure 6. Responses to Question B
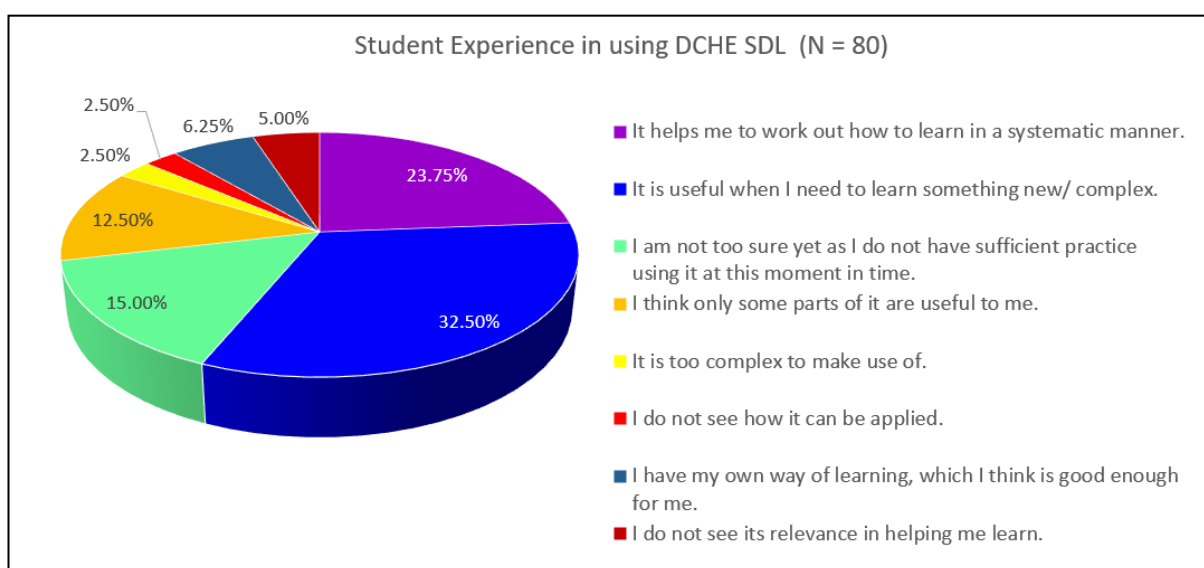
Figure 7. Responses to Question C

For the first run of this initiative, it can be seen from Figure 5 (with 69 valid responses) that the majority of students are able to relate to the use of the SDL model. In general, students are able to identify with the key steps in being a self-directed learner, and quite a number are able to mention metacognition as an important factor. However, despite the high positive responses, only about 73% of respondents found the 3 workshops useful (Figure 6, with 75 valid respondents). This may be due to the opinions of some students who are still ambivalent about the importance of SDL as shown in Figure 7 (with 80 respondents). Only about 56% of students reported understanding the potential benefits of SDL, while about 16% do not think so: this is made up of 2.50% who thought that it was too complicated, another 2.50% who had no idea how to apply it, 6.25% who felt that their own way of learning is superior, and 5.00% who reported seeing no relevance of SDL in helping their learning.

Some of the negative responses may represent the current state of the students' perception of SDL, characterised by that of confusion, frustration, and dissatisfaction (Lunyk-Child et al, 2001). This is not a surprise, given that it is the first time our students are exposed to SDL. It could be worthwhile finding out students' perceived ability to learn on their own, which may have been built on learning strategies used during their secondary school days and require adjustment to match the needs of tertiary education. Some students are uncomfortable with the approach, as they expect that in a formal education setting (such as the 3 workshops) their

learning should still very much be "directed" by the lecturers, similar to that in Secondary Schools. Part of their perceived inability to use SDL may stem from what Butcher & Sumner (2011) termed as the "sense-making paradox" where students are required to employ deep-level thinking skills, but often lack the knowledge needed to deeply analyse information and successfully integrate it with their own existing knowledge. Some of the differences in students' attitude and perceptions toward SDL can also be due to different facilitation styles by the teaching team. The first 2 authors are involved in teaching of 3 out of a total of 7 classes. Also, due to other timetabling requirements, students in each class are not of the same academic capabilities. Response rates from the different classes are also different. These factors make it challenging to understand at a deeper level how receptive each student is to the explicit teaching of SDL. Lastly, this being the first run of the module, we are not able to make a comparison between students' learning results before and after applying SDL.

MOVING AHEAD

We will continue to analyse the survey findings and cross-reference other documents such as reflective journals and in-course assignment submitted by students as part of course work to gain further insights on their learning experience. At the point of submission of this paper, it is fair to say that we had barely scratched the surface of SDL. Much has been said in the published literature about SDL. Suffice to say, this topic still attracts a lot of attention, perhaps due to its elusive qualities which defy precise definition (Hewitt-Taylor, 2001; Grow, 1991). Levett-Jones (2005) noted that the introduction of SDL into a curriculum has not always been successful. It will be worthwhile for us to delve into available research to better understand the various findings on SDL, including student perceptions and perspectives (e.g. Douglass & Morris, 2014), teacher belief (e.g. Heimstra, 2013), learning environment and pedagogy (e.g. Ryan, 1993), just to name a few areas, as we continue to work on developing our students' skills in SDL.

Moving ahead, our students will take up modules related to chemical product design in Year 2 (Figure 4). The usefulness of project-based learning to teach students SDL skills have been reported in the literature (e.g. Eggermont, et al, 2015; Johnson, et al, 2015). Hence, we will work closely with the teaching team of *Introduction to Chemical Product Design* (Year 2, Semester 1) and *Chemical Product Design & Development* (Year 2, Semester 2) to continue to improve our students' SDL skills. We will also consider measuring the students' readiness for SDL through instruments such as Self-Directed Learning Readiness Scale (Guglielmino, 1977), Oddi (1986) and Gibbons (2002). Survey results using these instruments can help us pinpoint areas in SDL where students are weak in and design appropriate learning tasks. We are also interested in finding out if students are able to improve their SDL skills as they progressed through the spiral curriculum. In this regard, we are reminded of the works of Litzinger, et al (2003) as well as that of Francis & Flanigan (2012); whose research showed that SDL is not directly related to students' academic standing. This may also be an area worthy of further research as we track the students' progress over the 3 years of study.

Students' SDL skills development will come a full circle when they reach Year 3, when they will complete a capstone project and an internship program. This is where they need to transfer their SDL skills developed over the last 2 years into new applications. Stewart (2007) had shown that SDL readiness was a key enabler for achieving learning outcomes from project-based learning, which are often open-ended, ambiguous and requires knowledge beyond what had been covered in the curriculum. Other outcomes may include desired graduate attributes such as ethical reasoning, cross-cultural awareness, etc. As for the internship, students will be placed in a work environment that may involve tasks that are ambiguous and far-separated from their prior experience. Thus they must be able to adapt quickly, and this adaptation requires development of self-directed learning skills.

CONCLUSION

This paper shares the approach taken by the authors to integrate self-directed learning into a chemical engineering curriculum using the CDIO approach. Based on the preliminary findings, it would appear that it is useful to explicitly teach students the importance of self-directed learning and provide them with a model of how to do so. Also, it seems that engaging students early (specifically, in this case, right from Year 1) is a wise decision to take, even though the results showed clearly that more could be done to improve their learning experience, such as improving the workshop design for a start. However, as noted by Silen & Uhlin (2008), students need challenges, support and feedback in their struggle to become self-directed learners and thus require ongoing attention from lecturers. This is an area where training in facilitation will be useful for the teaching team. We will also continue to work with other lecturers to continue developing our students' SDL skills as they progress through the spiral curriculum; as well as engaging in other research into SDL. Future papers will share more work done in this area.

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WORKPLACE LEARNING FOR FACULTY DEVELOPMENT TO SUPPORT A SPIRAL CURRICULUM

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ABSTRACT

This paper shares how the Course Management Team of the Diploma in Chemical Engineering of Singapore Polytechnic uses workplace learning based on the 70:20:10 Model of Learning and Development to develop CDIO competency of its teaching team to deliver its new spiral curriculum course structure. With the spiral curriculum, we hoped to enhance student learning and retention of core chemical engineering knowledge as well as the development of self-directed learning. The DCHE course structure was henceforth redesigned to feature a sequence of 4 "cross-cutting" practical modules of increasing difficulty that use CDIO-designed learning tasks to equip students with laboratory and process skills required in the chemical process industries; and delivered using "block teaching" approach. A "cross-cutting" module, in the context of the DCHE spiral curriculum, is one in which the module content straddles other modules not only within the same semester of study but also across semesters. "Block teaching" refers to teaching in a more "compact" manner, in which a 45- or 60-hour module is completed within lesser weeks instead of over a full semester (15-weeks). The combined impact of "block teaching" and "cross-cutting" modules is that more lecturers are now required to be well-versed in teaching more modules in a more intensive manner. Such condition necessitates the training of lecturers in time for delivering the new spiral curriculum. The solution is to use the 70:20:10 Model to introduce workplace learning to develop lecturers' competency in using the CDIO approach to deliver the new spiral curriculum. An example is provided where the authors are tasked with developing a new "cross-cutting" module work in collaboration with Academic Mentor experienced in CDIO to prepare the materials, and conduct workshops for other lecturers in the teaching team.

KEYWORDS

Workplace Learning, Chemical Engineering, CDIO Standards 9 and 10

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to as a "faculty" in the universities.

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) at Singapore Polytechnic (SP) introduced its spiral curriculum that took effect from April 2018 for Semester 1, Academic Year 2018/2019 (Cheah & Yang, 2018). The revised course structure for the spiral curriculum (Bruner, 1960) requires a new way to teach where lecturers need to be more well-versed in several disciplines and also work closely with other lecturers. This is important to ensure that topics to be learnt are sequenced in a progressive manner so that modules within the same semester of study can mutually support one another, and modules at later semesters build on modules from earlier semesters. The DCHE Course Management Team (CMT) uses workplace learning to

help the DCHE teaching team address the challenges brought about by the implementation of the spiral curriculum.

WHAT IS WORKPLACE LEARNING?

Billet (2014) noted that over the past two decades, through interviews with workers from a range of occupations about how they learn through and for work, consistently they described it being premised upon: (i) engagement in work activities, (ii) observing and listening and (iii) "just being in the workplace". Working is therefore highly intertwined with learning and consequently, as in the words of Michael Fullan: "Learning is the Work" (Fullan, 2011). Learning at the workplace mostly occurs through work-related interactions, where skills are upgraded and knowledge is acquired and is generally described as contributing to the learning of both the individual employee and the organisation as a whole (Cacciattolo, 2015).

But exactly what is learning at the workplace, or more commonly, "workplace learning"? Lee et al. (2004) charged that there is no singular definition or one unified approach to what "workplace learning" is, what it should be, or who it is/should be for. Bratton et al. (2008) noted that the term workplace learning has become an established metaphor for capturing formal, non-formal, self-directed collective and even tacit informal learning activities. According to these authors, it is an interdisciplinary body of knowledge and theoretical inquiry that draws upon adult learning, management theory, industrial relations, sociological theory, etc.

Two other commonly encountered words are: work-based learning, and work-integrated learning, which are sometimes used interchangeably with workplace learning. In Singapore's context, the Institute of Adult Learning makes the following distinctions between workplace learning and work-based learning (IAL, 2016):
- Work-based Learning – prepares students for employment. Examples include internship and trainee arrangements, often undertaken in conjunction with classroom learning.
- Workplace Learning – develops employees through doing the work. This development leverages on learning that happens naturally in the workplace.

Lemanski et al. (2011) further classify work-based learning into three categories: Learning for Work, Learning at Work, and Learning through Work. On the hand, work-integrated learning is an "umbrella" term used for a range of approaches and strategies that integrate theory with the practice of work within a purposefully designed curriculum (Patrick et al., 2009). Table 1 shows the broad comparison between formal learning in educational institutions versus that in the workplace (Tynjala, 2008). Table 2 the comparison between work-based learning and workplace learning (IAL, 2016). Table 3 provides the benefits of workplace learning to both employers and employees (Haan & Caputo, 2012). Billett (1995) highlighted some of the factors limiting the efficacy of workplace learning, as shown in Table 4.

THE CHALLENGE OF TEACHING THE DCHE SPIRAL CURRICULUM

The revised DCHE course structure is shown in Figure 1. A key feature of the revised DCHE course structure is the introduction of modular certificates (MCs) for selected modules, one for each semester of study. There are two semesters in each academic year. The MCs form the series of "stackable credentials" available to adult learners, who want to obtain some form of academic recognition for their skills and competencies. A credential is considered stackable when it is part of a sequence of credentials that can be accumulated over time to build up an individual's qualifications and help him or her move along a career pathway or up a career ladder to different and potentially higher paying jobs (CORD, 2017).

One of the main challenges in implementing the spiral curriculum is the way teaching of modules will be carried out. While "standalone" in the sense of administrative matters, such as module codes, timetabling and examination, the integrative nature of spiral curriculum necessitates that a given module is to be tightly "bound" to other related modules. We termed such modules as "cross-cutting" modules, where the module content straddles other modules not only within the same semester of study but also across semesters. There is one "cross-cutting" module per semester in Year 1 and Year 2, i.e. total of 4 modules.

Table 1. Comparison between Learning in Formal Education and in the Workplace

Learning in Formal Education	Learning in the Workplace
Intentional (+unintentional)	Unintentional (+intentional)
Prescribed by formal curriculum, competency standards, etc	Usually no formal curriculum or prescribed outcomes
Uncontextualized – characterized by symbol manipulation	Contextual – characterized by contextual reasoning
Produces explicit knowledge and generalised skills	Produces implicit and tacit knowledge and situation-specific competences
Learning outcomes predictable	Learning outcomes less predictable
Emphasis on teaching and content of teaching	Emphasis on work and experiences based on the learner as a worker
Individual	Collaborative
Theory and practice traditionally separated	Seamless know-how, practical wisdom
Separation of knowledge and skills	Competences treated holistically, no distinction between knowledge and skills

Table 2. Comparison between Work-based Learning and Workplace Learning

Characteristics	Work-based Learning	Workplace Learning
Driver / Owner	Educational institutions	Employers
Partnerships	Educational institutions as Driver may partner with: • Employers to provide the internship/industry attachment • Consultants	Employers as Driver may partner with: • Consultants • Educational institutions (e.g. online literacy training)
Participants	Students / Trainees / Learners completing a qualification	Employees
Purpose	To expose participants to meaningful and relevant workplace experiences to better connect their learning to the workplace and deepen their skills, before graduation	To address skills gaps, improve performance and develop staff
Time	• Part of a qualification • Time in the workplace varies according to different educational institution's industry section requirements	• Ongoing • Specific work/business/ performance related outcomes often tied to a stipulated period of time dictated by employer

Outcomes for driver	• Qualification that represents skilled and work-ready graduates • Projects undertaken in the workplace are a source of holistic, authentic activity/service/ product that can be used for learning and assessment purposes	• Improved performance • Improved professional judgement • Development of a learning culture that supports innovation • Flexible, professional development appropriate to individual and collective (e.g. team) needs

Table 3. The Benefits of Workplace Learning and Skills Development

Benefit to Employers	Benefit to Employees
1. Improved productivity and growth – high literacy skills mean a more flexible workforce that can adapt to new technologies and processes quickly and effectively 2. Improved revenue per employee 3. Improved income – a company can increase its income by increasing its output by changing one of four factors: resource, physical capital, technology of human capital 4. Improved product cycle time 5. Cost savings – through improved efficiencies and reduction in error 6. Improved sales 7. Improved product quality 8. Improved health and safety records 9. Improved employee retention – training opportunities can often lead to enhanced employee morale and learning culture within a company 10. Improved knowledge transfer among employees 11. Better communication – as morale improves due to literacy gains and employees improve their skills, communication within the organization often changes for the better	1. Higher income – there is a strong association between literacy skills and income 2. Low incidence of unemployment – improved literacy makes employees less vulnerable to lay-off and displacement, and if they are laid off they find it easier to get new jobs 3. Higher labor market participation – well educated and trained individuals have more and better employment opportunities 4. Improved job security and enhanced job opportunities – workplace learning programs enable employees to work smarter and better, and, ultimately to take on increase responsibilities 5. Improved self-confidence – employees who improve their literacy skills gain the ability and confidence to empower themselves 6. More training – individuals with higher literacy skills and/or education are more likely to receive further training 7. New attitudes – employees tend to experience significant positive change in attitudes when they take part in workplace learning programs 8. Broader benefits – employees who gain literacy through their workplace take their improved communications and teamwork skills home and into their communities

`Table 4. Factors Limiting Efficacy of Workplace Learning

Limiting Factor	Consequence and (possible rectifying response(s))
Undesirable knowledge	• Inappropriate learning outcomes • (Selection of circumstances and expert others)
Access to activities	• Development of knowledge inhibited by paucity of experience • (Develop a learning curriculum to allow a pathway of experiences - from simple to complex, but also those that reveal the entire characteristics of work activity)
Reluctance of experts	• Limits on access to expert guidance may reduce modelling, coaching and support • (Establish conditions whereby experts are encouraged to act as mentors and guides)
Absence of expertise	• Limits on access to expertise will reduce guidance and support • (Provide access to various forms of expertise) • (Assist making external expertise relevant to particular circumstances)
Knowledge which is opaque	• Depth of understanding may be inhibited if knowledge is remote from learner • (Making explicit what is hidden) • (Use of instructional interventions to make knowledge accessible)
Instructional media	• Limits on types of knowledge and their embeddedness in practice • (Provide authentic experiences initially) • (Integrate instructional interventions with authentic experiences)
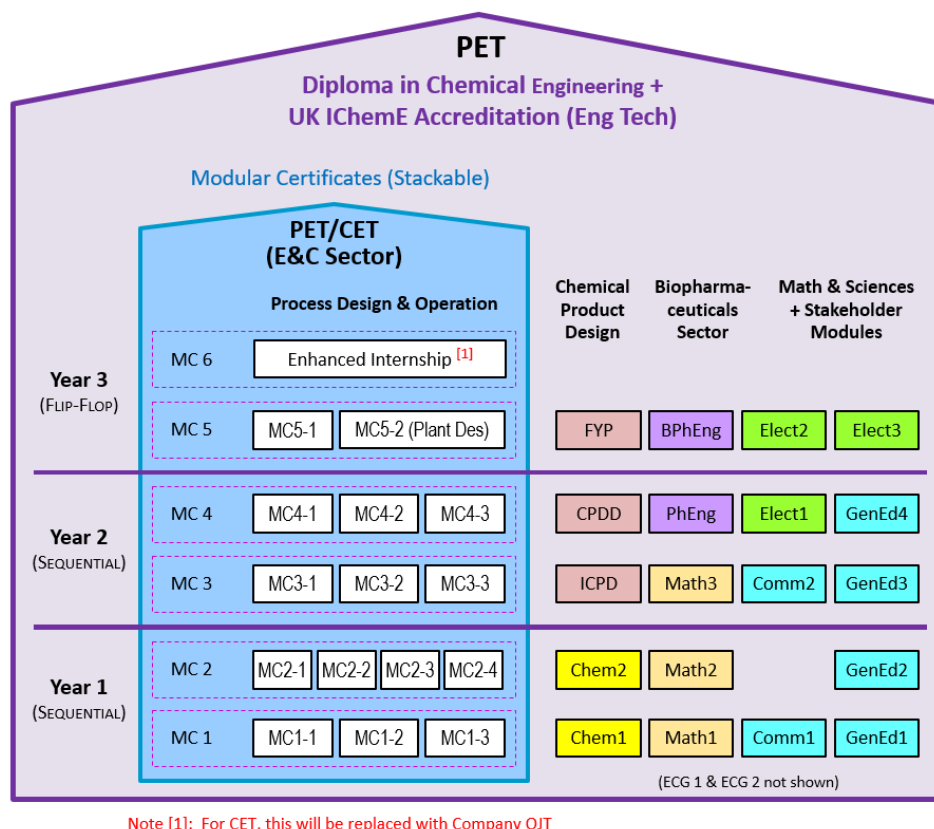
Figure 1. Revised Course Structure for Chemical Engineering with Spiral Curriculum

To facilitate the sequencing of topics in each semester, we use "block teaching" to align and sequence the core modules that are intertwined with the "cross-cutting" module. In such "block teaching", coverage of the core modules will be done in a more "compact" manner, in which a 45- or 60-hour module is completed within lesser weeks instead of the usual 3 or 4 hours per week over a full semester (15-weeks).

Our spiral curriculum was introduced in Semester 1, Academic Year 2018/2019 in April 2018. We rolled out "block teaching" in Semester 2, Academic Year 2018/2019 for our Year 1 students. The teaching schedule for the modules in MC2 is shown in Figure 2.

Week No: Semester 2, Academic Year 2018/2019																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Laboratory & Process Skills 2							M S T	Term Break			*Laboratory & Process Skills 2*							Sem Exam	
Core DCHE 1											*Core DCHE 1*								
				Core DCHE 2							*Core DCHE 2*								
				Core DCHE 3							*Core DCHE 3*								

Figure 2. Revised Course Structure for Chemical Engineering with Spiral Curriculum

As an example, consider MC2 for Year 1 students, with the "cross-cutting" 45-hour module *Laboratory and Process Skills 2*. This module was developed by the two authors. This module provides, in an integrative manner, the hands-on activities for topics covered in the 3 core modules (60-hours each) within the same semester, namely *Chemical Engineering Thermodynamics, Fluid Flow and Equipment*, and *Heat Transfer and Equipment*, shown as *Core DCHE 1*, *Core DCHE 2* and *Core DCHE 3* respectively in Figure 2 and delivered in "block teaching" format. Activities in *Laboratory and Process Skills 2* are designed to closely

sequence the topics in *Core DCHE 1*, *Core DCHE 2* and *Core DCHE 3*. This "cross-cutting" module also "backwards integrates" with learning from modules in previous MC1 (such as *Introduction to Chemical Engineering* and *Laboratory and Process Skills 1*); as well as "forward integrates" to support the acquisition of new knowledge from modules in later MC3 (such as *Process Instrumentation and Control*, *Process Operations Skills 1*).

THE AIM OF THIS WORK: DEVELOPING FACULTY COMPETENCY

In this paper, we are concerned with workplace learning for our lecturers. A key challenge of a spiral type course structure is that more lecturers are now required to be well-versed in teaching more modules in a more intensive manner. This is in contrast to previous course structure whereby each lecturer tends to focus on teaching 1 or 2 modules only. These lecturers may only have academic knowledge about the topics they are now required to teach, acquired many years back during their university days. More importantly, many of our lecturers do not possess extensive working experience in all chemical plant operations, and as such will have difficulty relating the topics in the spiral curriculum to real-world work situations.

CDIO Standards 9 and 10 relate to developing faculty competency so that can deliver such a spiral curriculum. More specifically, lecturers need to acquire the background technical knowledge in order to deliver the many modules with activities designed based on integrated curriculum and integrated learning experiences designed using the CDIO Framework. For example, a lecturer who had been teaching *Core Module 1* in the past must now be acquainted with the topics in *Core Module 2* and *Core Module 3*, in order to be able to effectively facilitate student learnings in their learning tasks in *Laboratory & Process Skills 2*; which contain elements of all 3 core modules.

Like other employees in today's world, there is a lack of time to attend full-time re-training away from work. Furthermore, such training programs are usually expensive, and availability may also clash with a lecturer's teaching commitments. To this end, we turn to the 70:20:10 model for workplace learning so that lecturers learn on the job.

WHAT IS THE 70:20:10 MODEL FOR WORKPLACE LEARNING?

The 70:20:10 Model is a learning and development model in which 70 percentage of learning happens in the workplace through practice and on-the-job experiences; 20 percentage comes through other people via coaching, feedback, and networking; and 10 percentage is delivered through formal learning interventions. It is a model that is easy to understand but equally easy to misunderstand. The 70:20:10 concept makes intuitive sense, as most of what employees learn, they learn on-the-job during the course of doing their work - that is where they spend most of their time. Practical examples of 70:20:10 are shown in Table 5. However, there appeared to be inconclusive "evidence" regarding the origins of the 70:20:10 rule (Kajewski & Madsen, 2012). Despite the lack of empirical data supporting 70:20:10, the percentages remained popular, widely quoted and used by many organizations. As noted by Arets et al. (2016), it is not about the fixed ratio, but rather, it is all about the mix in learning approaches that can be designed to bring about change. The numbers 70:20:10 merely served as a useful reminder that most learning occurs in the context of the workplace rather than in formal learning situations and that learning is highly context dependent.

Blackman et al. (2016) who studied the model for its effectiveness as a model for middle management capability development in the Australian public sector, cautioned that it is important the elements in the 70:20:10 model should not be perceived to be implemented in isolation. Rather, an integrated and complementary approach must be adopted.

Table 5. Practical Examples of 70:20:10

70 – Learn & Develop Through Experience	20 – Learn & Develop Through Others
• Apply new learning in real situations • Use feedback to try a new approach to an old problem • New work and solving problems within the role • Increased span of control • Increased decision making • Champion and/or manage changes • Cover for others on leave • Exposure to other departments/roles • Take part in project or working group • Coordinated role swaps or secondments • Stretch assignments • Interaction with senior management, e.g. meetings, presentations • Day-to-day research, web browsing • Leadership activities, e.g. lead a team, committee membership, executive directorships • Cross-functional introductions, site/customer visits • Research and apply best practice • Apply standards and processes, e.g. Six Sigma • Work with consultants or internal experts • Internal/external speaking engagements • Budgeting • Interviewing • Project reviews • Community activities and volunteering	• Informal feedback and work debriefs • Seeking advice, asking opinions, sounding out ideas • Coaching from manager/others • 360 feedback • Assessments with feedback • Structured mentoring and coaching • Learning through teams/networks • External networks/contacts • Professional/Industry association involvement or active membership • Facilitated group discussion, e.g. Action Learning
	10 – Learn & Develop Through Structured Courses
	• Courses, workshops, seminars • eLearning • Professional qualifications/accreditation • Certification • Formal education, e.g. University, Business School

AEEM (Adding, Embedding, Extracting Model) for workplace learning (Figure 3) is a useful model that can be used for exploiting development opportunities in the workplace and making informal learning more effective (Jennings, 2014).
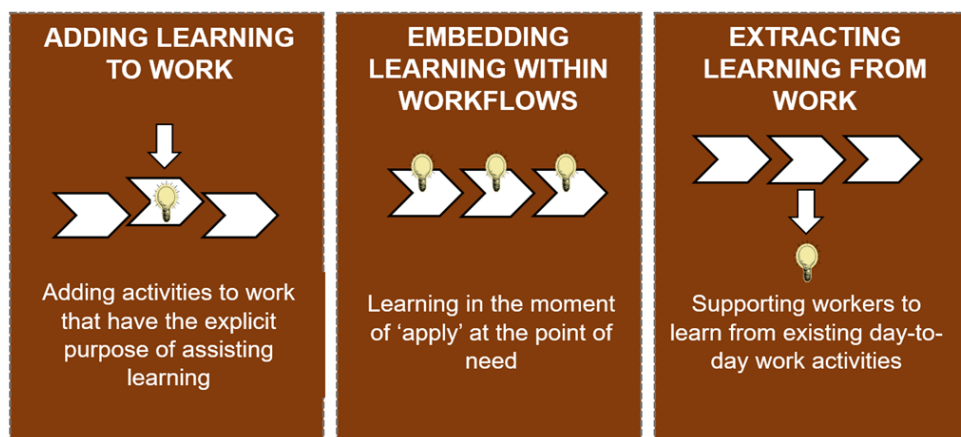
Figure 3. The Adding, Embedding, Extracting Model (AEEM) for workplace learning

Implementation of workplace learning can be enhanced with the use of proper performance support (Arets et al., 2016). Rossett & Schafer (2006) define performance support as "a helper in life and work" that provides "a repository for information, processes, and perspectives that

inform and guide planning and action". Performance support comes in many forms whether it is getting guidance via a checklist, common time slot for meetings, help desk, access to experts, etc.

WORKPLACE LEARNING IN DCHE USING THE 70:20:10 MODEL

The approach taken by the DCHE Course Management Team (CMT) is to use the 70:20:10 Model to introduce workplace learning to build up staff capability in chemical process plant operations. The 70:20:10 Model had been introduced by the SP Management recently to build up staff capability using an Individual Development Plan (IDP) where each lecturer plans for his/her personal and professional development. The IDP is to be used by a lecturer for any new teaching and learning needs, e.g. develop a new module, lead a project, or any other work-related competencies.

Workplace learning based on the 70:20:10 model was used to address the challenges brought about by the "cross-cutting modules" and "block teaching". The DCHE Course Chair formed three curriculum development teams, one for each year of a study led by one CMT member. All lecturers involved in the curriculum development work used the IDP to capture his/her developmental needs as part of their training records. Table 6 shows the work done in the three stages of the AEEM, using the "cross-cutting" module *Laboratory and Process Skills 2* as an example.

Table 6. Examples of Work Done in New Module Development

Adding learning to work	Embedding learning within workflows	Extracting learning from work
As members of the Year-1 Curriculum Development Team to rationalize, streamline, and sequence the content for "block teaching" in consultation with Senior Academic Mentor Time is set aside (Wednesday, 1 – 5 pm) during the developmental phase so that all involved do not have teaching duties during this period, hence can meet up for discussions	Lecturer in charge of developing an activity prepare suggested lesson plan for the activity, model answers and sample calculations, along with brief guidance notes Lecturer in charge of developing an activity conduct a boot camp for the rest of the teaching team, at least 2 weeks before the start of the semester On-going consultation with lecturer developing content: Just-in-time clarification (e.g. calculations or result analysis), updates on errors previously not spotted	Carry out regular updates among teaching team members via email, after every activity, on new learning if any, or insights Conduct After Action Review of the entire module at the end of the semester, identify areas of improvement, prepare new resource needs, if any Prepare facilitation notes based on teaching experience during the entire duration of the pilot launch, to assist in the next run of the module

Working with two other lecturers, the authors lead the development work for the module *Laboratory and Process Skills 2*, and together, the team designed 11 activities for students in Year 1, Semester 2. Preparing the teaching team for the delivery of the new module was quite extensive. The teaching team for the module is made up of eight lecturers, comprising three who developed the module (i.e. the authors and one of the two lecturers mentioned earlier) and five other lecturers who were not involved in the module development. Three of these five lecturers were full-time staff while the remaining were adjunct lecturers. The lecturer who developed an activity took the lead to provide proper performance support for the rest of the teaching team. The first author, for example, conducted a 3-hour boot camp for the three

activities that he designed. To help the teaching team, he also drafted some brief guidance notes and prepared model answers for each activity. Similar performance support was provided for the remaining eight activities.

The second author, who serves as the module coordinator, takes responsibility on all administrative matters related to module development, including coordinating with the technical support team assisting in the running of each activity

REFLECTION: CHALLENGES AND LEARNING POINTS

One of the key challenges in the development of the module is that of coordination. During the earlier phase of module development, numerous discussions were carried out to scope and sequence the activities. This was done in parallel with the planning of how the "block teaching" for the 3 core modules is to be done. The development team also had on-going discussions with other colleagues who had the relevant industry/academic experience for each of the activity being developed, and worked closely with module development teams for the 3 core modules in the same semester as well as module development teams for core modules in the past and subsequent semesters to ensure industry relevance, integrativeness and progressiveness.

Another challenge is to keep all team members updated and abreast of the latest version of each activity. The 11 activities in *Laboratory and Process Skills 2* is conducted one per week over a period of 13 weeks within a 15-week semester – one week is taken up for mid-semester test (MST) during which no classes are conducted, and one week for make-up class in the event of a public holiday (Figure 2). The module is delivered to 7 classes each week. Despite the best of intentions, and having cross-checked the design of each activity, not all mistakes were picked up before the start of the semester. As it turned out, several minor mistakes were discovered during the delivery of the module.

The teaching team may not have been fully prepared to deliver each activity exactly as intended. Simply put, the lecturer who designed an activity best knows exactly how it is to be delivered. However, he/she may not be able to share every single aspect or insight required for exact delivery during the boot camps. Indeed, some insights only came to us later, at the time of our own delivery of the very activity itself. Due to timetabling constraints, the authors' own class is scheduled in the middle of the week. Hence, it is not always possible to share these insights in time with other teaching team members whose classes preceded our own.

Furthermore, to conduct numerous boot camps for a large teaching team presents its challenges due to the availability of all members, in particular, adjunct lecturers. Lecturers who are full-time staff also had other work commitments. As a result, all boot camps had to be conducted twice, so that all members are briefed on what to do for each activity. Even then, several one-to-one sessions had to be arranged for individuals who were unable to attend any session. There was also an instance where an adjunct lecturer pulled out at the last minute due to other commitments. All these translate to more time and effort for the authors, who had to ensure all members were sufficiently prepared to facilitate the learning process effectively.

The most important benefit from the development of this new module in accordance to the spiral curriculum and preparing colleagues for the module delivery was the stretch opportunity offered. It accorded much room to develop technical skills sets (particularly for lecturers who had little to no relevant process industry experience), work collaboratively and grow professionally. Colleagues who had the relevant industry or academic experience were able to develop as mentors and to help ensure knowledge continuity to younger colleagues. The teaching team had also to be willing to get out of their comfort zone and take on teaching the new module, of which some content could have been learnt only "just-in-time" from the boot

camps before they had to teach students. The other benefit gained was the enhanced understanding of the entire course structure and the content of all the related modules in the preceding semester, current semester and the subsequent semesters, that would help in teaching or future module development.

The teaching of *Laboratory and Process Skills 2* ended in end-February 2019. A meeting for After Action Review was carried out in March 2019. The entire module team got together to share their learning experience, having all facilitated a class or two for the semester. A positive climate was maintained whereby everyone spoke freely about the pluses and minuses of the first run of the module. Broadly, team members expressed satisfaction with the on-the-job workplace training that was put in place. The mutually-supporting nature of our implementation of 70:20:10 model for workplace meant that every lecturer had a role to play in training fellow colleagues and in return be trained. Lecturers teaching some of the technical topics for the first time, in particular, reported the usefulness of the boot camp. Everyone also contributed positively to ways to improve the module in the future. Looking ahead, the authors will embark on preparing some facilitation notes based on experience gained for this first round of the module run.

CONCLUSION

This paper presented an approach used to implement workplace learning for lecturers teaching the Diploma in Chemical Engineering based on the 70:20:10 Model. While many of the activities described in this paper are not new, what is new here is the way professional development for lecturers can take place, at least for the team. With the 70:20:10 Model and DCHE workplace learning through the development of the new module and preparing colleagues for module delivery, we clearly see the benefit of shifting from formal training that takes place away from work, to informal learning as part of work. The ultimate goal would be to use workplace learning and development to promote a culture of lifelong learning whereby every lecturer can be a self-directed learner, for their students.

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USING COURSE AND PROGRAM MATRICES AS COMPONENTS IN A QUALITY ASSURANCE SYSTEM

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ABSTRACT

The CDIO framework is an integrated and important part of the new quality assurance system within the Faculty of Science and Engineering at Linköping University. Both the CDIO Syllabus and the CDIO Standards are used extensively in the system. First, the paper presents the development and use of the second generation of course matrices (previously denoted ITU-matrices) and program matrices, which build upon an adapted and extended version of the CDIO Syllabus. The extension is made to also include bachelor's and master's program in subjects outside the engineering field. Second, the paper presents how the CDIO Standards are used in the quality reports, which are vital parts of the quality assurance systems. As a result, the CDIO framework is used for the design, management, and quality assurance of all education programs (approximately 60 programs) within the Faculty of Science and Engineering at Linköping University.

KEYWORDS

Quality assurance, CDIO Syllabus, CDIO Standards, course matrix, program matrix, Standards: 1-8, 11

INTRODUCTION

Design, execution, evaluation, and quality assurance of engineering education are complex and demanding tasks. The tasks have many dimensions such as the mix of knowledge and skills needed for the graduates to be prepared for the professional career, the progression of knowledge and skills over time during the education program, the desired level of knowledge in various fields according to some taxonomy, and the complexity of the problems studied. Keeping in mind that these aspects do not fully allow themselves to be put in a geometric structure, two-dimensional structures (matrices) can be of great value and enable structured work and processes. Already from the start of the CDIO Initiative, several such matrices and similar structures have been proposed. Within the CDIO framework one of the fundamental documents is the CDIO Syllabus, see Crawley (2001), which in many approaches is a key element when designing such matrices. The report presents several matrices representing the mapping between the CDIO Syllabus and other reference systems, such as the ABET criteria. Notable is also that the report presents early applications of the Syllabus survey, which is a useful tool based on the CDIO Syllabus. In addition, Bankel et al. (2003) extended the

application of the Syllabus survey by applying it to three Swedish engineering education programs. Bankel et al. (2005) introduced a second dimension via the steps Introduce (I), Teach (T), and Utilize (U), leading to the so-called ITU matrices. These matrices were introduced as a tool for benchmarking an existing curriculum using the CDIO Syllabus as reference frame. To some extent, this gives a way to characterize progression over time in the program. Simply, there should be more I's in the beginning and more U's at the end of the education program. Bankel et al. (2005) represents the starting point of the use of this type of matrix within the engineering education at Linköping University, and the first generation was presented by Gunnarsson et al. (2007). Experiences and results from systematic use of the CDIO Syllabus for developing program goals and learning outcomes were described by Gunnarsson et al. (2009). Related types of matrices were presented by Malmqvist et al. (2006), who employed a systematic procedure for setting up program goals and mapping them to individual courses.

Another interesting contribution was reported by Willcox and Huang (2017), where a visualization tool was used to interactively illustrate the connections between various courses and the items of the CDIO Syllabus. The connections are given by the information encoded in the corresponding course (there denoted ITU) matrices. It should be stressed that there are numerous other examples of the use of different types of matrices based on the CDIO Syllabus, and it is not the aim to give a complete overview in this paper. Additional information can be obtained via the link *Knowledge library* at the CDIO web site.

Within Linköping University, a successive development of these tools has been undertaken in order to meet regulations by authorities in higher education and to be able to use the same tools for other types of programs in related fields as natural sciences and biomedicine, see Fahlgren et al. (2018). The more official use of the matrices in the model for quality assurance has triggered further development of the LiTH Syllabus, which is a local adaptation of the CDIO Syllabus. (LiTH is an acronym for the Swedish name of the Faculty of Science and Engineering.) In addition, the CDIO Standards, which is the second fundamental document of the CDIO framework, has been used for a long time within the Faculty of Engineering and Science. For example, the self-evaluation based on the Standards has been carried out for most of the programs. As a result of the close connection between the Standards and the ESG criteria, the Standards have become an important tool when writing the quality reports that are important parts of the quality assurance system. This will be discussed in more detail below.

This paper has two main messages: First, to present and illustrate how the CDIO framework, including both the CDIO Syllabus and the CDIO Standards, is an integrated part of the quality assurance system covering all education programs within the Faculty of Engineering and Science at Linköping University. Second, to present the process for developing the second generation of course and program matrices based on the adapted version of the CDIO Syllabus. The paper is organized as follows. The first two sections present brief introductions to the new Swedish quality assurance system and the CDIO framework, respectively. The following section describes the adaption of the CDIO Syllabus within the Faculty of Science and Engineering, with respect to the needs, contents, and development process. The last section describes the use of CDIO Standards in the quality assurance system together with comments on how the standards relates to the ESG criteria. The paper ends with discussions and conclusions.

THE NEW SWEDISH QUALITY ASSURANCE SYSTEM AND ITS APPLICATION

Quality assurance of higher education in Sweden is assessed by the Swedish Higher Education Authority (UKÄ). A new model, consisting of four components, has recently been implemented, and the keynote in the new model is the shared responsibility for quality assurance between the Higher Education Institutions (HEIs) and the Authority. Additional information can be obtained via the link *Quality assurance of higher education and research* (2018). The new national model is based on the Higher Education Act, the Higher Education Ordinance and the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG).

One of the components, which is in focus in this report, is institutional reviews of the quality assurance processes. The others are appraisal of applications for degree-awarding powers, thematic evaluations and specific program evaluations.

The main part of the quality assurance efforts is completed by the HEIs and the responsibility of the Authority is to assess that the HEIs have systematic quality assurance processes that are sharp enough to really ensure that education at all levels maintains a high quality. The six assessment areas are:
- governance and organisation
- preconditions
- design, implementation and outcomes
- student and doctoral student perspective
- working life and collaboration
- gender equality

The application of the new model for quality assurance at Linköping University

At Linköping University (LiU), a new system for quality assurance has been launched and a pilot study was performed in 2017. This new focus resulted in a more systematic approach to quality assurance as well as quality enhancement. The LiU model is consistent throughout the university but with a certain degree of freedom for the faculties, when it comes to how the quality promotion is organised. All programs and courses offered at LiU are to undergo in-depth quality assurance every sixth year. Since this systematic approach is new, even the model itself will be evaluated and adjusted in a continuous manner over the next years. For each program under review, a quality report is written. More information about q*uality assurance at LiU* (2018) can be found at the LiU website. The criteria for first-cycle and second-cycle educational levels are:
  i. The design, execution and examination of the education ensure that the students have achieved all learning outcomes in question, when the degree is awarded.
  ii. The design and execution of the education promote the students´ learning and encourage students to play an active role in the learning processes.
  iii. There is a clear coupling between teaching and research in the educational environment.
  iv. The number of teachers and their collective expertise are sufficient and are proportional to the contents and execution of the education.
  v. The education is applicable and prepares students for a career characterized by change.

vi. The education strives to ensure that the students participate actively in improving the education.
vii. A perspective of gender equality is integrated in the design and execution of the education.

The written reports containing descriptions of how the criteria are fulfilled as well as follow-ups of some key indicators, are discussed in a program dialogue between the board of studies (represented by the chairperson and the faculty program director) and the faculty management (the dean, the pro-dean for education and the head of the faculty office) in the presence of student representatives. The program dialogue leads to an assessment by the dean, which results in a plan of action for each object evaluated.

All material from each year and all faculties: quality reports, approved plans of action, and a summary of an analysis that focuses on strengths as well as challenges for each faculty, are submitted by the deans to the vice-chancellor annually. Thus, action plans can be compiled at the program level, at the faculty level, as well as on the university level and become part of the strategic agenda at all levels.

The CDIO framework as a basis for Quality Assurance at the Faculty of Science and Engineering

At the Faculty of Science and Engineering, the CDIO framework (Syllabus and Standards) has been an important tool in structuring the programs when it comes to aspects like design, implementation and outcomes as well as student-centered learning, learning resources and faculty competencies. These aspects are covered in ESG 1.2 Design and approval of programs, 1.3 Student-centered learning, teaching and assessment, 1.5 Teaching staff and 1.6 Learning resources and student support. For more information on ESG, follow the link *Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG)* (2015). The ESG Standards mentioned above directly overlap with assessment areas in the national Swedish model for Quality Assurance as well as with several criteria in the LiU model for Quality Assurance. The CDIO framework and the use of the Syllabus and Standards are presented in more detail below.

THE CDIO FRAMEWORK

The fundamental aim of the CDIO framework is to educate students who are "ready to engineer" and to raise the quality of engineering programs, see Crawley et al. (2014) and the web site CDIO Initiative (2019). The CDIO framework is thus not a Quality Assurance System, but a systematic approach to enhance the quality of an educational program. The framework relies on four key components:

- A "definition" of the role of an engineer.
- Clearly defined and documented goals for the desired knowledge and skills of an engineer listed in the document the CDIO Syllabus (2019), which serves as a specification of learning outcomes.
- Clearly defined and documented goals for the properties of the engineering education program collected in the document CDIO Standards (2019), which works as guidelines of how to design a well-functioning engineering education. For example, CDIO Standard 12 Program Evaluation emphasizes the importance of continuous improvement.
- An engineering approach to the development and management of education programs.

According to the CDIO framework, see Crawley et al. (2014) page 50, the goal of engineering education is that every graduating engineer should be able to

> *Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.*

This formulation can serve as a definition providing the basis for the entire CDIO framework. Adopting the definition, it is natural to design and run an engineering education program with this in focus. The CDIO Syllabus is a list of the desired knowledge and skills of a graduated engineer. The document can be found via the CDIO web site, and it consists of the following four main sections:

1. Disciplinary knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: Teamwork and communication
4. Conceiving, designing, implementing, and operating systems in the enterprise, societal, and environmental context – The innovation process

Via the sub-sections and sub-sub-sections, the document offers an extensive list of knowledge and skills, which can be used to specify learning outcomes of individual courses or education programs. The CDIO Standards (2019), which also can be found and explained in detail via the CDIO web site, is a set of twelve components that are necessary for designing and running an engineering program that enables the students to reach the desired knowledge and skills.

ADAPTING THE CDIO SYLLABUS

The LiTH Syllabus

As mentioned in the Introduction, the first generation of an adapted version of the CDIO Syllabus was developed more than ten years ago. Triggered by the new quality assurance system, the first step in the development of the new generation of course matrix was to develop a new version of the LiTH Syllabus. The document is based on a translated version of CDIO Syllabus 2.0, see the web site *CDIO Initiative* (2019), and then adapted to also cover education programs outside the engineering field. The revision has consisted of three main parts:

- A thorough revision of the wordings and formulations
- A revision of section 5, for non-engineering programs
- Introduction of subsection 1.4 and 1.5 concerning disciplinary knowledge and reasoning

The first item is of editorial type, but for items two and three some additional comments are motivated. Section 5 of the Syllabus was introduced 2007 to cover programs within natural sciences, as an alternative to development of products and systems, which is the focus in Section 4, the emphasis was on design and execution of research projects. Since then new programs have been introduced, and this made it motivated to widen the scope of Section 5. The focus in the new version of Section 5 is on "knowledge development" and "design, execution, presentation, and evaluation of research and development projects". Section 5 also starts with subsections corresponding to 4.1 and 4.2, i.e., the societal and economical context, including sustainability issues. Subsections 1.4 and 1.5 were introduced to match the requirements about deeper disciplinary knowledge and insight into research work for five-year engineering programs.

Development process

The development has been carried out within the advisory group for education (LGU) at the Faculty of Science and Engineering, which is a group including the chairpersons of the five boards of studies, the dean and the pro-dean for education, the faculty program directors and student representatives. LGU meets every week, and the group is vital for the coordination and development of all education programs within the Faculty of Science and Engineering. The new version of the LiTH Syllabus has also been approved by the Faculty Board. The document, which is in Swedish, can be accessed via the web site *CDIO Introduction* (2019).

Mappings between the LiTH Syllabus and the Degree Ordinance

Another step in the process has been to revise and design mapping matrices that connect the learning outcomes in the Degree Ordinance and the items in the LiTH Syllabus. As mentioned in the Introduction, Crawley (2001) presented such mappings between the CDIO Syllabus and for example the ABET criteria. Within the Swedish system, Johan Malmqvist at Chalmers University of Technology, did initial work setting up similar mapping matrices between the Degree Ordinance and the CDIO Syllabus. These ideas have been applied and extended within the Faculty of Science and Engineering at Linköping University, which has resulted in mapping matrices for four different types of education programs: engineering programs over three or five years, bachelor's, and master's programs. The resulting document can be accessed via the web site *CDIO Introduction* (2019).

Course matrix workshops and information about the CDIO framework

Since the course matrices are important components of the quality assurance system, it is important that the course matrices themselves have high quality. Therefore, several different activities are carried out to support the individual teachers in the generation and development of the matrices for their courses. This involves workshops and other types of information activities for the teachers. A web site, presenting the main ideas of the CDIO framework, has been made accessible, see *CDIO Introduction* (2019), and relevant documents be can accessed via the web site. Workshops for teachers have been arranged at the campuses where the Faculty of Science and Engineering runs education programs.

Program matrices

The purpose of the course matrices is to be a tool to show that the learning activities and examination in the individual courses contribute to the fulfillment of the overall program goals, and, of course, also of the goals in the Degree Ordinance. This is done as a combination of a top-down and a bottom-up approach. The top-down approach starts from a high-level formulation of the goals for the "LiTH Engineer", structured according to the sections of the LiTH Syllabus. These goals are then elaborated for each individual education program and expressed on level x.y of the Syllabus. Hence, for each of the items x.y, the program goal document, i.e. the Program Syllabus, contains a formulation about the expected level of proficiency of the graduates of the program for the type of knowledge and skill covered by item x.y. In the bottom-up process the contents of the course matrices of the individual courses in a program are collected in a program matrix. The courses in the program are listed along one dimension and the subsections x.y of the LiTH Syllabus define the other dimension. Depending on how the individual course matrices have been filled in one can check to what extent the overall goal corresponding to that subsection is covered in the program simply by checking that the columns of the program matrix is "filled" in a satisfactory way. The program matrix is

hence an essential and very useful tool for verifying that criterion (i) (see above) in the quality assurance framework is fulfilled. An example of a program matrix based on the first generation of the LiTH Syllabus is given in Gunnarsson et al. (2007).

USING THE CDIO STANDARDS

The CDIO Standards in comparison to ESG
The national Swedish quality assurance system is developed and implemented in accordance with national legislation as well as with the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG). Part 1 of the ESG standards and guidelines handles internal aspects and are recommendations for the HEIs. The Standards provide guidance on important areas and issues to have control of in order to give a high-quality education. The focus is on teaching and learning, including well-functioning learning environments and links between the education and related research as well as stimulation of innovative competencies. Several ESG Standards can be recognized from CDIO Standards. However, there is not a 1:1 match, and some ESG Standards are not corresponding to any CDIO Standard, as seen in the Table 1.

Table 1: The correlation between ESG Standards and CDIO Standards. The ESG Standards are at the left and the CDIO Standards at the top.

	1. The context	2. Learning outcomes	3. Integrated curriculum	4. Introduction to engineering	5. Design-implement	6. Engineering workspaces	7. Integrated learning	8. Active learning	9. Enhancement of faculty	10. Enhancement of faculty teaching	11. Learning assessment	12. Program evaluation
1.1 Policy for Quality Assurance												x
1.2 Design and approval of programmes	x	x	x	x	x		x	x			x	
1.3 Student-centered learning, teaching and assessment		x	x	x	x		x	x			x	
1.4 Student admission, progression, recognition and certification												
1.5 Teaching staff									x	x		
1.6 Learning resources and student support						x			x	x		
1.7 Information management												x
1.8 Public information												
1.9 On-going monitoring and periodic review of programmes												x
1.10 Cyclical external quality assurance												

The ESG Standards are more focused on the student life cycle at the university than the CDIO Standards, which are more closely connected to the education itself. Thus, the ESG Standards are suitable for quality assurance on a higher level than the CDIO Standards that are more suitable for program evaluation, which of course is an extremely important part of the students experience at the university and for their working life as engineers.

Using the CDIO Standards for quality assurance and enhancement

To be able to use CDIO Standards to evaluate the progress of quality enhancement, a self-evaluating tool has been developed based on the CDIO Standards, see Kontio (2016). A key function is to follow how effective the program is to reach its intended goals. Beyond, using the tool for self-evaluation, it has also been used for cross-evaluation and cross-sparring, meaning more of learning from and supporting each other in the process, by inviting external CDIO community members to take part.

At the Faculty of Science and Engineering at Linköping University, the CDIO evaluation tool has been used earlier, but not in a systematic way. To adopt to the new quality system at the university, the CDIO Standards, especially Standards 3-8 and 11, have been valuable in writing parts of the quality reports mentioned above. These CDIO Standards include integrated curriculum, introduction to engineering, design-implement experiences, engineering work-spaces, integrated learning experiences, active learning, and learning assessment. All together they meet the criteria (ii) and (v), i.e. the design and execution of the education promote the students' learning and encourage students to play an active role in the learning processes as well as that the education is applicable and prepares students for a career characterized by change. For each program under evaluation, comments on how the CDIO Standards are met have been requested. The information is valuable in itself but has also enabled a structured analysis of how the different parts of the curriculum work and are linked to each other, which is a good start for further development. In addition, the knowledge about the Standards and the underlying rationale have increased, and a common language has been established.

DISCUSSION

The Linköping University system for quality assurance is aimed as a combined instrument for quality assurance and quality enhancement. Seeking to achieve both may seem obvious when such a tool is developed, but because of their different natures, this is also a challenging task. For example, Williams (2016), has given an account for different perspectives on their relationship: from non-related, completely separate processes through competing or even reciprocally harmful practices to symbiotic coexistence. Elton (1992) characterized these processes as quality A's associated with control and quality E's associated with internal drive for change, respectively: Assurance, Accountability, Audit, and Assessment versus Enhancement, Empowerment, Enthusiasm, Expertise, and Excellence.

As a quality model, that is, a framework or theory of learning that helps us operationalize teaching aims and manage learning activities (Biggs 2001), the CDIO Syllabus and CDIO Standards provide linkage between the A's and the E's. More specifically, they translate the quality assurance perspective imposed by the Degree Ordinance, with quality seen as fulfilling a minimum set of standards (see Harvey & Green 1993) into a quality enhancement perspective with quality as transformation—enhancing the participant (ibid.). For example, the Degree Ordinance requirement "demonstrate the ability to identify, formulate and deal with complex issues autonomously and critically and with a holistic approach and also to participate in research and development work and so contribute to the formation of knowledge" are itemized into Syllabus entities such as 2.1.1 Problem Identification and Formulation and 2.1.4 Analysis with Uncertainty. The latter is a more natural basis for designing and developing learning activities.

Likewise, the Standards proved to be a suitable tool for grasping the complexities of educational programs. In the context of describing the design and execution of the programs, they serve as a means for rediscovering them—a framework for a qualitative analysis focused on learning that is typically associated with quality enhancement (Biggs 2001). This is especially valuable to new teachers as an introduction to the program rationales, but experienced teachers may also benefit from a reminding expansion of their views of the program they work within. We are not always aware of the bigger pictures.

An essential aspect of the CDIO components is that they are developed by engineers for engineers, thereby offering a sense of familiarity; they contextualize the quality processes into something that matters to engineering teachers. This community aspect has also been emphasized in the work presented in this paper: the new version of the Syllabus was developed in cooperation among teachers, students, and administrators.

CONCLUSIONS

Over the years the CDIO framework has turned out to a robust and very useful framework for various aspects of management of educations programs within the Faculty of Science and Engineering at Linköping University. More recently the use of the framework has been extended and deepened via the new quality assurance system as reported above. One of the main benefits is that the framework provides a common language when discussing program management and quality issues. The framework has a strong support in the organization, ranging from student representation in boards and groups to decisions in the Faculty board about the use of the framework. In addition, the close connection to other frameworks, such as ABET and ESG, gives additional credibility to the framework.

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TEACHING ELECTRONICS-ICT:
FROM FOCUS AND STRUCTURE TO PRACTICAL REALIZATIONS

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ABSTRACT

We present a four-year electronics-ICT educational master program at Ghent University in Belgium. The students develop knowledge and skills from novice to experienced electronic circuit designers. In the corresponding topics, the immersion into engineering problems is deepened. The horizontal and vertical alignment of courses in the four-year master program at our university is discussed. The curriculum of the four-year master program is highly project-oriented and all topics are clustered around a well-considered set of standards. This clustering supports the logical structure of the program, with students gradually acquiring the necessary competences. All standards and their mutual interaction are extensively discussed in the paper. We also focus on four design-implement projects included in the electronics-ICT program, explicitly following CDIO-guidelines. Whereas the first-year project has a limited level of difficulty, the challenges increase significantly in the course of the next years. Students learn that product design is an iterative process on different levels, where the design strategy can be changed continuously based on important and crucial feedback. Different evaluations have demonstrated that our students are not only aware of CDIO-principles, but are also convinced of the quality of the results obtained by following the standards.

KEYWORDS

Design-Implement Experiences, Engineering Workspaces, Integrated Learning Experiences, Active Learning, Learning Assessment and Program Evaluation, Standards: 5, 6, 7, 8, 11,12.

INTRODUCTION

In the Belgian system for higher education, one can study technological topics at three different levels. The first level is a three-year study and is called professional bachelor. The second level requires four years of study, consisting of three years of (academic) bachelor and one additional master year. The third level consists of three (academic) bachelor years and two additional master years. Whereas the differences between pursuing a professional or academic degree are rather straightforward, the differences between the second and third level are not that clear, because both levels lead to an engineering degree. The third level (with five years of study) however, focuses on fundamental knowledge and theoretical research, resulting in products and solutions for the market in the far future. The second level (with four years of study) works on applied engineering sciences and solves today's problems, with engineers working in multidisciplinary teams.

With the last curriculum reform at Ghent University, the four years study program of electronics-ICT was reorganized, stressing more than in the past on the connection between the important theoretical basis and the practical applications in the study field of electronics. At the same time, many extra CDIO-principles have been added to our program. Because more project courses are offered, horizontal and vertical alignment of the curriculum is essential. A similar reorganization was presented by Shen (2015).

After elaborate internal consideration, it was decided to restructure the curriculum throughout the four-year study program in 6 different standards, thereby clustering all relevant topics. Besides basic engineering outcomes – as core of the program – a number of specific outcomes are defined. The cluster for elementary scientific topics, the engineering topics, the research topics and finally specialized electronics and ICT topics are the classic outcomes, whereas innovation, sustainability and communication skills are the specific ones.

Especially for the project-oriented courses, an alignment of the topics and the level of difficulty is of paramount importance. Students learn that product design and development is an iterative process at many levels, where constant feedback helps to adjust the design strategy to obtain a high-quality product as the final result. Creativity is stimulated by allowing many degrees of freedom to define the final product. The project definition not only needs to challenge every student on state-of-the-art subjects but should also drive them to apply recently taught knowledge. Interaction between the professors responsible for those project courses is very important and is organized on a regular basis. The increasing project complexity is also described in Kjærgaard et al. (2012) and is in complete agreement with CDIO Standard 5. The four projects of increasing complexity go hand in hand with the four years of study. The second bachelor year project course was described in Verhaevert et al. (2016), whereas the capstone project of the third year was discussed in Van Torre et al. (2017).

This paper is organized as follows. In the next section, the learning outcomes are structured and extensively discussed, showing the horizontal and vertical alignment within our curriculum. The following section elaborates on the project courses and the increased difficulty level during the studying years. The section thereafter handles the CDIO-benchmarking of the engineering learning outcomes. This paper is finalized by the conclusions in the last section.

LEARNING OUTCOMES STRUCTURED

Learning outcomes

The term learning outcome is an educational concept related to the alignment, the structure and the coherence of a study program. Learning outcomes clarify how a curriculum is composed logically so that students gradually acquire certain learning outcomes and how it is monitored that specific scientific themes throughout the study program are adequately addressed. Setting up a thorough program requires consulting stakeholders such as students and professors, as well as industrial advisors. Keeping the intended learning outcomes up to date also requires ongoing regular interaction on content, teaching principles and testing methods between the involved professors.

A number of desired learning outcomes are generally implicitly or explicitly included in study programs. Besides the classic learning outcomes, more specific learning outcomes such as communication skills or sustainable development enjoy a growing interest. Classic learning outcomes express the core of the curriculum and occur in many courses throughout the curriculum. These learning outcomes usually relate to different course learning outcomes and sometimes even to a complete field of competence. Mapping these learning outcomes is often a relatively easy exercise. One selects some global goals from the study program and places all course units there. This is a puzzle that usually falls into place quickly.

Equally, individual courses can also have specific learning outcomes. These relate to more specific topics such as communicative skills, entrepreneurship and sustainable development. These can be themes the course has traditionally focused on for years, which are typical for the curriculum. However, they can also be previously unexplored or highly fragmented themes for which more deployment or visibility is important in the future. A theme such as 'sustainable development' is a good example and can be covered in many courses. However, in the past, student surveys highlighted a lack of attention to this topic. These specific learning outcomes are often more difficult to implement because one has to search in which course units the theme can be properly addressed. That is why we integrated these themes in the learning outcomes, which will be explained further on.

Vision and operationalization

Learning outcomes provide insight into the program and the mutual coherence of the course units. As a result, they promote communication and form a good basis for internal consulting within the educational staff. For example, if one wants to put more emphasis on a particular topic in the program, this does not necessarily have to result in a large program reform. By elaborating the learning outcome around this theme, possible fragmentation is avoided. Additionally, the horizontal and vertical alignment is often very useful in shaping an appropriate test policy within the study program

When a study program is launched, there has been a lot of preceding discussion on the design and implementation of the overall alignment. Making the learning goals and outcomes explicitly available in a graphical way, does not only ensure that external parties quickly obtain information about the study program, but it also makes clear to (new) professors to which particular learning outcomes their course contributes. Moreover, learning outcomes can also make clear to students at which stage they are in the learning process.

The program committee is in charge of the structure and the quality control of the educational study program and consists of 9 professors, 3 assisting teachers and 6 students, sometimes supplemented with members from the industry. This committee defined 6 educational goals, as a vision and mission statement on the education of electronics-ICT engineering students. They focus on electronics-ICT engineers who will be able to:

1. anchor theoretical elementary sciences directly based on intensive practice and practical sessions
2. turn scientific ideas in a creative and innovative way into products for the society of tomorrow
3. sell ideas and products in a communicatively strong way
4. be team-oriented and directly employable in the professional field
5. perform multidisciplinary and academic research
6. be experts in the fields of 'analogue and digital electronics', 'information and communication technology' and 'data processing and multimedia'

These goals were translated and converted into 6 different learning outcomes: elementary scientific learning outcomes, entrepreneurship and sustainability learning outcomes, communication learning outcomes, engineering learning outcomes, research learning outcomes and finally electronics-ICT learning outcomes. They are visualized in different colors in Figure 1.
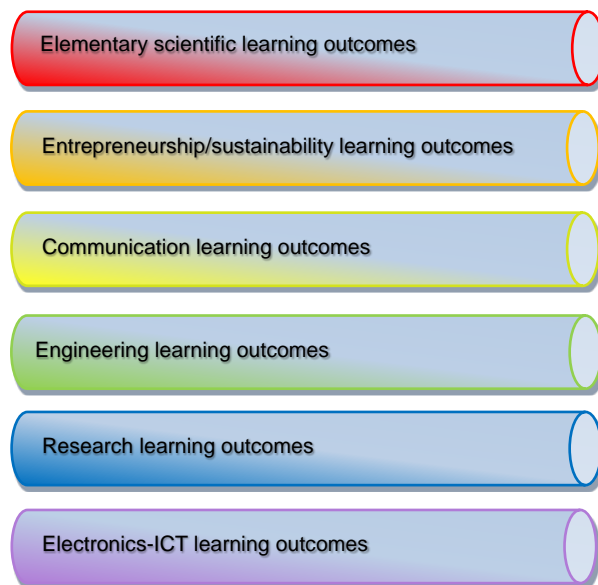
Figure 1. 6 different learning outcomes

Specifically, the program committee wants to realize its vision and mission statement through:

1. knowledge creation as a fundament of creativity in practicums and seminars organized in small groups
2. a multidisciplinary approach in which the unknown poses a challenge rather than a threat
3. the use of a wide and varied range of teaching methods that acquire communication skills
4. presenting complex issues in which each team member is challenged to 'dare to think'
5. guidance of keen academic thinking in projects and guided self-study
6. accountability of theoretical knowledge through practical applications

The above operationalization of the vision and the mission statement explicitly states how the program committee outlines the education of the electronics-ICT engineers of the future. Those operational goals can be directly linked with the vision and mission statement and also with the learning outcomes. However, different cross connections are possible. For instance, operational goal 6 (with practical applications) can be part of the research learning outcomes and can also have a match with communication skills at the same time.

Applied on the study program

Deploying the operational goals results in a horizontal and vertical alignment of the courses. The colors of the 6 different learning outcomes are used to visualize the complete study program throughout 8 semesters of study, or 240 credits (with 30 credits per semester) in Figure 2. To each of the learning outcomes, various courses are connected, taking into account that the study program is a balanced sequence of course units, supporting each other. A number of course units link with 2 or even more learning outcomes and were therefore assigned 2 or more colors.

A number of courses in Figure 2 are framed in yellow. This indicates that more attention is paid to communication skills in comparison with other courses. It is also important to be aware of the fact that none of those colored courses may be interpreted too strictly. For instance, in course units being part of the red elementary scientific learning outcomes it is of course allowed to teach and test skills of other learning outcomes, but in a more limited way.

DESIGN-IMPLEMENT PROJECTS IN ELECTRONICS-ICT

In this section of the paper, the focus lies on the different courses of the engineering learning outcomes. More than in other courses, the students learn to think and act as an engineer. In the electronics-ICT educational program, these design-implement projects are the core and are meant to support and to complement the other theoretic courses, not only from the previous semesters but also from the same semester (Svensson & Gunnarsson, 2012).

Specifically for the engineering learning outcomes, a horizontal and vertical alignment is extremely important. Before the program reform, many small projects existed in almost every engineering course. By setting up an alignment the many small projects disappeared and large annual projects resulted in less overlap, more challenge and last but not least more enjoyable learning. This section is focused on the different courses involved and on their gradually increasing difficulty, as is described in (Kjærgaard, Brauer & Andersen, 2012), according to CDIO Standard 5. As can be seen in Figure 2, Engineering project is the first project course. It is followed by a technically more demanding Multidisciplinary engineering project in the second year and the Bachelor thesis in the third year. The four-year educational program is finalized with a Master thesis as a capstone of the curriculum.

Besides other courses in Figure 2, the courses related to the engineering learning outcomes are also yellow squared, indicating that communication learning outcomes are involved, according to CDIO Standard 7. Combined with technical and engineering skills, the students are trained in communication skills, such as a paper or a (poster) presentation. They are encouraged to exercise these communication skills by communicating about particular design choices and preliminary project results to the other teams.

Figure 2. Structure of the study program

Semester 1	Semester 2	Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
Mathematics I (6)	Mathematics II (6)	Mathematics III (3)		Discrete mathematics (3)			
			Signals & systems (6)	Control theory (6)			
Mechanics (6)	Physics I (6)	Physics II (3)					
Design tools (3)		Applied fluid mechanics & thermo-dynamics (6)					
Chemistry (6)	Computer science (6)	Programming in C en C++ (6)					
Materials (3)	Environmental management (3)		Sustainable energy technology (3)	Choice (6): Entrepreneurial skills project (6) - Basic entrepreneurship (3) - Quality management (3)	Business administration (3)	Choice (3): Emerging technologies in ICT and automation (3) or Introduction to Entrepreneurship (3) - Internship 1 (3)	Semiconductor components and electronic devices (3)
	Engineering project (3)		Multidisciplinary engineering project (3)		Bachelor thesis (6)		Master thesis (18)
			Numerical analysis (3)			Multimedia (6)	
	Electrical & electronic principles (6)	Statistics (3)	Data processing (3)				
Electricity (6)		Digital electronics I (6)	Embedded systems: microcontrollers (6)	Digital electronics II (6)	Embedded systems: hardware synthesis (3)	Embedded systems: algorithms (3)	
					Digital signal processing (6)	Wireless and mobile communications (6)	
			Computer networks (3)		Data communication (3)		
					Computer architecture (6)	High frequency techniques and EMC (3)	
			Analog electronics I (6)	Analog electronics II (6)		Major (9) & choice (9): Analog design (6) - Biomedical electronics (3) - Design methodology for FPGAs (6) - Electronic measurements and EMC (3)	
					Choice (3): Power electronics (3) - Operating systems (3)		

This interaction often leads to redesigns, forming a highly valuable experience frequently leading to a better final design. Also, academic referencing becomes more refined and important, further in the curriculum.

Every course starts with an introductory class, where not only the technical details of the project are presented, but also the project methodology and assessment parts. According to CDIO Standard 11, different assessment types are used, adapted to what is taught and practised. Writing and presentation skills are assessed by a language professor. The students are also

introduced in the CDIO principles (Khan, Kristian, Ying & Jung, 2015), especially for the brainstorming and planning of the different tasks and responsibilities. The topics are all multidisciplinary (CDIO Standard 8), using concepts from other courses to provoke a deeper understanding of practical issues in the domain of electronics-ICT. Depending on the project topics, additional presentations help students to acquire related theoretical background and technical issues necessary for the project.

Together with the reorganization of the content, some practical issues were also taken care of. The workspaces for students are now accessible every day and are user-friendly with all necessary equipment, as being part of CDIO Standard 6. On a weekly basis the students are supposed to work on the project within specific hours, but are free to spend extra hours anytime. Since the reorganization, the supervisors are not merely teachers, but act as trainers and/or coaches (according to CDIO Standard 5), helping the students to quickly achieve intermediate results. Because early success is a very important motivating factor, the project proposals include a number of small goals of increasing complexity. Different ways of active learning are included, as also reported in (Gonzáles, Hurtado, Renneberg, Bravo & Viveros, 2016).

The rest of this section focuses on the four different CDIO courses, as part of the engineering and communication learning outcomes. A flowchart with the consecutive design-implement projects can be found in Figure 3.

| Semester 2 | Semester 4 | Semester 6 | Semester 8 |

- Engineering project
- Multidisciplinary engineering project
- Bachelor thesis
- Master thesis
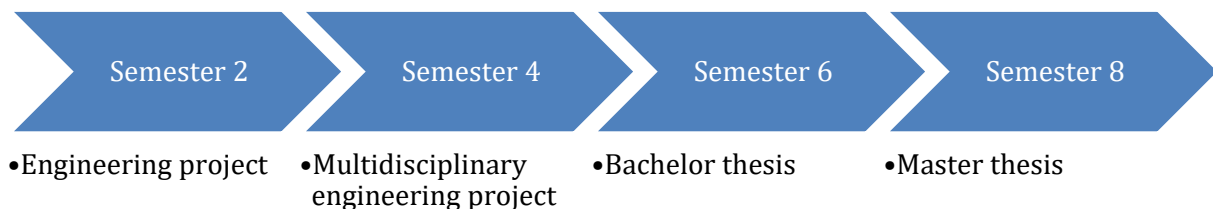
Figure 3. Consecutive design-implement projects

Engineering project

One of the first experiences in the domain of electronics-ICT is the Engineering project in the first bachelor year (Engineering project course specification, 2019). In teams of 5 to 7 students, an electric motor is designed and implemented, by using basic mechanical and electrical components such as magnets and reed switches. Every team is also required to control the motor with an Arduino microcontroller board. On a weekly basis the project progress is discussed within the team, together with the supervisors, encouraging the students to take initiative and solve problems in a creative way.

Considering the communication skills, the focus is on correct and adequate use of language in reports and reference lists. Also the concept of collaborative writing is explained, how titles and paragraphs are structured and formulated in a clear and precise, linguistically correct way. In every project meeting, another student is chairman and secretary, which offers the opportunity for every student to experience every role.

Multidisciplinary engineering project

In the second year, as visible in Figure 2, the Multidisciplinary engineering project is scheduled. This more advanced-level design-implement project (Multidisciplinary project course specification, 2019) was the topic of an earlier publication (Verhaevert & Van Torre, 2016).

Where the previous project was more initiating, this project is meant to present a first serious challenge in electronic product design. Another topic is chosen every year and a large complexity is maintained. In 2018, the students designed a receiver for DAB (Digital Audio Broadcasting). Instead of changing roles, every student in a group of 5 to 7 students needs to meet different, but dedicated job profiles (e.g. project manager, analogue design engineer, digital design engineer, printed-circuit board designer). Team meetings with the supervisor are complemented with additional lab sessions, especially toward the end of the semester. The students learn that product design is an iterative process on many levels, where feedback is used to adapt the design strategy and/or final product. The supervisor provides the necessary background for the students, by technical and scientific support.

Although a project report and a product demonstration are required, this course also focuses on oral presentation skills. Therefore, during the semester, a class is organized to teach the requirements for the presentation, especially concerning the structure and the layout of the slides. Because every team member should have an active contribution, advice on team presentations with alternating presenters is provided. The importance of body language, pronunciation and keeping the attention of the audience is also addressed and exercised in an intermediate presentation with peer-assessment by other students. Feedback on the presentation skills (by self-, peer- and tutor-evaluation) has no impact on the final marks in this stage.

Bachelor thesis

The three years of the bachelor program are finalised by means of a Bachelor thesis (Bachelor thesis course specification, 2019), which was extensively described in Van Torre et al. (2017). This design-implement electronics-ICT project is characterized by an even larger responsibility for the student. For every assigned project, a team of 3 students is composed. All topics are linked to different research groups, giving the students the chance to experience the research culture. In the structure, a blue color is added to this course, linking it with the research learning outcomes. Every team member needs to profoundly analyze the entire project, resulting in a literature review, handed in as a 10-page document with a correct reference list. Afterwards the team plans the project in different subtasks, integrating all aspects in one functional analysis. Besides a fully detailed functional description, a technical implementation is realized and should be presented as a separate chapter in the final text.

Writing a project report and performing an oral presentation has already been experienced previously by the students, but in this project, the expectations are set higher. There is more focus on a professional, objective and academic writing style as well as on text structure. The report also needs to be as complete as possible, because the obtained results should be easy to reproduce. Besides a report and an oral presentation, for this project a poster is required, where the students are guided to an academic poster with correct layout and language.

Master thesis

The final bridge between education and the job as an engineer is the Master thesis (Master thesis course specification, 2019), which also completes the master program. This final project is, in fact, a research project in close co-operation with the industry. The student performs technical-scientific research individually and independently in the chosen research domain. The students prove creativity, originality, inventiveness and craftmanship in the obtained research-oriented attitude. Members of the industry act as supervisor and assist the students on the go with use cases, practical issues and other industry relevant topics, resulting in research-driven practical design-implement projects.

For reporting, both a presentation with oral defence and extensive written report are expected, with a lot of attention to the problem definition and the approach followed. The work should reflect a critical attitude and research mentality. In the Master thesis, there is a close link with the industry, with industry members reading the manuscript and being part of the thesis committee. This focus results for the student in a broader and clearer scope on the defined problem. The last part of the communication learning outcomes focuses on the professional life as an engineer. There is information on business correspondence and preparation for a job application, with special attention for job advertising, curriculum vitae, cover letter, job interview, personality test, elevator pitch, coaching, etc.

ENGINEERING LEARNING OUTCOMES BENCHMARKING

The electronics-ICT engineering program described above is embedded in domain-specific learning outcomes defined by decrees from the Flemish government. Those learning outcomes describe the teaching qualification and thus give substance to a common set of learning outcomes that all students within the Flemish region are expected to acquire within a specific program. Especially for the engineering learning outcomes, a curriculum benchmarking is required, but has not yet been defined by the Flemish government. Those engineering learning outcomes are the core of the curriculum and an international benchmarking is strongly desired.

The program committee wants a curriculum that is organized around mutually supporting courses, where CDIO activities are highly incorporated with many student design-build-test projects. The program needs to integrate the learning of professional skills such as team work and communication, to feature active and experimental learning and to constantly improve through quality assurance processes with higher aims, surpassing accreditation requirements (Crawley, Brodeur & Soderholm, 2008). The 3 overall goals of the CDIO initiative (master a deep working knowledge of technical fundamentals, lead in the creation and operation of new products and systems and understand the importance and strategic impact of research and technological development on society) and the 12 standards have been the basis for a profound program reform, with impact on every study year and for every member of the educational staff (according to CDIO Standard 12).

During the roll-out of the new curriculum, the entire educational staff was invited for a workshop, where the project topics were discussed and the new program was critically reviewed. The resulting self-assessment of compliance was composed of a check of all 12 CDIO Standards and was used to benchmark the engineering learning outcomes of the electronics-ICT curriculum. Those 12 Standards (CDIO Standards 2.1, 2019) are as follows, with the self-assessment of compliance score between parenthesis as a result of the rubrics:
1. Adoption of the principle that product, process and system lifecycle development and deployment - Conceiving, Designing, Implementing and Operating - are the context for engineering education (score 4/5)
2. Specific, detailed learning outcomes for personal and interpersonal skills and product, process and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders (score 5/5)
3. A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills and product, process and system building skills (score 4/5)
4. An introductory course that provides the framework for engineering practice in product, process and system building and introduces essential personal and interpersonal skills (score 4/5)

5. A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level (score 5/5)
6. Engineering workspaces and laboratories that support and encourage hands-on learning of product, process and system building, disciplinary knowledge and social learning (score 4/5)
7. Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills and product, process and system building skills (score 5/5)
8. Teaching and learning based on active experiential learning methods (score 4/5)
9. Actions that enhance faculty competence in personal and interpersonal skills and product, process and system building skills (score 3/5)
10. Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods and in assessing student learning (score 3/5)
11. Assessment of student learning in personal and interpersonal skills and product, process and system building skills, as well as in disciplinary knowledge (score 5/5)
12. A system that evaluates programs against these twelve standards and provides feedback to students, faculty and other stakeholders for the purposes of continuous improvement (score 5/5)

This program reform and the adoption of the engineering learning outcomes have not yet reached a final point. Systematic and continuous improvement is recommended. The program committee for instance has plans to promote the realized products (from all study years), not only for the students and educational staff involved, but also for external stakeholders like alumni or industry members. We have ideas for a workshop, a YouTube-channel with videos made by students or even an electronic newsletter on a regular basis (explaining the current status of some student projects). Also, extra training in the CDIO principles for the educational staff can be useful. We should also be critical to the horizontal and vertical alignment of both the engineering and communication learning outcomes. Slight changes, like particular topics not yet taught to the students, can be solved ad-hoc by additional classes.

CONCLUSIONS

This paper described the experience with teaching electronics and ICT in engineering education at Ghent University. In the first part of the paper, the focus and the structure of the curriculum is described, resulting in different learning outcomes and a course scheme, showing horizontal and vertical alignment. In a second part of the paper, the engineering learning outcomes, combined with those for communication, are elaborated on by means of the description of four different design-implement projects throughout the four years study.

The horizontal and vertical alignment promotes focus and structure to the curriculum for both educational staff and students. The staff can rely on the logic of the program and the different courses. For the students this causes flexibility in selecting courses adjusted to their own preferences. The gradual construction of engineering, management and communication skills results in a wide variety of project topics and report results. Students are extremely motivated and result-driven, obtaining excellent team results in nearly all cases, working more hours than required or performing extra work, especially during the final phase of the project. By experiencing the complete design cycle, hands-on and with many degrees of freedom, creativity is boosted. The student assessment results confirm a wide appreciation of all these project courses.

As a weakness it should be mentioned that knowledge gaps are possible, by replacing traditional courses by project courses. As part of a team, every student is often free to select a particular role or to work on a dedicated part of the project. Some students may systematically choose a role corresponding to their own strengths, while their weaknesses stay uncompensated. This behavior is hard to exclude, given the nature of the project. Awareness for this risk needs to be part of the introductory classes, making the students responsible for their own knowledge acquisition path by selecting the right role and/or project part.

An opportunity not yet explored, is to present a variety of topics more closely related to industrial partners and hence overcoming the limited pool of projects from the educational staff. Another possibility is community service learning, where students engage in service, reflect on their experiences and also learn on a personal and civic level. The design of a proof-of-concept for third parties can be extra motivating, but a suitable level of difficulty and allowing enough student creativity need to be taken into account. Lundheim et al. (2016) suggest new ideas and relevant topics for the industrial link and Törnqvist (2015) gives a selection of such community service learning requests.

Popular students are shielded by other students, which can impact their peer-assessment. This is a risk, influencing the assessment results too much. Now it is solved by using the peer-assessment results only as a guideline, however other solutions should be investigated.

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PROJECT-ORIENTED TRAINING OF BACHELOR'S DEGREE STUDENTS IN CHEMISTRY

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ABSTRACT

Surgut State University joined the CDIO initiative in June 2017 at the 13th International Conference in the University of Calgary with three Bachelor's programs, including Chemistry. In accordance with standard 4, the discipline "Introduction to project activity" (1-2 semesters) has been introduced to the reformed curriculum. It forms the foundation for engineering practice and project activity in the field of creating products (chemical substances and materials) and systems (methods and technologies) and is aimed at learning basic personal and interpersonal competencies. In the first semester, students of a Chemistry program immerse themselves in the theory of project activities, and in the second semester they choose the project (for example, the creation of new materials covering silicon solar cells or the development of a chemical monitoring system for plants grown in closed systems) and assemble a team. In the second year, a team of students continues to work on the project at the discipline "Project Activity". The main goal of the second stage is the advanced hypotheses confirmation (the study of the physicochemical properties of substances and materials, technology optimization) and the testing of created products and systems in real conditions. During this stage, not only do students receive new knowledge about research methods but also they get experience in analytic equipment and processing of analysis results.
Thus, in accordance with the standard 5: a first and a second year student at the Chemistry program participates in at least in two educational and practical disciplines in designing and creating products, one of which performs in the first course at an elementary level, and the second one at an advanced level. Along with professional competencies, students develop their personal and interpersonal competencies (communication, flexibility, ability to work in a team), as well as increase the level of personal motivation for engineering professions in chemistry.

KEYWORDS

Syllabus, learning outcomes, project activity, standards: 1, 2, 3, 4, 5.

INTRODUCTION

Surgut State University joined the CDIO initiative in June 2017 at the 13th International Conference in the University of Calgary with three Bachelor's programs, including Chemistry (Petrova, 2018).

In accordance with standard 4, the discipline "Introduction to project activity" (1-2 semesters) has been introduced to the reformed curriculum. It forms the foundation for engineering practice and project activity in the field of creating products (chemical substances and materials) and systems (methods and technologies) and is aimed at learning basic personal and interpersonal competencies. In the 1st semester, students of a Chemistry program immerse themselves in the theory of project activities, and in the 2nd semester they choose the project (for example, the creation of new materials covering silicon solar cells or the development of a chemical monitoring system for plants grown in closed systems) and assemble a team. The project leader of a student team is a professor who helps students to define the project's goals and objectives, as well as a project plan. The leader appoints a project curator (5th course or PhD student) who helps 1st year students to distribute tasks among team members and oversees the implementation of project stages. In addition, the leader and the curator have got professional competencies that allow students to be trained on how to create products and systems. For example, students obtain nanocomposite materials with semiconductor properties using molecular imprinting technology of perylenediimide dyes on the surface of titanium dioxide nanoparticles; or create a system of plant state chemical monitoring in the interdisciplinary project "The Local Farm", launched by the Institute of Natural and Technical Sciences of the Surgut University. Let us focus on the latter project.

"THE LOCAL FARM" PROJECT

Local (vertical) farms are multi-tiered or tubular hydroponic installations, in which, as a rule, a whole range of greens and lettuce cultures are grown using solar or artificial lighting with a lamp system. Such farms with productivity more than 100 times higher than the productivity of traditional greenhouses have appeared in the USA, Japan, Singapore and European countries. They are capable of producing hundreds of tons of products annually, ensuring the food security of the population of cities and regions.

The goal of the Surgut University project is to develop an automated technology for growing crops in greenhouses according to the principles of agrophotonics in local (vertical) farms and to create an intelligent system for the management of the local farm resources. The technology provides the production of finished products from previously germinated seeds, thus it can be implemented in any climatic conditions in the presence of seed material, as well as in remote and inaccessible regions of the North and the Arctic, providing indigenous people and shift workers with fresh products rich in nutrients and vitamins (Fig. 1).

Compared to world analogues, this project will create an automated system for controlling hydroponic installations of local farms using controllers, video surveillance cameras, sensors and chemical monitoring system. The controllers directly control basic parameters of a farm, such as temperature, humidity, lighting, watering, fertilizers, etc. Obtaining information about the current value of the parameters is carried out by using sensors: temperature, humidity, light, etc. Control actions are calculated by a controller based on the current values of parameters and necessary values received from the server. The additional control over the plant growing process is carried out by using surveillance cameras installed on the farm, the image from which is processed and stored in real time on a cloud server, where a cloud database is formed, and then transferred to a remote client. In addition, the quality and plant state control of each grown batch is carried out by using methods of chemical analysis. The

complex of chemical analysis techniques, determined indicators and the quality and the plant state data form a chemical monitoring system, which is also stored in a cloud database. The cloud-server serves as a repository for the history of monitoring farm parameters, as well as a communication channel between the remote client and the controller. A remote client is a web application that is used to initialize the farm, as well as to monitor and control the process of growing plants. All parts of the system are connected via the Internet.
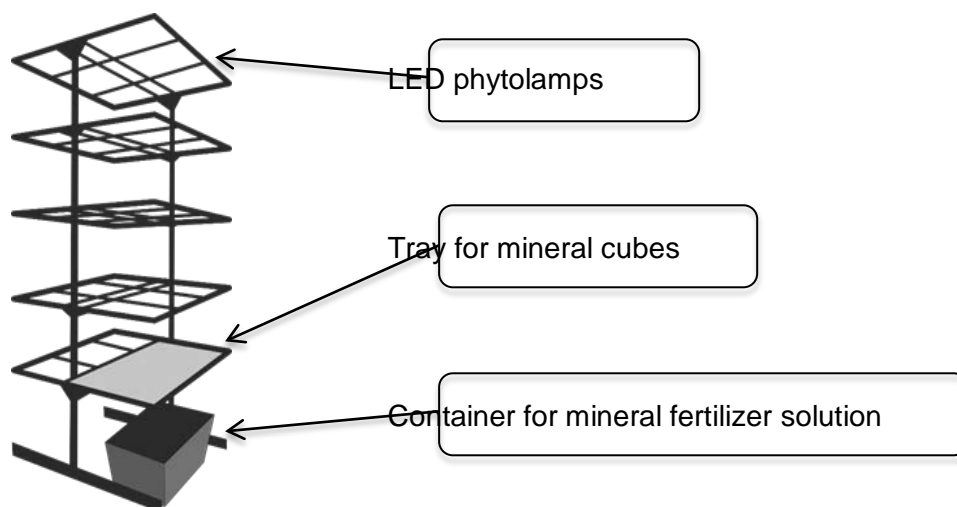
Figure 1. Structure description and its main elements of the local farm

The "Local Farm" project at the Surgut University was launched in October 2018. The first test batch of plants (14 species of lettuce and essential oil plants) was obtained in December 2018. Cut samples were transferred to a laboratory for chemical analysis. The samples were stored in a refrigerator for 2 days. For the formation of a chemical monitoring system, a team consisting of 5 undergraduate 1-st year students of Chemistry, 2 postgraduates, 2 technicians and a lecturer of chemistry department was formed.

At first, the professor (leader) gave students the task to study the literature on chemical analysis of plants, and technicians and graduates (curators) - to evaluate the material and technical resources of the Chemistry Department to carry out the experimental work. To start the monitoring system, three methods were chosen for a dry matter determination by a gravimetric method, nitrates by ionometry and elemental composition by an X-ray fluorescence analysis. Standard methods were used: GOST 26671-2014 "Products of processing of fruits and vegetables, canned meat and meat and vegetable preserves. Sample preparation for laboratory tests", GOST 29270-95 "Products of processing of fruits and vegetables. Methods of nitrate determination" and GOST 28561-90 "Products of processing of fruits and vegetables. Methods of dry matter or moisture determination". The students carried out experimental studies by a team under the guidance and supervision of curators who also taught them how to work with the used equipment: drying ovens, muffle furnace, ionomers with nitrate-selective electrodes, energy dispersive X-ray fluorescence analyzer. The obtained results for normalized indicators (nitrates and heavy metals) were compared with the permissible levels of nitrates for fresh lettuce grown in greenhouses from October 1 to March 31 (SanPiN 2.3.2.1078-01 "Hygienic requirements for safety and nutritional value of food products", section 1.6. Fruits and vegetables) - 4500 mg/kg, and maximum permissible concentrations (MPC) of heavy metals in plants (Baker, 1981).

Determination of dry matter was carried out in three samples of lettuce cultures by the thermogravimetric method. Samples were ground by grinding in a mortar. Nitrates were extracted with a potassium aluminum sulfate alum solution. The subsequent determination of nitrate concentration was performed using an ion-selective nitrate electrode by the calibration curve method (Table 1). Exceeding the permissible nitrate content in the studied varieties of lettuce can be caused both by the individual characteristics of plants (the ability of plants to accumulate nitrates largely depends on their type and variety), and by low light and humidity in the laboratory. With a decrease in light and humidity, the nitrate concentration in different cultures may increase by 2-10 times (Andryushchenko, 1983).

Table 1. Results of determination of dry matter and nitrates in lettuce cultures samples

№	Sample	Dry substances,%	Nitrates, mg / kg
1	L3	4,5	5204
2	L5	3,4	6371
3	L6	4,2	5643

Elemental analysis was carried out after dry ashing of 14 samples of cultures in a muffle furnace at 500°C for 4 h. The ash was pressed into tablets weighing 2,5-2,7 g (20 mm diameter) with boric acid as a carrier using a laboratory hydraulic press. X-ray fluorescence intensity measurements were made under vacuum on energy-dispersive X-ray fluorescence spectrometer EDX-8000 (Shimadzu). Content of elements in the samples was calculated using PCEDX-Pro software and fundamental parameters method (Table 2).

Table 2. The results of elemental analysis of lettuce crops (L) and aromatic plants samples: basil (B), parsley (P), dill (D), arugula (A)

Ele-ment	Samples										MPC, mg/kg
	L1	L3	L4	L5	L6	E8	B11	P12	A13	D14	
	Content, %										
K	81,11	79,58	74,46	77,10	75,34	76,90	73,38	81,11	56,80	80,21	-
Ca	8,71	10,53	14,15	10,80	13,51	11,68	16,01	7,82	20,90	10,50	-
P	5,13	4,50	5,16	5,89	4,99	5,83	5,78	5,91	4,47	4,95	-
Mg	1,82	2,08	2,24	2,68	2,46	1,47	1,94	1,97	3,96	1,35	-
S	1,74	1,84	2,08	2,01	2,44	2,42	1,71	1,73	12,80	1,63	-
Cl	0,58	0,61	0,97	0,69	0,42	0,64	0,45	0,94	0,41	0,62	-
Sr	0,13	0,16	0,20	0,15	0,19	0,17	0,24	0,10	0,32	0,14	-
Si	0,37	0,24	0,30	0,26	0,25	0,55	0,22	0,08	-	0,19	-
Mn	0,16	0,15	0,18	0,21	0,16	0,13	0,09	0,07	0,18	0,20	0,3
Fe	0,14	0,19	0,15	0,11	0,13	0,12	0,07	0,17	0,08	0,10	-
Zn	0,04	0,07	0,04	0,04	0,05	0,03	0,05	0,03	0,03	0,04	-
Cu	0,03	0,03	0,03	0,03	0,03	0,03	0,04	0,03	0,03	0,03	5,0
Rb	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,03	0,02	0,02	-
Br	0,008	0,004	0,007	0,003	0,005	0,004	0,005	0,005	0,003	0,006	-
Ag	0,007	-	-	-	-	-	-	-	-	-	-

Plants are an intermediate link through which elements pass from soil, air, water to animal and human organisms. Both macro- and microelements were found in the studied plant samples (Table 2). The normalized superecotoxicants include heavy metals, which are distinguished by hazard class (Baker, 1981): lead – 1 class; chromium, molybdenum, copper – 2 class;

manganese – 3 class. Only manganese and copper were found in the studied samples. Therefore, plants in greenhouses do not accumulate many heavy metals and are safer compared to those grown in the open (unprotected) soil that is subject to man-made pollution.

PROJECT ACTIVITY

The tasks assigned to students in the project by the teacher and curators can be divided into five groups: a review on chemical analysis of plants, sample preparation (grinding, extraction, ashing, etc.), measurements, processing results and report, presentation and project defense at Chemistry department (Table 3). Students distributed the work in the project on their own, adhering to the principles of ethics, honesty, justice, trust and loyalty. Each experimental task in three determinations (dry matter, nitrates and elemental composition) was performed by 1-2 students. In addition, students who did a review on selected methods were engaged in processing the results, preparing a report and part of the presentation. Consequently, each of the five students in their work performed all kinds of project tasks.

Table 3. Task distribution in the project

Student	Tasks				
	Review	Sample preparation	Measurements	Processing results and report	Presentation
1. Determination of dry matter					
Student 1	+			+	+
Student 2		+			
Student 3		+			
Student 4			+		
Student 5			+		
2. Determination of nitrates					
Student 1			+		
Student 2	+		+	+	+
Student 3	+			+	+
Student 4		+			
Student 5		+			
3. Elemental analysis					
Student 1		+			
Student 2		+			
Student 3			+		
Student 4	+		+	+	+
Student 5	+			+	+

At the end of the second year, students defend the project at the Chemistry Department. The project results can be presented by one or several team members, all students of the group take part in the discussion, and the committee of professors of the department evaluates the students. According to the defense results and the submitted report, students receive a credit for the subject "Introduction to project activities".

The result of the project activities of first-year Chemistry Program students, integrated into the interdisciplinary project of Surgut State University "The Local Farm", was the creation of chemical monitoring system of the state and quality of plants grown in protected (closed) soil.

Such monitoring system allows to optimize the technology of growing various crops in the laboratory (at the stages of project implementation), and can also be transformed into the conditions of crop production.

All students in the Local Farm project had got credit for "Introduction to project activities" subject. The student feedbacks were positive. They enjoyed working in a team and participating in a real interdisciplinary project. In addition to professional skills in chemical analysis, they received skills in teamwork and interpersonal communication, as well as presenting the results of the project.

In the second year a team of students continues to work in the project at the discipline "Project Activity". The main task of the second stage is to confirm advanced hypotheses (the study of the physicochemical properties of substances and materials, optimization of technologies) and the testing of created products and systems in real conditions. At this stage, students not only get new knowledge about research methods, but also they get experience in analytic equipment and processing of analysis results. In addition, the approbation of products and systems can take place in the enterprises of industrial partners of the university. Therefore, the project products and systems can be estimated by the industrial partners. So, in the "The Local Farm" project in the second year, students continue to expand the created chemical monitoring system with new methods of chemical analysis of plants, test it in real conditions with new objects, optimize the technology of growing crop products, form a cloud monitoring data system.

In accordance with the list of planned learning outcomes of graduates (CDIO Syllabus) in engineering and technology educational programs (Crawley, 2013), we conducted a comparative analysis and coordination of the requirements contained therein with the competencies of bachelors on Chemistry, set out in the new standards of FGOS 3^{++} (Russia) and implemented in the disciplines "Introduction to project activities" and "Project activities" (Fig. 2). It was shown that the requirements for learning outcomes are in good agreement with the competences in the categories of general professional skills (OPK-1 and OPK-2), intercultural interaction (UK-5), teamwork and leadership (UK-3), communication (UK-4), project development and implementation (UK-2). This demonstrates the applicability of CDIO standards to the implementation of Bachelor's programs on Chemistry.

Learning outcomes:

1. Experimentation, Investigation and Knowledge Discovery

2. Ethics, Equity and Other Responsibilities

3. Teamwork

4. Communications

5. DESIGNING (The Design Process, The Design Process Phasing and Approaches, Utilization of Knowledge in Design, Multidisciplinary Design, Design for Sustainability, Safety, Aesthetics, Operability and other Objectives)

6. IMPLEMENTING (Designing a Sustainable Implementation Process, Hardware Manufacturing Process, Software Implementing Process, Verification, Validation, and Certification, Implementation Management)

Competences (FGOS 3 ++):

1. OPK-1. Able to analyze and interpret the results of chemical experiments, observations and measurements

2. UK-5. Able to accept a variety of cross-cultural society in the socio-historical, ethical and philosophical context

3. UK-3. Able to carry out social interaction and realize own role in the team

4. UK-4. Able to carry out business communication in oral and written forms in the state language of the Russian Federation and in the foreign language (s)

5. UK-2. Able to determine the range of tasks within the framework of the goal and choose the best ways to solve them, based on the existing legal norms, available resources and restrictions

6. OPK-2. Able to conduct a chemical experiment in compliance with safety standards, including the synthesis, analysis, study of the structure and properties of substances and materials, the study of processes involving them

Introduction to project activities

(1-2 semester)
and

Project Activity

(3-4 semester)

Figure 2. Comparative analysis of learning outcomes (CDIO Syllabus) and competencies (FGOS 3++) implemented in the disciplines "Introduction to project activities" and "Project activity" of Bachelor's Program on Chemistry

CONCLUSION

Thus, in accordance with the standard 5: a 1-st and a 2-nd year student of the Chemistry program participates in at least two educational and practical disciplines in designing and creating products, one of which performs in the first course at an elementary level, and the second one at an advanced level. Along with professional competencies, students develop their personal and interpersonal competencies (communication, flexibility, ability to work in a team), as well as increase the level of personal motivation for engineering professions in chemistry.

During the project activity, not only do students receive new knowledge about research methods but also they get experience in analytic equipment and processing results of analysis. In addition, the approbation of products and systems can take place in the enterprises of industrial partners of the university. Therefore, the project products and systems can be estimated by industrial partners.

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DEVELOPING LABORATORY PROJECTS FOR A JOINT CHINESE/NZ MECHANICAL ENGINEERING PROGRAMME

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ABSTRACT

In engineering education, the underlying theory is developed in classroom lessons and its application in engineering is usually reinforced with laboratory experiments. Practical laboratory experiments that are performed in small groups or teams are common practice in most engineering programmes at a tertiary level around the world. In the Chinese education system, however, students often have little exposure to team-based assessments, and practical components are more observational that participatory. This paper reviews two project-based laboratory experiments that were developed for groups of 45 and 80 mechanical engineering students respectively in a Chinese University, as part of a collaborative degree program with Otago Polytechnic New Zealand. The first laboratory was part of strengths of materials course and was designed to reinforce understanding of strain gauges, which are passive transducers that convert a mechanical displacement due to applied force into a change of resistance. The second laboratory was developed for the thermodynamics and heat transfer course, where the students were required to conceive, design, construct and test a solar hot water system. Through developing more project-based and team-centred laboratories for larger classes, we discovered potential to integrate technical knowledge and logical problem-solving techniques with important aspects of group culture and language learning. We believe project-based and team-centred laboratory experiments run for larger classes in contexts like China can function as important steps towards more open-ended project-based and learner-centred learning. Further, building in language learning opportunities (LLOs) help to initiate students into the target language medium. Through the merging of a traditional laboratory with a CDIO-based project cycle and focus on language learning, we believe we can prepare students for successful learning in a project-based environment on a joint degree programme.

KEYWORDS

Project-Based Laboratories, Strain Gauges, Solar Water Heating, Project Groups, Language Learning Opportunities, Standards 2, 4, 5, 6, 7, 8.

INTRODUCTION

Outcome- or project-based learning (PBL) is a method of teaching that emphasises what learners can do once they are trained (Marwan Shamel, 2010). This is considered an essential feature of the CDIO initiative, where it provides the platform to implant essential graduate

attributes and skills into an engineering program. Armstrong (2008) describes those attributes and skills which the new graduate must acquire at the completion of the engineering program. Along with a solid foundation in engineering principles, they are believed to be vital tools needed to handle the dynamism of the current world.

In our previous papers, we discussed the development and the implementation of a project-based learning (PBL) model for non-native English learners following the CDIO initiative (Weerakoon, Dunbar, & Findlay, 2014), (Weerakoon & Dunbar, 2017) (Weerakoon & Dunbar, 2018). We described a programme developed and taught in a language immersion situation in New Zealand which provided students with a better understanding of applying engineering knowledge into working examples, along with developing both engineering and English language and communication skills relevant to the real world. The above studies demonstrated that a motivation factor for students engaging in PBL is that it brings the learners' engineering knowledge closer to real life context and technology, and encourages them to be independent lifelong learners, critical thinkers, and good communicators.

We believed that many of the lessons and experience from that process should also be applicable when delivering courses in a non-immersion (English as a Foreign Language (EFL)) situation at university in China. We were conscious, however, of cultural and logistical challenges that were likely to arise when adapting this model to a new environment. This paper, therefore, outlines initial steps towards implementing PBL engineering laboratories that focus on developing integrated engineering, communication and language attributes in a Chinese university context.

Essentials of Engineering Laboratories in Engineering Education

Engineering is primarily devoted to harnessing and fine tuning the three essential resources - energy, materials and information - available for the making of all technology (Feisel, 2005). Feisel (2005) distinguished three basic types of engineering laboratories, including educational instructional laboratories which are often designed for undergraduate students and involve knowledge that is already known to practise engineers. A common goal of instructional laboratories in engineering programs is to relate fundamental theory to practice and to connect the real world into what would otherwise be theoretical education. Instructional laboratories are also at times considered to be a motivational factor to continue in the study of engineering since laboratories in many engineering programs are the only means by which students learn by doing things.

Engineering laboratories generally follow the introduction of the fundamental theory in classroom lessons and focus on reinforcing their application in engineering. However, there often seems to be a disconnect between those learning practices and full understanding of how this transformation process is achieved in the laboratories. To bridge this gap, the current study designed laboratories for two engineering courses - Thermodynamics and Heat Transfer and Strength of Materials - based on the CDIO model of conceiving, designing, and constructing the experiments prior to testing the laboratories to acquire the known knowledge.

One of the characteristics of many Chinese Engineering institutes is large class numbers, and undergraduate programs often lack facilities for student-centred laboratory experiences. In these institutes, engineering programs are mainly focussed on strengthening work on fundamental theory, and as a consequence, many undergraduate students have limited opportunities to develop skills on how theory connects to practical applications, lateral thinking

and learning by doing. Laboratories are often 'observation'-based rather than experiential learning. We believe this also contributes to the disconnect between theory and practice that these students experience.

English Language Medium and Cultural Issues

The case study presented here is based on a joint programme between Otago Polytechnic and a Chinese university. In this collaborative programme, students study the first three years in China before coming to Otago Polytechnic for a final year. The medium of instruction in China for the engineering courses is English, although local teaching assistants (TAs) are available to help with communication issues. Students also have separate English language classes provided by the Chinese institute based on the Chinese College English curriculum. This curriculum, however, does not provide specific engineering-related support. We believe, therefore, that as far as possible engineering classes and especially laboratories need to provide opportunities for students to build confidence in using the English language for engineering communication purposes.

Observation of engineering classes on the joint programme delivered in China has shown that many, perhaps most, students struggle to understand large portions of lectures delivered in English. TAs, therefore, play an important role in translating engineering content. Students generally have more developed reading and writing skills than oral skills, but for engineers to practice, they need to develop good oral communication skills. Large classes limit the amount of language production that can occur in these classes, but team-based laboratories provide more opportunity for embedding communication and language learning opportunities.

Another aspect we considered prior to implementation was the impact that culture would have on the effectiveness of team-based and student-centred laboratories. We knew that Chinese students had seldom been exposed to group-based projects in an educational learning environment, but Chinese culture has long been identified as 'collectivist' (Hofstede, 2001). Team dynamics differ somewhat from those that we were familiar with in New Zealand (and from our experience with Japanese students on our previous projects), so we were uncertain what to expect. In particular, the large class sizes meant that we needed to work with a number of larger groups in limited space, and we were keen to observe the effectiveness of student-centred and project-based laboratories under these conditions.

DEVELOPMENT OF PROJECT-BASED LABORATORIES

For this pilot study designed to test the effectiveness of CDIO-based laboratories in the Chinese context, two laboratories were designed to meet part of the learning outcomes of the strength of materials course and a thermodynamics and heat transfer course as shown in Tables 1 and 2 below. The thermodynamics and heat transfer course consists of 60% internal assessments including assignments and practical laboratories, and a 40% final exam. The strength of the material course consists of 50% internal assessments including assignments and practical laboratories and 50% final exam.

Table 1 Learning outcomes and assessments for Thermodynamics and heat transfer

Learning outcomes	Assessment type	Weighting
1. Describe methods of energy production and their environmental effects	Assignment and exam	28.3%
2. Explain and apply the first and second laws of thermodynamics	Laboratory and exam	43.3%
3. Discuss the properties and characteristics of thermodynamic systems	Assignment and exam	28.3%

Table 2 learning outcomes and assessments for Strength of Materials

Learning outcomes	Assessment type	Weighting
1. Identify modes of failure in components	Assignment and laboratory	25%
2. Determine safe working stresses for components	Laboratory	10%
3. Analyse components in terms of principles of strength of materials	Exam and laboratory	65%

The strength of materials laboratory was designed for a class of 45 students from the 2016 intake and was delivered in 2017; the thermodynamics and heat transfer laboratory was delivered in 2018 to both the 2017 intake (80 students) and the 2016 intake (45 students). The thermodynamics and heat transfer laboratories were delivered separately to the two intakes during the 2018 winter months in the northern hemisphere.

Because the project-based learning laboratories were aimed at the course laboratories component which makes up only 20% or less of the overall course mark, the students completed the design and testing phases using out-of-class time and were provided with approximately six (06) hours of class time to complete their construction based on the design.

Task Design: The strength of Materials Laboratory

The development of the strength of materials laboratory was aimed at reinforcing the fundamental theory related to strain gauges. Strain gauges are passive transducers that convert a mechanical displacement due to applied force into a change of resistance. This is a fundamental theory addressed in the study of strength of materials. Generally, the concept of this conversion process is developed in classroom lessons, and its application in engineering is reinforced with laboratory experiments including bending, deflection and vibration. However, we have found there to be a disconnect between those learning practices and a full understanding of how this conversion process is achieved.

To bridge this gap, the laboratory was designed to allow students to conceive, design, construct and test a cantilever beam to measure mechanical displacement due to an applied load, and thus determine both the modulus of elasticity of the cantilever material and the deflection of the beam under various loads.

This is a well-defined design problem and designing the laboratory consisted of providing clear English language instructions relating to the strain gauge installation method at the appropriate location of the cantilever, soldering of the strain gauge terminals, and construction of the

quarter bridge circuit to measure the change in resistance due to an applied force. The results could then be used to establish the modulus of elasticity of the materials and predict the deflection of the cantilever.

In this laboratory session, students were divided into six teams. The teams were expected to perform all laboratory outcomes including extracting experimental data for scientific calculation independent of other teams. Materials provided for cantilever testing were steel, brass or aluminium, a two wire 120-ohm strain gauge, terminal cables and metal surface preparation materials for strain gauge installation, and adhesives. A dial tester measured the deflection of the cantilever.

Task Design: Thermodynamics and Heat Transfer Laboratory

The development of this laboratory was aimed at harnessing the solar radiation energy and effective transfer of this energy to generate thermal heat using water as the medium. This was an open-ended design problem where students were tasked with conceiving, designing, constructing and testing to determine the effectiveness of the solar hot water heating system. The aim of the laboratory was to produce 10 litres of warm water raised to a minimum of 45 degrees during a typical winter period in the northern hemisphere (at roughly 40°N) and to calculate the heat transfer effectiveness. Students were then expected to connect their learning to the theory learnt in class. Therefore, the laboratory instructions were primarily focussed on meeting the assessment outcome rather than the construction process or experimental procedure. The students were provided with the freedom to decide their own test procedure.
All teams were provided with the same resources to construct their hot water system:

- 12 mm internal diameter tube between 35m to 40m in length
- Materials to design the frame to accommodate 32m of tube length
- Transparent sheet to create a greenhouse effect
- Insulation sheet to rest the tube on top
- Various pipe fittings to circulate and collect water
- Thermocouple to measure water intake and outlet temperatures
- One radiometer to measure the incident solar radiation
- 500 ml measuring beaker

The team composition for the 2016 intake was the same as for the strength of materials laboratory. However, the 2017 intake had 80 students. The students were divided into 10 teams. Two teams were then joined together (to make five larger project groups) to conceive, design and construct the solar hot water panel. Because the two teams that made up each project group came from different classes, they conceived a common final design solution for the solar hot water panel outside classroom hours. Then, when construction commenced, the first team would hand over the construction responsibility to the second team at the end of each 90 minute laboratory session. The process continued until the whole panel was completed and ready for testing. Then the project groups were split into the original teams again and testing of the panel was carried out outdoors by each team separately. This model introduced added complexity with respect to interpersonal relations, negotiating a common goal, responsibilities and time management, and most importantly communication when the responsibility of handing over the construction was taking place, not only amongst individual team members, but also between teams in a group.

Since this was an open-ended problem, the students were given the flexibility to use waste or surplus materials which they could salvage besides the laboratory resources provided in order to fine tune the panel design to its solar energy harnessing effectiveness. The instructions for the laboratory were worded to clearly aim at meeting the laboratory outcomes using the resources provided rather than focusing on the construction process or the experimental procedure.

Construction Process: Strength of Materials Laboratory.

Figure 1a shows the steps associated with the installation of the strain gauge on the material surface. It consists of surface preparation - indicating the attachment location and cleaning of residue; application of adhesive tape and adhesive to attach the strain gauge; and holding until the strain gauge clasps the surface. The next step consisted of soldering the terminals, attaching the terminals to the strain gauge reader and subjecting the cantilever for a range of static loadings to measure the strain reading and deflection, as shown in Figure 1b.

a) Strain gauge Installation   b) Experiment setup
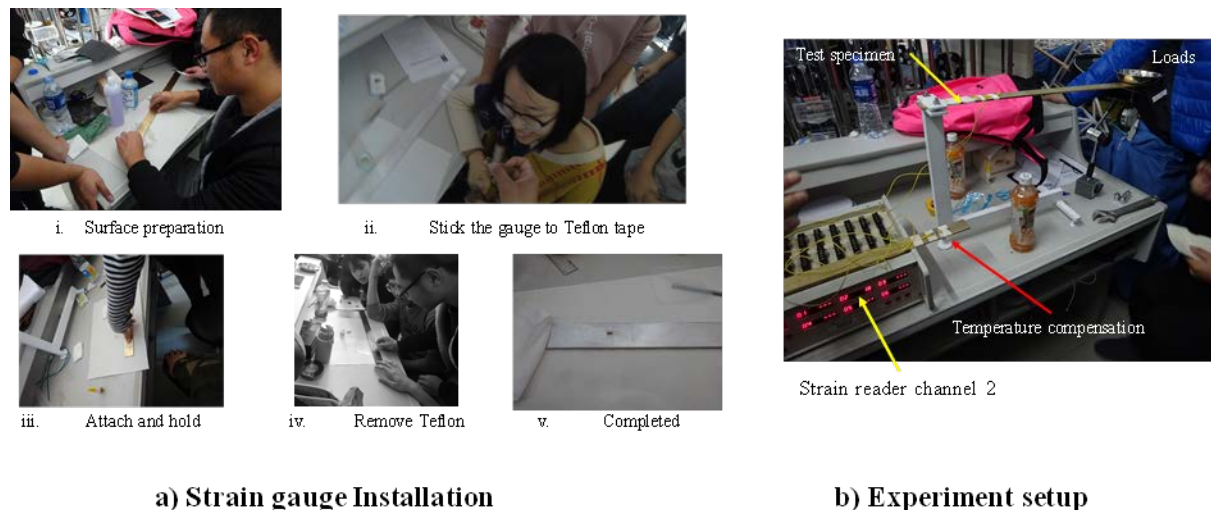
Figure 1 Strength of material laboratory

Construction Process: Solar Hot Water Heating System

Figure 2 shows the steps broken down to construct the solar hot water panel. The first step involved constructing the frame to house the water circulating tube, followed by insulating the wall of the housing. One project group was provided with a coloured tube with 12 mm internal diameter tubes while all other project groups were provided with transparent 12mm internal diameter tubes. All project groups from both intakes (2017 and 2018) formed the same shape for the configuration of the water tube inside the housing. However, some project groups decided to attach sheets of salvaged black garbage bags between the insulation and the water tube. Some other groups painted the top surface of the transparent tube with mat black as shown in Figure 2b. The tube was secured to the wall of the housing, so that the tube would not collapse under the weight of the water during testing. The transparent sheet was laid over the housing to create the greenhouse effect. Finally, the pipe fittings were connected to circulate the water through the water mains.
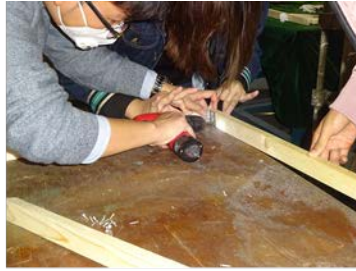
i.   Cutting to length   ii.   Connecting the angles   iii.   Completed housing

iv.   Handing over   v.   Installing tube   vi.   Installing tube
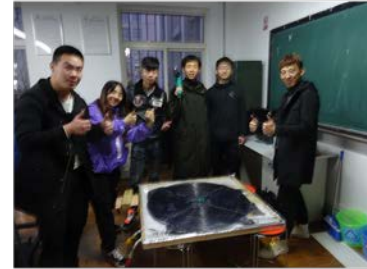
Figure 2 constructing the solar hot water system

RESULTS

Strength of Materials Laboratory

This laboratory consisted of six teams. Two teams constructed the cantilever using the same material so that their results could be compared with each other and their proximity to theory measured. Five out of six teams met all the laboratory assessment outcomes. One team completed the construction, but their strain gauge did not work due to imperfection. This team used aluminium for the cantilever

As shown in Figure 3, both teams using the brass material estimated values of modulus of elasticity that were comparable with theory. The teams using steel and the one team using aluminium for the cantilever material estimated values of modulus of elasticity that were double that predicted by theory. A common experimental error observed with all three cantilevers was students not removing the masking tape clasped over the strain gauge prior to testing. This was only identified by the students when the calculations were completed. The brass teams exposed the strain gauge prior to testing. They were then able to explain to other teams the reason for their results being closer to theoretical calculations.
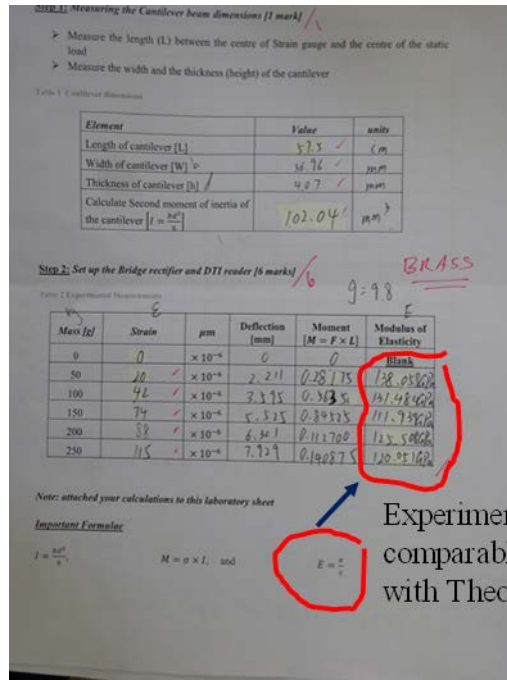
Figure 3 Experimental modulus of elasticity estimation for brass

Thermodynamics and Heat Transfer Laboratory

All teams from both intakes in 2016 and 2017 completed all of the requirements to meet the laboratory outcomes.   However, the design arrangement for the tube configuration was the same for all teams or project groups. No team attempted to alter the tube configuration inside the housing. Figure 4 shows the testing of the panels outdoors, carried out by the 2017 intake. The students who understood the fundamental theory in heat transfer coped well with their design output by carrying out simple modifications to resources provided. As shown in Figure 4, their designs achieved over 60 degrees with outlet water temperature. The inlet temperature of water from the mains was about 18 degrees. Those panels achieved between 30 to 35 percentage efficiency in converting the total incident radiation to thermal heat. The panels that performed best were the ones that had a black sheet between the tube and the insulation, while the panels with transparent tube painted mat black performed better than those panels with wholly transparent tubes.

| i. Testing outdoor | ii. Collecting hot water | iii. Measurements |

iv. Outlet water temperature
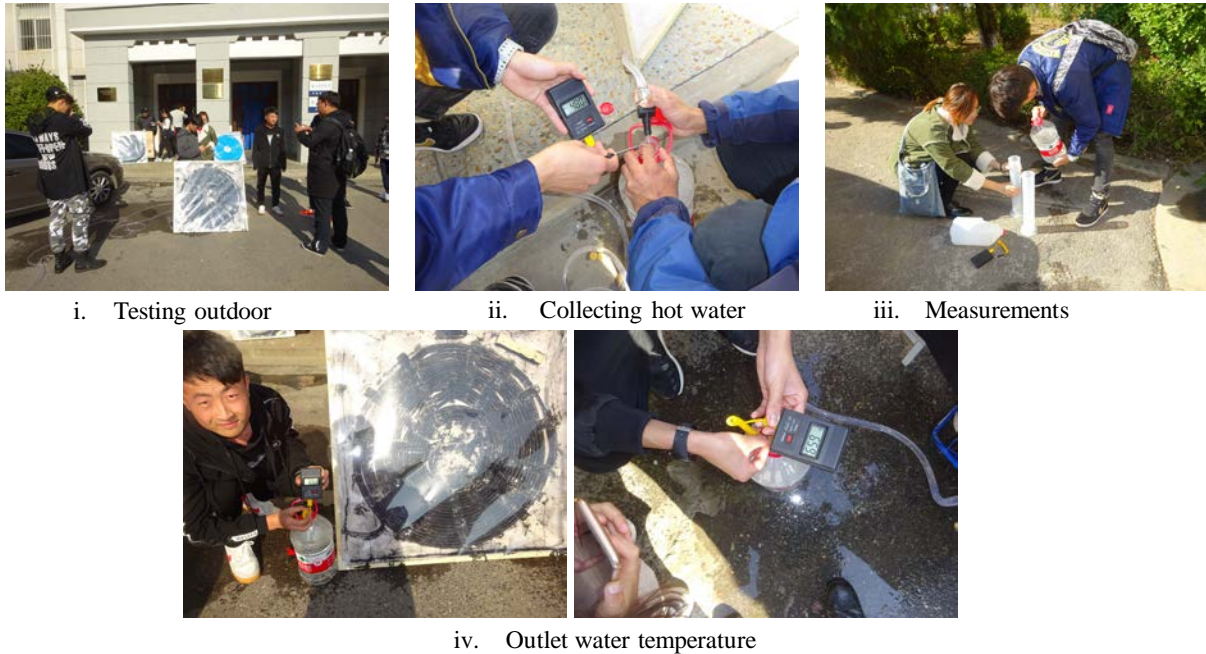
Figure 4 Testing the hot water solar panels

DISCUSSION

Reflecting on mistakes

As we identified in a previous paper (Weerakoon & Dunbar 2017), mistakes in practical procedures often lead to learning for both students and teaching staff. There are many errors associated with strain gauge readings, including heat from the strain gauge, large changes in the temperature in both the test specimen and the strain gauge, faulty adhesive bond between the strain gauge and the test specimen, errors due to transverse sensitivity of the gauge, the circuitry between the gauge and the instrument and instrument itself. However, at molecular level strain is related to relative spacing between the atoms. Therefore, strain gauge has a finite stiffness. In this case, the students used masking tape to protect and reinforce the strain gauge during soldering. The teams using the brass cantilevers removed the masking tape after soldering and prior to testing the cantilever, thereby removing the additional stiffness from the strain gauge. However, other teams failed to remove the masking tape, providing the additional stiffness to the strain gauge. Consequently, with all other errors being within operational range for all teams, the additional stiffness restrained strain. Since the modulus of elasticity is the ratio of stress over strain, those teams obtained a relatively larger value for modulus of elasticity. However, had this being highlighted during the test, students may not have fully understood the role of their large experimental error, so a comparison between teams and team reflection added to the learning from this laboratory.

Understanding Counterintuitive Concepts

On a clear sky day, the direct incident solar radiations range between 700 to 900 W/m² around part of China where the case study was located. A basic heat transfer calculation will demonstrate the degree of potential solar energy that could be harnessed by the water inside

the solar panels. However, prior to testing the solar hot water heating systems outdoors, the students had already judged that the temperature of the water inside the solar panel would not be heated. Although they understood the theoretical calculations, they appeared unable to apply this reasoning to establish the heat transfer mechanisms, and potential ability to harness this incident solar radiation. Before the test, when this was demonstrated in the classroom, this was contrary to their perception. However, after the test, their understanding of the heat transfer theory grew so that they could see the application of theory in a real context. This connection between theory and practical experiential observations is a key to deepening understanding. In feedback sessions, students were clear that the laboratories had impressed on them an understanding much deeper than that achieved from classroom calculations.

Team Dynamics and Communication

Generally, we found that teams worked well in a Chinese cultural context. One reason for the successful gelling of the teams may be that we implemented these laboratories with second year students who were already familiar with each other and had long developed and established relationships between the individual members. In collectivist cultures, this team 'bonding' can take longer than in individualist cultures, because team unity is based on relationships more than goals (Davis, 2001)
.
One innovation that was introduced for the larger number of students in the 2017 intake was the implementation of project groups, in which two teams from separate classes were combined to work on a single project. This was necessitated by the large numbers and lack of laboratory resources but proved to be particularly insightful in that we were able to identify opportunities to build in communicative attributes through the exchange of information at handover time.   Students were observed to struggle with this handover, and subsequent mistakes were identified due to miscommunication.   The importance of describing the development of a project and giving instructions and accurate steps needed to be reinforced. One way we believe may be effective in future is to show students how to develop checklists that they could use to ensure that all relevant information has been transferred accurately.

Although students had not been exposed to a group or a team projects much prior to their introduction for these courses, the feedback from evaluative interviews and focus group discussions with the students was overwhelmingly positive. Students felt motivated to be *actively involved* in the laboratories and expressed the desire to have more laboratories in future. They felt that they benefited from the opportunity to communicate in realistic team-based scenarios. They enjoyed the opportunity to try ideas in the design and construction phases and felt that they could understand the fundamental ideas more deeply after completing the projects.

Language learning opportunities

Although language learning outcomes are not measured directly in the engineering courses of this programme, we have observed that, without the increased opportunity to use language in a context-rich environment, language improvement is likely to be severely limited. During observations of the laboratories, and from subsequent feedback, it has become clear that in an EFL context, in particular, students need to be offered and guided towards opportunities to use the second language in context. We refer to these language learning opportunities (LLOs). In these first laboratories, we focused on the laboratory report writing and ensuring that students were introduced to the genre and language required for writing a simple laboratory

report, which was a natural part of the laboratory process and a required part of the assessment. From our experience of these two laboratories, however, we believe there is ample opportunity to build in further language production and reception opportunities that will enhance language skills.

Although students have separate English language classes, embedding LLOs into engineering laboratories has several benefits. It provides a chance for oral production skills that tend to be overlooked in large lecture-based classrooms; students have a range of props and techniques (drawings or tools for example) that can be used to enhance communication and help put language into a real communicative context. Further, communicating with each other in small groups can help reduce the anxiety that is common in speaking in front of larger groups.

One major area for improvement identified for future is a need to develop mechanisms for monitoring and developing the take-up and effectiveness of LLOs. It is clear from our observations that some naturally occurring LLOs (for example, intra-group communication during design and construction) were taken up more readily than others. These LLOs must be identified and evaluated so that we can develop a working set so that student attention can be drawn to these opportunities, and so that they can be adapted and reused in future laboratories and practical classrooms, and their effectiveness in terms of overall communicative competence of students measured.

CONCLUSION

Previously we have written extensively about integrating project-based engineering and language learning in a New Zealand (English language immersion) context. In this paper, we have described initial steps to expand this process to an EFL context on a joint engineering programme in China. Operating overseas, and in an EFL environment created a new set of challenges, partly cultural, and partly logistical. However, we believe this paper demonstrates that the basic theory and practices that we developed for onshore delivery can be adapted to an offshore EFL context. In this context, careful consideration needs to be given to cultural factors including team development and the language of instruction. Feedback suggests that these project-based laboratories lead to both deeper and more motivated learning and that they also present a number of language learning opportunities. Further investigation and evaluation of these learning opportunities and learning outcomes will take place as students progress through the joint programme and arrive in a PBL environment in New Zealand, but we are confident that the introduction of these project-based and student-centred laboratories will help prepare students for this process of adaptation.

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SYSTEMS-APPROACH DESIGN OF AN UNDERGRADUATE STEM PROGRAMS ACADEMIC METHODOLOGY

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ABSTRACT

The goal of education is to empower students with knowledge and skills required to enter their professional lives and bring added value to society, through successfully tackling complex socio-technical problems. Yet, many programs have been designed without duly considering how that end goal is to be achieved. In addition to the students, other stakeholders need to be factored in.

This paper describes how effective undergraduate programs in the science, technology, engineering and mathematics domains were designed following the systems approach. The identification of the learning objectives led, through consideration of all stakeholders and their requirements, to the identification and evaluation of alternative academic methodologies. The selected one was project-based-learning coupled with continuous assessment. Although project-based learning is well known, alone it does not render the required results. Feedback is a pivotal element in any educational process and continuous assessment proved to be the true learning enabler when applied in project-based learning environments. Projects are executed in an incremental manner, going from course-specific projects, through trans-disciplinary projects that span across several courses, to the final capstone or graduation project. Connection with industry is always close and is articulated in multiple cooperation strategies; the main ones and the lessons learned are summarized. Being validation essential in the systems approach, this paper shows how validation was recurrently performed and how the collected feedback was used to fine-tune and improve the methodology.

The main results achieved in over six years are presented. Moreover, the road ahead is presented with the sketch of a third element that will further reinforce the effectiveness of the methodology. Students' self-assessments bring gradually implemented, to complement the methodology. It helps students develop the maturity required to have proper awareness of the quality of the work they perform, so as not to have to rely entirely on external evaluations.

KEYWORDS

Systems, approach, academic, methodology, standards: 7, 8, 11, 12.

THE SYSTEMS APPROACH

An approach is a way of going about tackling a problem. Systems have been designed and developed by human beings for centuries. In 1637 the French mathematician and philosopher René Descartes published his famous Discourse on the Method of Rightly Conducting the

Reason and Seeking Truth in the Sciences (Quintás-Alonso, 1999). One of the four precepts that Descartes formulated gave name to that specific way of conceptualizing systems, namely the reductionist approach. Specifically, that precept, which was one of the main tenets in the Discourse, was the idea of dividing and conquering. Problems that could not be solved due to their size and complexity were decomposed into parts, and each part further again into smaller parts if so needed, down to a level at which the parts could be solved. The integration of the solutions would then be the solution to the original problem. The approach was clever except for the fact that it neglected the interaction among the parts, which normally are as important as the parts themselves. The growing complexity of the systems that were required around the middle of the 20th century, as well as the awareness of the importance of the relationships among their parts or components, fostered a new paradigm in the conceptualization of systems. The need to deal with multi-faceted problems, to integrate multiple disciplines and to exercise a global view meant the advent of the discipline of systems engineering, also known as the systems approach (Blanchard & Blyler, 2016; Blanchard & Fabrycky, 1981; Sage, 1992). Figure 1 depicts the eight elements of the systems approach (Sols, 2014). The last decades have witnessed an unprecedented growth in the adoption of the systems approach across all industrial domains, as well as in academia, which is reflected by the exponential growth of programs on systems engineering worldwide, that has gone from one in the 50´s to over three hundred nowadays (INCOSE & SERC, 2017).
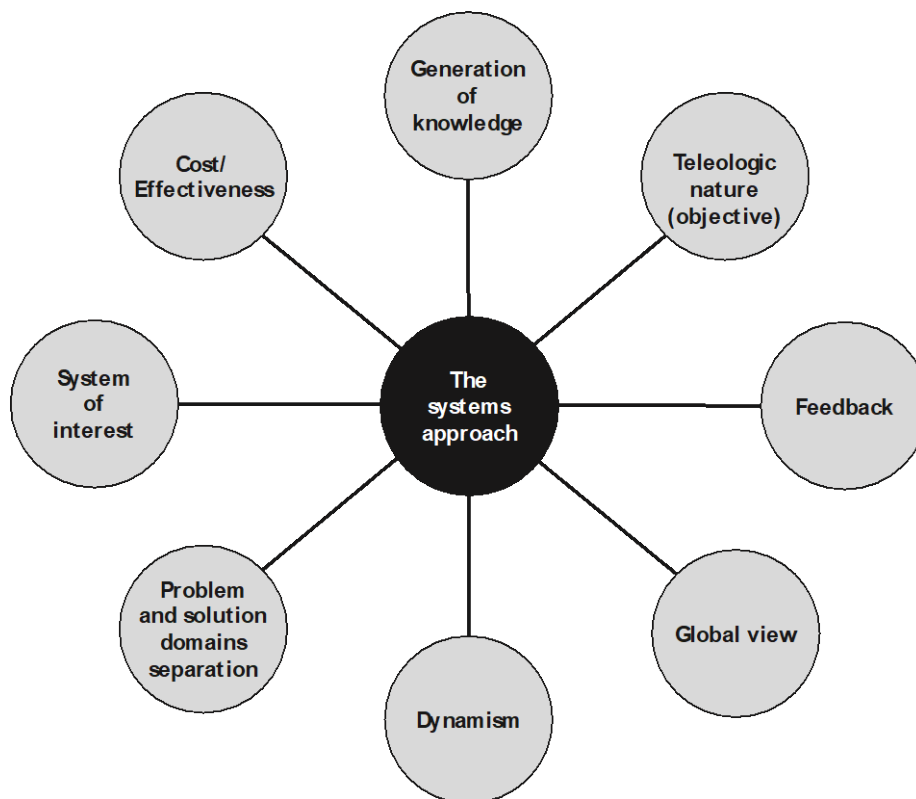
Figure 1. The elements of the systems approach

LITERATURE REVIEW

Pivotal to the success of any academic program is that the institution running it is a learning organization, capable of capitalizing on lessons learned and of sharing the knowledge, always

developed at individual's level. The systems approach was described as the fifth discipline, the one that characterizes learning organizations (Senge, 1990). After Senge's seminal book, other authors have expanded into how to build truly learning organizations (Edmondson, 2012; Garvin, 1993; Garvin, Edmondson, & Gino, 2008). Efforts to develop the academic methodology should build on recommendations and lessons learned. A significant number of sources proved valuable, particularly on the Conceive, Design, Implement & Operate (CDIO) initiative (Bankel et al., 2005; Berggren et al., 2003; Ceawley, Malmqvist, Lucas, & Brodeur, 2011). Furthermore, the fostering of continuous improvement and the value of assessment were considered (Davis & Aydeniz, 2007). After project-based learning was selected, several sources were checked for continuous development and improvement of the methodology (Boss, 2015; Ho & Brooke, 2017).

THE DESIGN OF AN ACADEMIC METHODOLOGY

In 2011 a decision was taken to improve the academic methodology, adopting the best practices in order to ensure effective achievement of the education goals. The drivers were the vision, mission and values of Universidad Europea, compiled in Table 1.

Table 1. Vision, mission and values of UEM

Vision	At Universidad Europea, we consider academic excellence to be one of our strategic pillars. Thus, our educational model has embraced the principles of the European Higher Education Area based on the individual's holistic learning. In this model, the professor is a mentor as well as an adviser who supports the student throughout their university life. The student, on the other hand, maps out their own educational journey, developing the knowledge, competencies, skills and values demanded by society at the moment.
Mission	To provide our students with comprehensive education, educating leaders and professionals who are prepared to respond to the needs of a global world, to contribute value in their professions and to social progress through an entrepreneurial spirit and social commitment. To generate and transfer knowledge through applied research, likewise contributing to progress and positioning ourselves at the cutting-edge of technical and intellectual development.
Values	**Collaborative**: We bear the seal of approval that sets up apart for our entrepreneurial spirit: we are resolute and audacious, placing the student at the forefront. We collaborate and work together to implement the best practices at our institution. **International**: As members of the Laureate Network we have a global vocation and scope while retaining strong local roots. We offer international resources to support and strengthen local education. The magnitude and influence of the Laureate Network enable us to provide our professionals and students with excellent opportunities. We are an inclusive, multicultural organization that values diversity and respects all cultural perspectives and characteristics. **Analytical**: We implement a rigorous self-assessment process to constantly increase our information and knowledge so as to improve our

	performance. This reflexive approach, based on data analysis, sets us apart from other institutions.
	Trustworthy: If we want to be "here for good" we must gain the trust of our students and their families, employers and the communities where we operate. All levels of our organization are subject to the highest demands; we work with integrity and assume full responsibility for our actions.
	Audacious: We are entrepreneurs; we strive to be audacious and are willing to take calculated risks while at the same time basing our decisions on rational, reflexive planning. We are quick to leverage opportunities and make positive changes in order to enrich our students' experience. We search for new ways to improve learning without borders and transform the traditional educational model. We have an innovative mentality and we provide members of the university community with the chance to challenge the status quo. We apply creative approaches to education and business. We never cease to explore new approaches, new technologies, new business models and new theories. We are leaders, not followers.
	Responsible: Assuming responsibility for our students' results is the cornerstone of our revolution in the field of education. We focus on students and employers to adapt our programs to their needs. We strive to maintain high rates of retention, graduation and employability so that our students joining the labour market generate a positive social impact.

The systems approach was applied, to begin with, by considering the ultimate goal of academic programs, as generically defined in the Vision and Mission, and as specifically described in the competencies to be achieved in each program, which are detailed in their corresponding Degree Reports. In addition to focusing on the goal and to identifying the customers (the students), all other stakeholders were acknowledged, together with explicit identification of how they could influence the quality of the programs, or be affected by them. Among the stakeholders, it is worth mentioning the following: companies and institutions, which are the desired employers of the students who graduate; ANECA and Fundación Madri+d, respectively the national and the regional agencies for quality accreditation and assessment; other Spanish universities offering the same academic programs; and entities providing institutional and programmatic quality seals. Feedback was understood as validation of the goodness of the selected approach, to be continuously carried out due to the dynamic nature of the academic environment. Several methodologies were considered (design concepts, in systems engineering terminology), and the selected one was project-based learning (PBL). PBL has been successfully applied and has been consistently advocated for by top institutions (Alan Leshner and Layne Scherer (Editors), 2018; Graham, 2018). Many authors have also documented the power and benefits of PBL (Larmer, Mergendoller, & Boss, 2015; Wurdinger, 2016).

The systemigram depicted in Figure 2 portrays the multiple cause-and-effect relationships that gravitate around the quality of academic programs. The result was the selection of PBL, to be coupled with two other key elements: continuous assessment (feedback being always instrumental in the systems approach) and student's self-evaluation, fostered in order to help students develop and mature as professionals. The three elements that integrate the methodology, that could be thought of as *enhanced project-based learning*, together with the Vision, Mission and Values, integrate the so-to-speak academic DNA, depicted in Figure 3.
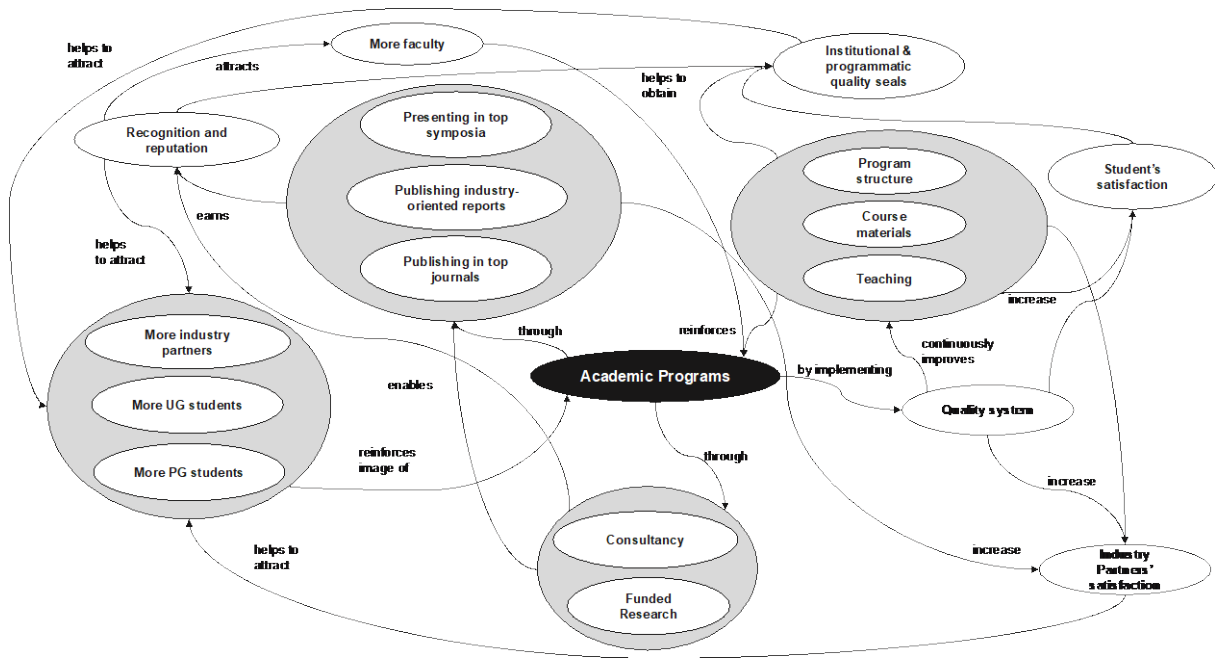
Figure 2. Systemigram that portrays cause-and-effect relationships
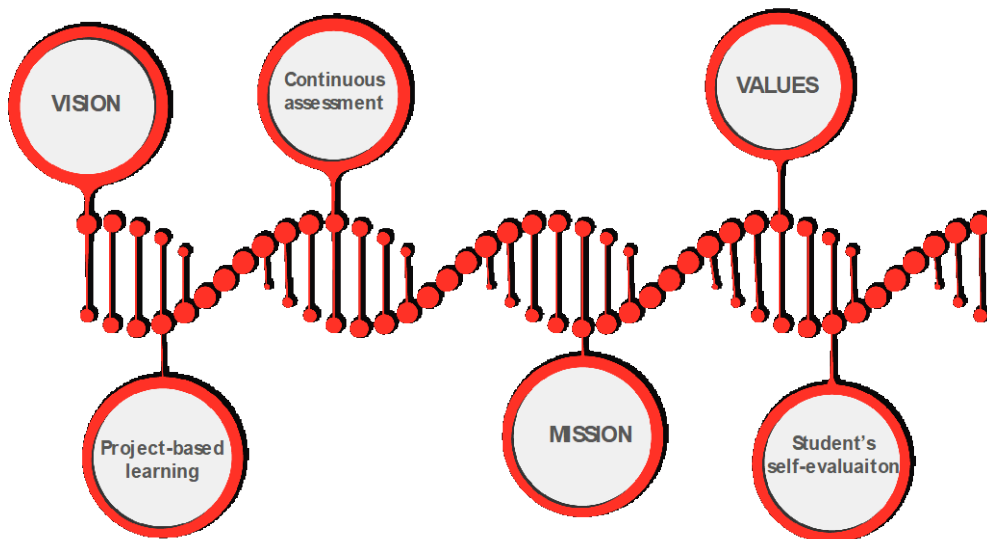
Figure 3. Drivers and elements of the academic methodology

The difference between enhanced PBL and conventional academic approaches is substantial, as can be seen in Figure 4. In enhanced PBL marking is still discrete, although much more diluted throughout the semester, and feedback is given continuously; that feedback is what really leverages learning, which is the ultimate goal of any academic program.
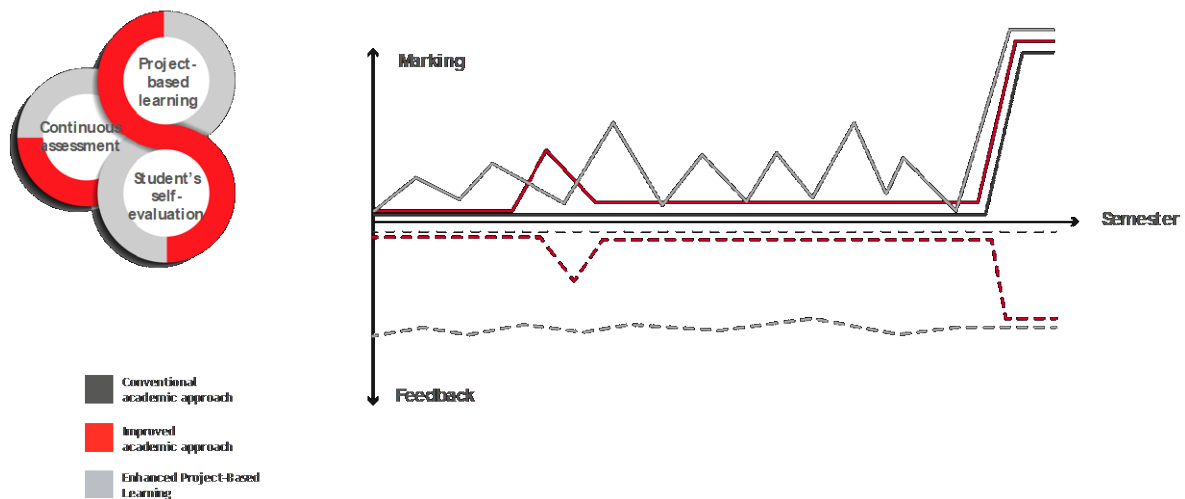
Figure 4. Enhanced project-based learning

Pivotal in the academic methodology is the so-called integration projects. All academic programs have learning objectives, and the necessary studies are divided into subjects, and correlations are made between them. Usually, there are 40 subjects in a single bachelor's degree and between 10 and 20 in a graduate degree. The underlying hypothesis, as important as it is often forgotten, is that students combine all of the knowledge they acquire in their different subjects. In the real world, there are no purely accounting, thermodynamics, algebra, strength of materials, marketing, or humanities problems, to name a few common subjects in different programs. Graduates are supposed to be well-educated professionals able to apply what they've learned and help solve complex problems. However, those problems have multiple facets: social, technical, economic, legal, ethical, etc. As a result, professionals must be able to employ all the necessary resources from what they've learned and created the appropriate synergies. Unfortunately, the majority of academic systems make teaching into a knowledge silo; students learn each subject but are not able to develop an overall view involving all of the things they've learned. Students pass and graduate, but don't fulfil the true objective of learning. The Graduation Project is insufficient to bring together and put into practice everything students learn. This is frequently brought to light when many graduates join the workforce and show their inability to apply that holistic vision to complex social and technical problems. In the project-based learning method, students work on several projects in different courses each academic year; this allows them to support the theoretical knowledge they've gained with practical activities. One can only consider to have understood, what one can apply successfully. But the method goes much further than that. In the integration projects, students work on a project in which they must simultaneously apply the bodies of knowledge from several subjects. For example, in the Industrial Systems Engineering Bachelor's Degree an extraordinary project involving two subjects is carried out: Theory of Machines and Mechanisms and Automatic Systems and Control. In Aerospace Engineering there is an

impressive project involving no less than four subjects: Fluid Mechanics II, Aerodynamics and Aeroelasticity, Graphic and Mechanical Design, and Management Skills.

A big picture vision is precisely one of the key elements of the systemic approach, the paradigm for analysis and complex problem solving. An academic method simply cannot be envisaged if it does not stimulate and support the big picture vision, where students really combine everything they have learned and are able to successfully put that knowledge to use. The experience shows that through those integration projects, the walls of the knowledge silos are torn down and students are able to really see the big picture. The effect is even more extraordinary when several integration projects are done over the course of their studies. The important thing is not only to understand what should be done, how, and why; one must create the appropriate automatic systems to avoid the frequent gaps between theoretical knowledge and knowledge applied in practice. The human brain works in two modes: automatic, or system 1, and conscious, or system 2. With integration projects, students get used to combining areas of knowledge, which affords them that extraordinary automatic system to take on problems with a global or holistic view. This is what makes them into true professionals able to add value to their companies, their customers, and society in general.

All approaches need to be validated, and so has been the adopted methodology. The last six academic years have witnessed a substantial improvement in the performance of our students, as captured by key performance indicators such as Net Promoter Score, Attrition Rate, and Graduation Rate. Moreover, companies have shown great interest in, and support of, the projects conducted in class. Every year a Project-Based School Awards ceremony is held in September, at which the best projects from the previous academic year (selected by the faculty) are presented to the companies that attend. It is the representatives from the companies who vote and select the winners. Last September over 30 top-level Spanish firms, to include a number of multi-national companies, attended the Award ceremony and picked the winners. Very frequently it is the companies that suggest the topics, at the beginning of the academic year, on which the students can work. This close cooperation between industry and academia is pivotal to the success of the academic model and to the overall student's experience. A number of papers have been published on the implementation of the methodology (Terrón López, García García, Velasco Quintana, Gaya López, & Escribano Otero, 2015; Terron-Lopez, Archilla, & Velasco-Quintana, 2017; M.J. Terrón-López et al., 2016; M. J. Terrón-López, Velasco-Quintana, García-García, & Ocampo, 2017).

If the integration projects enable the integration of areas of knowledge within the degree pursued, extra-curricular activities conducted in clubs and associations allow students from different programs to work together. This environment comes extremely closet o what they will find in their professional lives when they will need to work together with professionals from other backgrounds. For example, it is normal to see in the activities carried out in the Formula Student Club or in the Robotics Club, to name a couple, students from degrees such as industrial engineering, software engineering, design, and even students from degrees offered by the other colleges, such as marketing students or economics students from the School of Social Sciences and Communication. Learning to work with students from other programs, undertaking the same challenges and generating synergies from their varied backgrounds, is what forges true professionals capable of adding value to their employers and to society, at large.

The combination of project-based learning (especially, through the performance of integration projects) and of extra-curricular activities in clubs and associations is what accelerates the learning curve and the development of the needed professional skills. The experience

gathered over many years, with a large number of alumni have demonstrated their competences in a large array of firms, validates the goodness of this academic approach. This capability of educating real professionals is, precisely, the ultimate goal of academic education.

CLOSURE

Project-based learning, coupled with continuous assessment, has proven to be a wonderful academic methodology. Being the goal of any program for its students to attain a certain level of understanding and command of the corresponding body of knowledge, the putting into practice of the conceptual foundations presented in class is what truly enables students to master the knowledge and to be capable of successfully putting it into practice, to contribute to the solving of problems. When on top of that the self-evaluation is fostered in students, their maturity spikes. Project-based learning demands that students question everything, not taking anything for granted. This helps them to learn how to learn, which is the ability we all need throughout our professional lives.

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WORK INTEGRATION SOCIAL ENTERPRISES: A TESTBED FOR CHALLENGE-BASED LEARNING?

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ABSTRACT

Work Integration Social Enterprises (WISE) are a particular enterprise form permeated by a so-called 'double business idea'. Besides the commercial imperative of providing product and services, WISE offer employment and training opportunities for individuals considered less able to compete in mainstream labour markets. The paper argues that this multiple goal structure makes WISE an ideal testbed for Challenge-Based Learning (CBL). The latter deepens both problem-based learning and CDIO, by featuring open-ended problems that stress an entrepreneurial, value-driven and sustainable approach to problem formulation and decision-making. The aim of this paper is to describe how real-life design projects conducted in collaboration with WISE take CBL a step forward compared with those involving more 'traditional' enterprise forms. Evidence is gathered along 4 main lines of thought, which are: 1) iterative problem formulating and designing; 2) entrepreneurial mindset and of value-driven learning; 3) social sustainability-aware designing; and 4) social-constructed learning. The findings indicate that WISE-based design experiences bring forward additional characteristics compared with more 'traditional' engineering ones. Students are able to expand the scope and depth of their problem identification and formulation activities, due to the continuous dialogue with a broad range of stakeholders, enthusiasts, and volunteers. They become more aware of the multifaceted meaning of the word 'value' in engineering, realizing the existence of competing value systems for the design problem. Eventually, their decision-making activities emphasize the pursuit of different goals and objectives (e.g., technical feasibility, business viability, and sustainable development) in the design process.

KEYWORDS

Challenge-based learning, project-based learning, Work Integration Social Enterprise, entrepreneurial mindset, global engineer, Standards: 5,7,8.

INTRODUCTION AND OBJECTIVES

Engineering systems today are characterized by increasingly complex and multifaceted values, and engineers must become aware not only of the economic and technical aspects of a design but shall also be able to grasp 'softer' and more intangible value dimensions in their work (Huntzinger et al., 2007). The tension between these growing needs in contemporary undergraduate engineering education is a major driving factor in the development of the

Conceive-Design-Implement-Operate (CDIO) framework (Crawley et al., 2013), as well as in the definition of learning outcomes that are more holistic and closer to the professional role of the contemporary engineer (Splitt, 2003).

In recent years, the original CDIO concept has evolved to highlight the need for engineering graduates to use design as 'learning through' rather than 'learning to' experiences (Malmqvist et al., 2015). Challenge-based learning (CBL) (Kohn Rådberg et al., 2018) is then proposed as an evolution of CDIO and more traditional problem-based learning approaches. CBL is inspired by the idea of 'grand challenges', which are described as issues that critically need to be addressed to ensure a sustainable future for the generations to come (Al-Atabi, 2013). Grand challenges are a cornerstone of national research and innovation agendas (see: European Commission, 2014) and inspire the design of learning experiences that foster the identification, analysis, and design of a solution to a socio-technical problem.

Sustainability is a critical dimension to be leveraged when designing CBL experiences. Nevertheless, while the introduction of social sustainability aspects in engineering education is of foremost importance for the creation of a 'Global engineer' (Bourn and Neal, 2008), sustainability is often confined to environmental aspects and suffers from the under-development of the social dimension (Missimer et al., 2017).

The main aim of this paper is to provide evidence of how innovation projects with Work Integration Social Enterprises (WISE) represent a step forward in leveraging a social sustainability dimension in engineering education and CBL. WISE are a particular enterprise form that, besides the commercial imperative of providing product and services (e.g., cafés, laundries, recycling centres, and others), offers employment and training opportunities for individuals considered less able to compete in mainstream labour markets, such as the physically and developmentally disabled (Cooney, 2016). While obeying the commercial logic of efficiency, profitability and competitive rivalry, WISE also serve a social welfare logic, maximizing a program of supportive intervention to produce results for its beneficiaries.

Intuitively, WISE are of great interest when it comes to foster competing 'value systems' and objectives in problem-based learning experiences. Hence, this paper argues that their multiple goal structure makes then an ideal testbed for CBL. Yet, in spite of their intriguing mix of business and social values, little is known about the pedagogical benefits of choosing WISE as case study providers in engineering education.

Emerging from 9 innovation projects conducted within the Value Innovation course at Blekinge Institute of Technology (BTH) between 2016 and 2018, the objective of this paper is to describe how real-life design projects with WISE have the potential to take CBL a step forward compared with projects involving more 'traditional' enterprise forms. The evidence is gathered along 4 main lines of thought, as presented in the following sections, which are: 1) iterative problem formulating and designing; 2) entrepreneurial mindset and of value-driven learning; 3) social sustainability-aware designing; and 4) social-constructed learning.

ENGAGING WISE IN CBL EXPERIENCES: A LITERATURE REVIEW

The main driving factor for selecting WISE as case study providers are to ensure a quality design-implement (D-I) experience for students. Advanced D-I experience (Crawley et al., 2011) are key features of CDIO programmes. These are characterized by tasks of increased complexity and authenticity that allow students to design, build and assess an actual product, process or system in a way that the object created is operationally testable. CBL experiences are further described as learning situations that expand and deepen both problem-based learning and CDIO (Kohn Rådberg et al., 2018) (Figure 1). In problem-based learning, students are posed with a design, research or diagnostic 'problem', and the learning takes place through the process of working out the solution (Hmelo-Silver, 2004). CBL finds the starting point in

large open-ended problems and stresses a value-driven approach to problem formulation and decision-making (Malmqvist et al., 2015) while addressing societal concerns and fostering an entrepreneurial mindset and working method.

In CBL, products are still developed through a process of conception, design, implementation, and operation. However, a stronger focus is put on problem identification and formulation, on establishing a dialogue with core stakeholders, on the business model components of engineering solutions, and the societal context and impact of a product rather than just the corporate benefits (Kohn Rådberg et al., 2018). These experiences also expand on the meaning of 'values' and 'ethics' in addition to customer needs in decision-making.
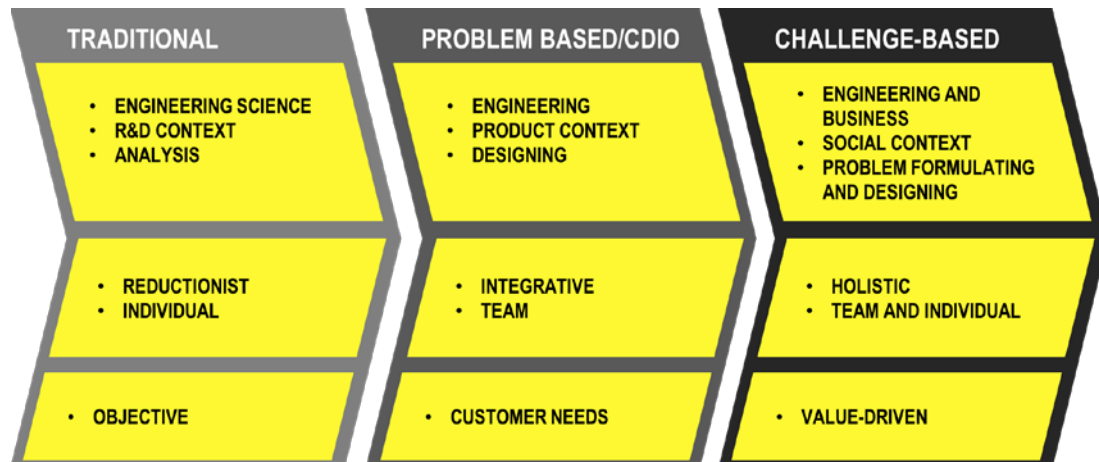
Figure 1: Evolution from traditional to problem-based to challenge-based education (adapted from Malmqvist et al. 2015).

The opportunity to exploit principles of Design Thinking (DT, a key component of CBL according to Kohn Rådberg et al. 2018) has long been debated (Melles et al. 2012), mainly as a way to move beyond today's conventional problem solving in social enterprises (Brown and Wyatt 2010) and to generate ideas with superior social sustainability content (Vezzoli et al. 2017). The literature proposes several DT application examples in the domain of social innovation and social entrepreneurship, such as those documented by Selloni and Corubolo (2017), Chou (2018) and Mosely et al. (2018). Nowadays, Design Thinking is also part of the innovation toolbox for the development of social enterprises incubated at the National University of Singapore (Prakash and Tan 2014).

Pirson and Bloom (2011) are among the firsts to highlight the critical role of DT in curriculum design from the perspective of educating social entrepreneurs. The application of DT in social enterprise-based projects is shown to stimulate the generation of more creative solutions to solve existing problems (Kickul et al. 2018) and to facilitate learning as students create and incubate social ventures (Coakley et al. 2014). Yet, literature does not analyse in detail the pedagogical impact of engaging social enterprises in engineering education, and little information is provided about the additional characteristics brought forward by these projects compared with more 'traditional' engineering experiences.

DEVELOPMENT OF THE 'VALUE INNOVATION' COURSE AT BTH

Recent literature has highlighted the benefit of value creation projects for engineering education (Bosman and Fernhaber, 2018). These projects connect the traditional scientific method and the engineering design process to business and marketing, through a focus on

'goals' rather than on 'problems'. This iterative process promotes a method of solution-focused thinking, which encourages engineering students to think outside the box and to apply active learning and creative thinking to theoretical concepts. Furthermore, value creation projects increase motivation for learning by allowing students to see the value by connecting real-world applications to the class topic (Bosman and Fernhaber, 2018).

Value Innovation is a 7,5 ECTS Master Programme course at Blekinge Institute of Technology. The expression 'value innovation' originates from innovation management literature. It refers to the creation of new and uncontested market space through the development of solutions that generate a leap of value for customers and users, while reducing cost and negative impact on our planet and society. The main objective of the course is to raise students' understanding of how to develop innovative products and services with a focus on value creation, going from the analysis of customer and stakeholders need, to the generation of innovative concepts, to the creation and verification of value-adding prototypes. The course introduces students to the Design Thinking (DT) methodology framework (Leavy, 2010). This represents a paradigm shift from the traditional linear problem-solving approaches and fits well with design situations dominated by ambiguity and lack of knowledge (wicked problems).

The course features lectures on design and innovation, which include a mix of short theory reviews and active work in different group constellations. These are complemented by workshops and class exercises that give participants a first-hand experience of the most relevant tools in the DT toolbox. Importantly, course participants are given the opportunity to apply the acquired theoretical base in a 'real-life' development project conducted in collaboration with selected company partners. In line with the CDIO framework, the course is designed with an overreaching project work that kicks-off just after the course introduction and stretches along the entire period of the study (8 weeks). Each project is conducted by small cross-functional design teams (4 to 6 participants), which mix students from the Master Programmes of the industrial economy (year 4), mechanical engineering (year 5) and sustainability innovation (year 4).

Experience and lessons learned from the project work are shared during presentation events in the classroom, while peer evaluation and group coaching (feed forward) are used to stimulate critical reflection regarding the process and the results. Results are gathered in a written report, which constitutes the basis for grading. Individual self-reflections aim at further stimulating students in learning about methods and tools for value innovation.

Redesigning Value Innovation: leveraging WISE collaborations to foster CBL

An important aspect of designing value innovation projects concerns the Operating stage of the CDIO model, which is acknowledged to be the most difficult phase in an academic setting. As discussed by Biggs and Tang (2011), students need to expect success when engaging in the learning task because nobody wants to do something they see as worthless.

At the end of the 2015 edition of Value Innovation, there was a general feeling of "pointlessness" with regards to the design challenges featured in the course. Students expressed their dissatisfaction with the idea of conducting "bold projects" with large Original Equipment Manufacturers (OEM), mainly due to the intrinsic difficulties in measuring the value added of their work when embedded in the larger processes of a multinational enterprise. Furthermore, the analysis of the students' self-reflection reports at the end of the course highlighted a widespread will to apply their knowledge for the good of society.

Several participants later approached the author (in the role of course coordinator) to ask for advice on how to exploit the 'value innovation toolbox' for the good of no-profit organizations they were volunteering in, such as the Red Cross and community centres. These inputs suggested the author, in its role of course coordinator, to make the course being part of the

European project "Social including och Tillväx i Blekinge" (in English: "Social Inclusion and Growth in Blekinge"), with the aim of involving WISE as case study providers in the course.

Working Integration Social Enterprises

The WISE phenomenon emerged during the 1990s, awakening interest across Europe due to its unique business orientation. WISE combine rehabilitation and work training as a way for long-term unemployed to return to the labour market by creating jobs that are adjusted for them. Sweden counts today about 340 WISE that employ approximately 10200 people. The main goods and services being offered are hotel and restaurants services (25%), public services (17%), education (16%), services to enterprises (15%), services to the public administration (15%), and processing industry (9%) (Hulgård and Bisballe 2004).

Due to their unique combination of business and social values, WISE are often described as permeated by a so-called 'double business idea' (Peverada, 2016). While traditional entrepreneurship targets the creation of financial returns to its owners, WISE see economic gains most as a means of achieving other (social) goals (Tynelius, 2011), which is supporting people in their journey to employment and self-sufficiency. Importantly, the social dimension is not detached from the business one: at the end of the day, it is the ability to generate (even marginal) monetary returns that allows reaching the social goal (Peverada, 2016).

Design challenges and projects with WISE

Between 2016 and 2018, 9 student projects (involving a total of 8 companies and 42 students) were conducted in collaboration with WISE in the Blekinge region. Table 1 details the challenge addressed the students' background and the extent to which CDIO was covered in each project. The main aim of all projects was for students to apply the acquired theoretical base in a 'real-life' setting, deepening their reflections on the application of different tools thanks to the frequent interaction with selected company partners.

Students were initially asked to describe target groups and customer types in relation to each design challenge. They later analysed the customer experience with regards to existing products/services by using needfinding methods and tools. The analysis of societal and technological trends helped in the development of innovative product-service concepts in the Ideation stage. In the Implementation stage, the students assessed the value of a new system by operating it, physically or virtually.

Table 1: Innovation projects with WISE (A: Problem formulation, B: Idea or model generation, C: Concept development, D: Testing/evaluation within an academic setting; E: Testing/evaluation by external stakeholders).

YEAR	PROJECT NAME	PARTICIPANTS	BACKGROUND	A	B	C	D	E
2016	The Sustainable agriculture experience challenge	5	Mechanical Engineering, Industrial Economy,	x	x	x	x	
	Product Service Systems innovation in caretaking	5	Mechanical Engineering, Industrial Economy	x	x	x		
	Theo-practical education for asylum seekers	4	Mechanical Engineering, Industrial Economy	x	x	x	x	x
	A new value proposition for the textile retail market in Blekinge	3	Mechanical Engineering, Industrial Economy, Sustainable Product Service Systems Innovation	x	x	x	x	x
2017	Kaffestugan: the 'all-year-around opening' challenge	6	Mechanical Engineering, Industrial Economy	x	x	x	x	x
	Redesigning the car washing experience challenge	6	Mechanical Engineering, Industrial Economy	x	x	x	x	

	Shoe-polishing Product Service System design	4	Mechanical Engineering, Industrial Economy	x	x	x	x
2018	The "socially responsible retail" design challenge	6	Mechanical Engineering, Industrial Economy	x	x	x	
	The "multipurpose service centre" design challenge	3	Mechanical Engineering, Industrial Economy	x	x	x	x

EVIDENCE OF CHALLENGE BASED LEARNING

In this paper, evidence of challenge-based learning is gathered mainly from the analysis of the project report and of the individual reflection papers submitted by the students at the end of the Value Innovation course. The analysis of the feedback received in course evaluation reports, together with the follow-up interviews with selected students and other stakeholders served as triangulation method.

A students' perspective on WISE attractiveness for engineering education

The underlying question when collaborating with WISE in engineering education concerns their 'attractiveness' for students in comparison to more 'traditional' company types. As a way to measure this dimension, each student was individually asked at the beginning of the course to rank project proposals from the most to the least preferred. All proposals were presented together in the same format during a project showdown event, describing the challenge by means of a title, a description of the challenge, and a set of expected deliverables related to each phase of the DT process. In the following 72 hours, students were given the task to reflect on and communicate back their preference list to the course coordinator.

Overall, WISE was found to be slightly more attractive for students compared to more 'traditional' company types. In 2016, while 4 of 7 (57,1%) course project proposals featured WISE, 61,3% of the students in the course indicated one of these 4 projects as they first-hand preference. In 2017, WISE projects attracted 48,65% of first-hand preferences while representing only 42,8% of the sample (3 of 7). In 2018, only 28,5% of the proposals (2 of 7) featured WISE, gathering 21,8% of first-hand preferences. WISE was also observed to attract a more mixed student population when looking at gender distribution. Among those who indicated WISE as their first-hand choice, about 70% were men and 30% women, which differs from projects in collaboration with more 'traditional' enterprises (85% man and 15% women).

Evidence of iterative problem formulating and designing

A recent study from Nespoli et al. (2018) shows that most design problems currently addressed by engineering students during their academic terms are still broadly-defined (as opposed to not-defined or ill-defined), only requiring the application of coded technical and scientific knowledge. However, the problems that are encountered when exercising the engineering profession "tend not to present themselves to practitioners as problems at all but as messy, indeterminate situations" (Schon, 1987, p. 4). While disciplinary knowledge prepares students to "solve the problem right", the integration of broader skills is necessary to teach them to "solve the right problem". Hence, the problem formulation is a main distinguishing characteristic of CBL, as well as a critical capability to master when working on issues and challenges related to sustainability (Kohn Rådberg et al. 2018). Multiple stakeholder expectations, as well as multiple disciplines, need to be taken into account when framing and analysing a problem.

Table 2 shows the level to which the design challenge was iteratively formulated from the description provided at the beginning of the course (i.e., at project showdown event).

Noticeably, most of the initial formulations were iterated and significantly refined emerging from the findings of the Initiation and Inspiration stage of the DT process, as well as from the continued dialogue with the collaborating company partners.

Table 2: Extent of problem reformulation from the initial design brief

YEAR	PROJECT NAME	EXTENT OF REFORMULATION	INITIAL PROBLEM FORMULATION	ITERATED PROBLEM FORMULATION
2016	The Sustainable agriculture experience challenge	SIGNIFICANT	Development of a machine for recycling plastic to be used in an existing showroom.	Development of the showroom experience within the sustainable agriculture theme.
	Product Service Systems innovation in caretaking	MODERATE	Development of subscription packages for caretaking services.	Development of a servitized business offer (Product Service Solutions) for catering food.
	Theo-practical education for asylum seekers	MINIMAL	Development of education and training activities for asylum seekers.	Development of an educational experience including practical training for asylum seekers.
	A new value proposition for the textile retail market in Blekinge	MODERATE	Development of innovative textile product (one-sale model).	Development of servitized solution for the textile retail market including communication channels
2017	Kaffestugan: the 'all-year-around opening' challenge	MINIMAL	Development of a new business offer for a café.	Development of the café' experience to make it attractive during winter months.
	Redesigning the car washing experience challenge	MODERATE	Development of a car washing service for private customers.	Development of a car washing experience including layout and work scheduling support design.
	Shoe-polishing Product Service System design	SIGNIFICANT	Development of a shoe polishing service.	Development of a Product Service System solution to wash and recondition work clothes.
2018	The "socially responsible retail" design challenge	SIGNIFICANT	Development of a retail business idea for a centrally located facility.	Development of an adventure park based on the 'anger room' theme
	The "multipurpose service centre" design challenge	SIGNIFICANT	Development of a multi-purpose service center for a rural community	Development of an adventure park based on the 'Wipeout' theme including service facilities

WISE were observed to be successful, in most cases, in stimulating students in independently formulating the problem to be addressed. The analysis of the students' reflection reports shows further evidence that collaborating with WISE was beneficial to leverage the ability to deal with wicked problems. WISE were perceived to be more 'heterogeneous' than traditional enterprise forms due to the unique context in which these companies operate. Each problem was perceived to be novel and inimitable, and solutions needed to be carefully developed on that basis, reinforcing the wicked dimension. WISE students were also observed to be comparably more aware than their counterpart that no single design solution is either 'good' or 'bad', but that there are multiple different ways of addressing the problem that are not always compatible with each other. Also, they appeared more aware that a solution may be favourable at one point in time, but highly problematic at another, which is one of the driving characteristics of wicked problems with a sustainability orientation (Lönngren, 2014).

Evidence of an entrepreneurial mindset and of value-driven learning

Engineering graduates are often comfortable — and sometimes quite good at — focusing on the technical feasibility of a solution. Yet, CBL highlights the need to foster an entrepreneurial mindset in the engineering graduates, designing solutions with the value proposition and user needs in mind, and not simply based on technical and functional concepts (Bosman and Fernhaber, 2018). This is because there are many innovations that are technically feasible but

that do not make any business sense, failing from customer desirability and business viability point of view. Hence, challenge-based experiences, differently from traditional problem-based learning, shall be conceived to serve a broader purpose than just 'designing' hardware, so to contribute to added value for the society (Kohn Rådberg et al., 2018).

The analysis of the data gathered both from the final project reports and from the individual reflection papers aimed at verifying in what way do WISE promote an entrepreneurial mindset among students. One way to measure the ability to expand the traditional 'functional' and 'performance' view (typical of Basic level courses) to include softer aspects of value, was to scrutinize the type of criteria used to select innovative design concepts at the end on the project Ideation stage. Students collaborating with WISE were able to address, on average, a broader range of stakeholders when defining concept selection criteria, compared with other groups. Importantly, the customer satisfaction dimension account only for about half of the criteria used (on average) by each team to measure the 'goodness' (i.e., value creation) of a design concept. The other half of the criteria include aspects related to the provider organization, to the employees working environment and to other stakeholders (e.g., employment agencies, mentors, etc.). The same phenomenon is not observed with the same intensity among the more students collaborating with more 'traditional' enterprises.

Evidence of social sustainability-aware learning

Graduating engineers are expected to demonstrate insight into opportunities and limitations of technology, its role in society and people's responsibility for how it is used (Kohn Rådberg et al., 2018). CBL experiences must have then a strong focus on the social impact of design (see: Malmqvist et al., 2015), fostering awareness on and developing skills for socially-sustainable design. Hence, the project reports were further analysed from the point of view of how much the different projects include aspects related to social sustainability in designing and selecting solutions for the given design challenges. The 5 social sustainability principles described in the FSSD framework (Missimer et al., 2017) were used as a reference to verify whether students embedded a social perspective in their work. These principles are described as:

- *Health*: individuals shall not be exposed to social conditions that systematically undermine their possibilities to avoid injury and illness; physically, mentally or emotionally, e.g. dangerous working conditions or insufficient wages.
- *Influence*: individuals shall not systematically be hindered from participating in shaping the social systems they are part of, e.g. by suppression of free speech or neglect of opinions.
- *Competence*: individuals shall not systematically be hindered from learning and developing competence individually and together, e.g. by obstacles for education or insufficient possibilities for personal development.
- *Impartiality*: individuals shall not systematically be exposed to partial treatment, e.g. by discrimination or unfair selection to job positions.
- *Meaning-making*: individuals shall not systematically be hindered from creating individual meaning and co-creating common meaning, e.g. by suppression of cultural expression or obstacles to co-creation of purposeful conditions.

Table 3 shows that most of the project teams included social sustainability aspects in the definition and evaluation of ideas, showing good awareness on the use of 'social lenses' to measure the goodness of a proposed solution concept. Even though not all aspects of social sustainability are covered in the projects, these are found to be much less leveraged in projects conducted with more traditional enterprise forms, in particular with regards to the 'health and 'competence' dimensions.

Table 3: Social sustainability principles coverage (x: covered, *p*: partially covered) when defining criteria for design concept selection

Project name	HEALTH	INFLUENCE	COMPETENCE	IMPARTIALITY	MEANING-MAKING
The Sustainable agriculture experience challenge	x				x
Product Service Systems innovation in caretaking			p	x	
Theo-practical education for asylum seekers	x	x	x		
A new value proposition for the textile retail market in Blekinge			x		
Kaffestugan: the 'all-year-around opening' challenge					
Redesigning the car washing experience challenge	p	x	p	x	p
Shoe-polishing Product Service System design	p		p		
The "socially responsible retail" design challenge	p		p		
The "multipurpose service centre" design challenge	p		p		x

Evidence of social-constructed learning

The main reason for introducing WISE in the engineering curricula discussion is that several key issues and skills which define the global dimension of engineering have a social nature. Design work is often understood as a socio-technical business in "the debates about whether the design is 'done', if the specifications have been 'met' and if the result is 'good'" (Minneman, 1991, p.63). Due to the complexity of the target group (i.e., long-term unemployed individuals), WISE are usually started in the form of projects, involving regional and local development funds, mentors, care institutions, career supporters, unemployment agencies and other professionals (Peverada, 2016). This strong multi-stakeholder structure was found to facilitate the social construction of knowledge among the nine student teams. WISE were observed to foster the social construction of knowledge among the participating student groups, mainly because they forced them to interact with a wider range of stakeholders than in a more traditional project setting. They were also observed to positively stimulate mutual learning and peer feedback (Elmgren and Henriksson, 2010), mainly because they allowed students to connect not only with business people but also with a variety of enthusiasts and volunteers that were seen as models, to admire and identify with (Biggs and Tang 2011, p.36).

DISCUSSION AND CONCLUSIONS

WISE-based design experiences have shown to bring forward additional characteristics compared with more 'traditional' engineering experiences, fostering a process where students can couple theoretical and practical learning, developing skills in problem formulation and sustainable development. Students have been observed to expand the scope and depth of their problem identification and formulation activities, due to the continuous dialogue with a broad range of stakeholders, enthusiasts, and volunteers. They were also observed to be more aware of the multifaceted meaning of the word 'value' in engineering, emphasizing the pursuit of different goals and objectives and stressing the existence of competing value systems for the design problem. Eventually, WISE represented an eye-opening experience with regards to

recognizing that the value generation process is not merely a matter of building a solution (feasibility), but also of addressing how customer/stakeholders will react (desirability) and of ensuring that the solution is sound in a business sense (viability).

Future work will aim at consolidating the use of WISE as case study providers, strengthening the collaboration with all the different actors involved. The inclusion of the Value Innovation course as part of regional incubator for WISE in the Blekinge region (Coompanion, 2018) is considered a step forward in this perspective. Future work will also be dedicated to strengthening practices with regards to the supervision and tutoring of the project groups. One major factor affecting successful project work and learning process was the guidance provided by the course coordinator acting as a tutor. Active involvement and guidance were required, especially during the first weeks of the project. Most of the guidance took place in project work sessions, where noticeable differences were observable between the groups. These sessions shall ensure that students working with WISE can reach the required technical depth for design solutions to be implemented and operated. This means finding the right trade-off between the time spent on development work and the time spent to interact with the actors in the WISE network. It could also be observed that some groups are more innovative and get started with the project very fast, while others require more support. It requires professional skills from the teachers to see where and when additional guidance is required, yet still remaining purely as a tutor and not to influence the problem-solving process by providing solutions.

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CAN DESIGN AND ANALYSIS BE EFFECTIVELY TAUGHT TOGETHER?

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ABSTRACT

This paper presents two major elements of a course redesign with the aim to strengthen the connection between engineering design and engineering analysis. The course, Aircraft Structural Design and Analysis, had previously been delivered with a heavy focus on mathematical analysis and solving complex problems. It was observed, however, that in later design projects within the curriculum, students were unable to apply these skills in a less constrained design context. To combat this, two-course elements were introduced. The first element was a design tutorial session that ran in parallel with the course and interfaced with real design activities being carried out within the AeroDelft Dream Team at Delft University of Technology. This session attempted to have students apply the skills they had learned in class to a less constrained design problem with more freedom than traditional practice problems, focusing on design thinking rather than reproducing an expected answer. The second element was a design-based final exam, where all of the questions within the exam were interconnected by a single design context. The first iteration of these design elements, including lessons learned and analysis of their impact on student success, will be presented within this paper.

KEYWORDS

Structural Analysis, Aircraft Design, Real World Learning, Integrated Learning, Course Evaluation, Standards: 4, 5, 6, 7, 8.

INTRODUCTION

Many lecturers in engineering often face the dilemma of how to teach design and analysis skills effectively and simultaneously for complex engineering disciplines. On the one hand, design requires a deep understanding of discipline-specific concepts, the meaning behind them, and realization that design-related decisions are more about compromise rather than correctness. Teaching design thus needs to emphasise decision making and justification. Analysis, on the other hand, requires a rigorous application of discipline-specific concepts to obtain answers to problems that can be assessed in terms of their correctness and sensibility. Teaching analysis thus needs to focus on precision and correctness. But how can we teach new concepts and ask on one hand for students to perform analyses to calculate precise correct answers we are looking for, yet on the other hand teach students that design does not have precise correct answers?

This is precisely the challenge faced within the 2nd year, 5 EC (= 140 h) bachelor course entitled *Aircraft Structural Analysis & Design* at the Faculty of Aerospace Engineering at Delft University of Technology. The course in its many previous forms followed a more analysis focused approach, relying on lengthy mathematical derivations of formulas that could be used in analyses that were then reinforced by numerous in-class and practice problems. Effectively, the course focused on analysis and expected students to absorb the concepts and be able to apply them on their own in a design setting. As a result, it was observed that students were incapable of applying their structural analysis skills in capstone design projects, more specifically the Bachelor final thesis design project, the Design/Synthesis Exercise, where the design problems were not formulated as questions with precise and correct answers. Secondly, the students perceived the course as abstract, difficult and not too relevant for the design work they had to carry out in the bachelor. As a result, the course is considered to be one of the hardest courses in the bachelor curriculum. In the past attempts have been made to make the course more accessible for students through computer-based homework introduced as early as 1990 and lab experiments to visualise the concepts (Saunders-Smits & de Vries, 2005). To address these issues, the course delivery was redesigned to place a larger emphasis on conceptual understanding and design, using the CDIO standards (Malmqvist et al. 2007) as its guide to activate students in their learning.

This paper reports on the course redesign, the lecturers' experiences during the running of the course, the opinion of the students on the new method and conclusions and reflections on the course with recommendations for further improvement.

Literature review on teaching structural design

Many engineering education educators agree that it is important to engage students with the material taught by using real-world examples (Malmqvist et al. 2007, Trevelyan 2016, Sheppard et al. 2009, and Goldberg & Somerville, 2014). At the same time, many lecturers find this daunting as they do not always have experience as a working engineer or are concerned that this will lower the level of the course by being "too applied" and not fundamental enough. There seems to be little faith by lecturers and the institutes they work at, in the ability of lifelong learning of their students to gain more knowledge independently, after having been taught the basic principles.

This is also very apparent in the field of structural mechanics. Within Europe, quite a few institutes advocate a traditional, extremely theoretical approach embedded into fundamental classical mechanics and the accompanying detailed mathematics. Typically, these courses are accompanied by laboratory exercises with all students carrying out the same measurements on the same experiments from year to year without any design freedom or connection to real life problems. Not surprising there is little literature available reporting on its successes. Other institutes choose a teaching approach that is closer to practice with example problems that resemble real structures and instead of repetitive experiments, the courses are accompanied or followed on by project-based design exercises with some design freedom and often involving practical skills and synthesizing mechanics with other courses such as reported by Crawley et al. (2005), Nengfu et al (2009) and Peng Lin et al. (2006) The authors' own department is also currently using this approach in their bachelor following the CDIO principles (Saunders-Smits et al. 2012). Although there is nothing wrong with this approach, in the act this is exactly the sort of projects that should be encouraged, they do have one downside. Due to the emphasis on synthesis, and practical and soft skills, there is often not enough room in these projects to truly carry out a detailed, realistic structural design of more complex structures such as ships, aircraft and launch vehicles, allowing students to really grasp structural design

concepts in these fields. This is why two of the authors decided to introduce team-based design tutorials and a design-themed exam based on a real aircraft design project in their Aircraft Structural Analysis and Design course.

COURSE SET UP & EDUCATIONAL APPROACH

The course is run during a 7-week period with 6 weeks scheduled before the Christmas break and 1 week scheduled after in line with the uniform scheduling of the university. The final 3 h, written exam for the course is set some two weeks after the last week of lecturing. The learning objectives of the course are for a student to be able to:
- Calculate stresses/strains in thin-walled structures using:
- Engineering beam theory (bending and shear) and torsion theory (closed and open sections),
- Modify the above theories in the presence of redundancy and/or cutouts,
- Calculate displacements using: beam theory and energy methods (incl. Castigliano's 2nd theorem),
- Determine the buckling loads for simple structures such as beams and trusses,
- Determine buckling/crippling loads for stiffened panels,
- Design such structures by determining the geometry such that structure does not fail (thickness of skins under bending, shear and torsion; cross-sectional geometry of beams under compression)

The lecturers were interested in trying a new approach with an aim to engage students more and were inspired by the Conceive, Design, Implement and Operate principle. They felt that by introducing design as an activity during the course students would be more engaged with the material, but to avoid the design being just another set of calculations on paper, they also looked at a way to implement design by using a real-world example of an aircraft that is being designed by one of the Delft Dream teams[1] meaning the design would also have a real life purpose and thus enhancing engagement. The design part would not be made a mandatory activity, but the design theme would also be used in the assessment making this attractive for students who are intrinsically motivated for engineering and design as well as the students who are unfortunately still just grade-focused.

As a result, two new course elements were introduced in the academic year of 2018-2019 in an attempt to effectively embed design thinking, reflection, and decision making into the course Structural Analysis and Design: A Design Exercise and Design-themed Exam.

The overall organization of the course now consists of two, 2 h weekly large classroom lectures in a modern multiscreen lecture theater with the use of a digital Blackboard and powerpoint presentations and a one 2 h weekly design tutorial on a Friday afternoon in the large dedicated groupwork classroom in Pulse, the recently opened modern learning centre at Delft University of Technology[2] (see Figures 1 & 2). Students are given (voluntary) homework to prepare for the design tutorial. To assist students in keeping up with the material 3 intermediate tests are administered allowing students to gain up to 60% of their final grade with the final exam counting for 40% instead of the final exam counting for the full 100%. The tests are optional, and the highest grade (intermediate test and final exam or just final exam) counts. This is done

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[1] https://www.tudelft.nl/en/d-dream/
[2] For a virtual tour of Pulse see: https://nmc360.tudelft.nl/vt_pulse/

to allow for students who fall ill or who are retaking the course as they did not pass it in previous years.
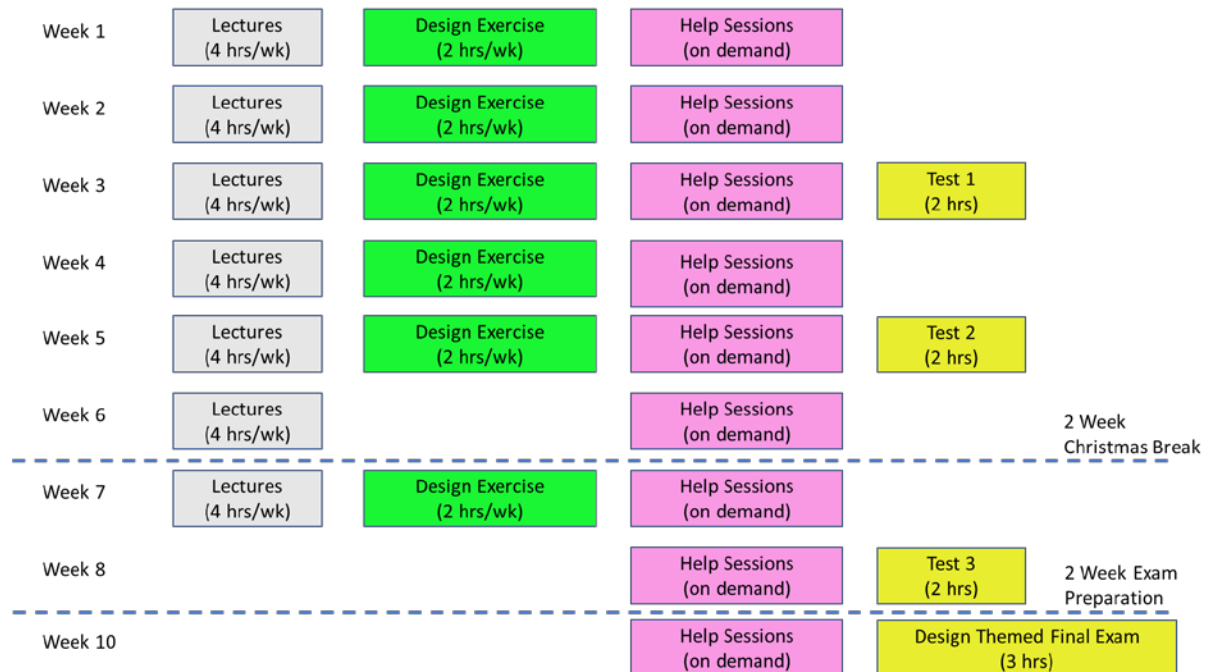
Figure 1: Organization of learning/assessment activities and related student time commitment for the entire Structural Analysis and Design Course.

The new elements include a new unifying design exercise which aimed to tie all analysis skills taught in the course to a real and relevant design problem, and a design-theme interlaced through the course final exam. Each of these elements will be described below in terms of their intended execution with a critical reflection on their success.

Design exercise

When designing technical artefacts, like aircraft and spacecraft, a considerable part of the time is spent on the structural design. The design process often starts with the use of statistical methods. This leads to a so-called Class I or conceptual design (Raymer, 2018; Roskam, 2004; Torenbeek, 1988). These methods give a first estimate of not only the performance but also the mass of the object. In the next steps of the design process, the object is detailed more and more. This includes designing a suitable structure and detailing it step by step. This starts with determining the loads on the structure, then designing the structural setup and in the end all the way to the bolts and nuts including determining the mass of the structure. In the framework of the course Structural Analysis and Design, six design tutorials have been incorporated to mimic this design process. The students were given a Class I design of an aircraft developed within the Dream team "Project Phoenix" (http://www.aerodelft.nl/project-phoenix.html) and were asked to make a structural design of the wing.

The topics addressed in the six design tutorials were:
1. Loading diagrams
2. Preliminary design for bending and torsion
3. Preliminary including shear

4. Structural idealizations
5. Stiffened skin panels
6. Holes and cut-outs

The topics of the design tutorial kept track of the topics discussed during the lectures. We framed the situation such that the students were put in the position of structural design engineer within the Project Phoenix "company" and made responsible for the structural design of the aircraft.

The intent of the tutorials was to give students complete design freedom and the chance to demonstrate the skills they acquired so far. However, after a couple of weeks, it was noticed that students struggled with this freedom. They felt insecure, were wondering what the "right solution" to the problem was and as a consequence of that felt lost or disinterested, and attendance dropped.

This observation led the lecturers to the conclusion that the students needed more guidance. After three of the six tutorials, the set up was changed. We framed this as a 'hostile take-over' of the company and converted the design assignments into more concrete design tasks for the remainder of the tutorials. The students appreciated this change. It gave them the feeling the tasks had become more manageable for them.

Figure 2: Students discussing the size of an inspection hole in the wing (left) and the dedicated lecture rooms for the design tutorials (right).

Facilities used

The tutorials were organized in a dedicated lecture room. This room has a set-up in which the students can find tables to sit at four ascending levels. Every level offers four project tables with eight seats each. Because of the ascending levels, the students all have a good view of the lecturer, the smart board and the presentation screens. The four levels are set up such that the accessibility for the lecturer is excellent. This allows a good interaction between the lecturer and the teams of students. Every table is equipped with power outlets for the student's laptop computers and a whiteboard such that the students can make sketches of their designs.

The students were asked to form their own design teams. Every tutorial started with a short introduction of the assignment of the day by the lecturers. After that, the students started working on the assignment. The lecturers walked around for one-on-one tutoring. Every now and then some common issues were addressed for the whole of the group.

On the web-based learning management system "Brightspace" that is available for all courses within TU Delft, a forum was created where the students could share and discuss their design solutions.

Design-themed exam

Traditional final exams for most engineering analysis course comprise of multiple questions designed to test individual learning objectives or skills taught within the course. These questions are typically designed to be completely self-contained questions that are not dependent on one another. There is good reason to have this independence between questions, as it is desirable to provide students with the opportunity to demonstrate their mastery of different skills without a lower mastery of one having a negative impact on the assessment of mastery in another. However, from an extreme point of view, this approach can diminish the necessary interconnection of these skills in a real engineering context – effectively cleansing the final assessment of the desired thinking for a CDIO mindset.

The goal of the *Design-themed exam* was to address the lack of interconnection between skills from a design context while still maintaining the independent assessment of the mastery of individual skills. Although these goals may seem to be in opposition with each other, this was achieved by utilizing the following elements within the exam:

- Providing a design case that provides a unifying context in which all individual questions relate to;
- Organizing individual questions in a logical order mimicking a typical design process;
- Utilizing *design iterations* and *working in engineering teams* as mechanisms to minimize the dependence between the assessment of mastery of individual skills;
- Adding reasoning-based sub-questions to allow students to demonstrate their understanding of the interconnection of individual concepts.

Each of these elements will be briefly summarized in the remainder of this section.

Contextual Design Case

Critical reflection on the meaning and impact of a result calculated by a student can only be achieved if there is a clear context for that result. This was the driving principle behind establishing a clear, yet simple, design context for all analysis-based questions within the exam. An example of such a case used within the 2017/18 final exam is provided in Figure 3.

Design Case Description:
A European consortium is designing a commercial tiltrotor aircraft that is being designed to compete in the regional aircraft market (concept image is shown on the right). You are part of a design team responsible for the design and sizing of the wing structure. All questions in this exam will relate to this design activity.

For all questions, when needed, you can assume the following material properties:

$$E = 70GPa \qquad G = 30GPa \qquad v = 0.33$$

$$\sigma_y = 482MPa \qquad \sigma_{ult} = 538MPa \qquad \tau_y = 245MPa \qquad \tau_{ult} = 310MPa$$

Figure 3. Example of an exam design case description

Four key elements can be observed in this description:
1. Visualization of the overall design concept to trigger the students' ability to see how elements of their analysis fit within an overall aerospace system;
2. Concise and relatable context with respect to desired functionality;
3. Defined role/responsibility for engineering team (i.e.: wing structural sizing);
4. Baseline set of material properties to be considered in all analyses.

Question Sequence Mimicking a Design Process

With a design context set, a series of questions were presented in an order that would be logical in terms of a design process. Specific elements of this are common between exams; however, depending on the concepts being tested and the particular scope of the *Contextual Design Case*, adaptations are made on a per-exam basis. The general process flow is summarized in Figure 4 by the blue arrows. All exams started with an analysis of the internal loading state, reinforcing skills from a prerequisite course and their connection to the context of the present course. Specific skills were then tested in the main areas of modelling and idealizing structural concepts; calculating relevant internal stresses using those models; as well as a select number of detailed analysis methods covered in the course, such as buckling & crippling analysis, energy methods, and design of cut-outs. This progression allowed the concepts from earlier questions to easily be connected to later questions using reason-based questions which will be discussed later.
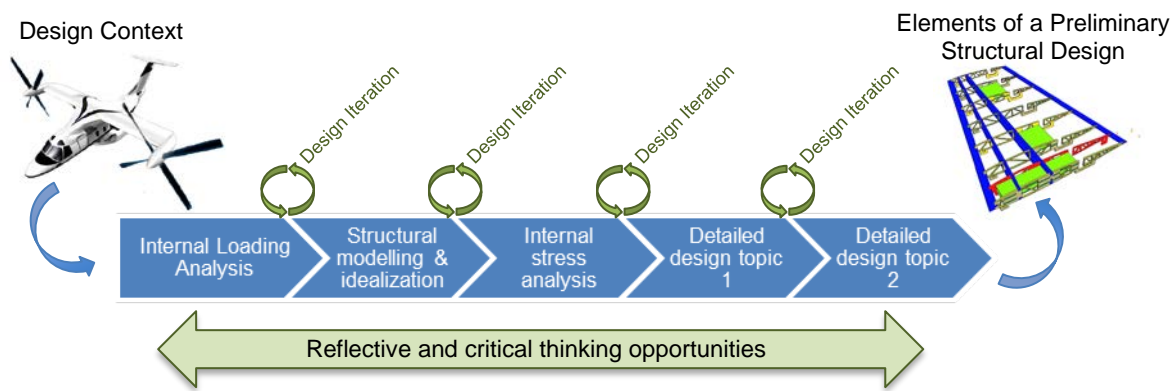
Figure 4. Overview of exam setup

Team-based Design Iterations

In order to mitigate the risk of early mistakes or poor mastery of specific skills early in the exam from causing a cascade negative effect on the overall exam, the concept of an engineering team-based design iterations were used to provide common intermediate design states within the exam for the students to work from. For example, after the student completed the first question analyzing the internal loading, follow-up questions requiring an internal loading to work from would provide an updated critical load state to analyze, stating that *this new loading state had been obtained by a team member after a design iteration*. The effect of this was threefold:
- it reinforced the iterative nature of early structural analysis and design,
- it provided assurance to the student that early mistakes would not adversely affect the entire exam,
- and it provided an opportunity for students to reflect on their earlier answers and potentially identify their own errors.

This last point requires further explanation. When introducing new values for variable updated through a design iteration, care was taken to provide updated values that were consistent with the design context. As a result, the updated values could be expected to be within the same order of magnitude as the original values calculated by students or related to their original answer through a described change in the design iteration. This addressed a skill that was found to be lacking in previous exams – students were rarely reflecting on their answer and how much sense it made. By providing the updated values, it was observed that students would often be triggered if the newly provided values were substantially different than their original values.

Reason-based Sub-questions

Sub-questions that required reasoning, rather than straight calculation, were also included to reinforce interconnections within the overall exam. In this way, we could ask questions about the impact of later detailed design analysis/decisions on the work performed earlier in the test or on forward-looking design decisions. For example, early structural models for which they performed calculations on earlier in the test could be revisited by asking the impact of adding several stiffeners to the model based on a detailed buckling analysis performed later in the exam. Rather than having the student perform the new calculations, they were asked to reflect on the expected impact of those changes on their earlier analysis and whether that earlier analysis would now be conservative or non-conservative. This critical reflection is a key part of the design process where earlier analysis needs to be evaluated in terms of whether they are *right enough* for the needs of the design.

COURSE REPORT AND EVALUATION

Course report

The course started with well over 300 students attending the first lectures, which quickly dropped down to a steady cohort of 150 – 200 students. This is not surprising as many students "check out" the course at the first lecture and then decide whether to take the course and whether to follow the live lectures or the recorded lectures. The lecturers heavily promoted the introduction of the new design tutorial in the first lecture and as a result, over 250 students turned up divided over two sessions for the first tutorial. This number also rapidly dropped off to only 70 students showing up for the last session. To assist students with questions on the homework problems and intermediate test preparations, daily help sessions were organized at lunchtime and manned by experienced teaching assistants. Typically, 5 - 10 students attended daily with that amount tripling on the days before the partial tests and exams. The partial tests were more popular with 456 students taking part in the first session and 406 and 303 students taking part in the second and third test respectively. A total of 422 students took part in the regular exam in January of 2019.

The drop off in student activity may seem drastic but is in-line with normal student behavior at the institute. Students are held responsible for their own planning and choices and there are no far-reaching consequences for them to drop out of courses or to not fully participate in a class. Mandatory attendance is not promoted for non-lab or project-based courses. As a result, students make their own choices and accept the inevitable delay in their study progress.

Course Evaluation Set Up

To evaluate the intervention of introducing design tutorials and a design themed exam to the course a questionnaire was handed out during the last lecture, the last design tutorial and the exam. The focus in the questionnaire was in particular on the learning activities offered to the students, in particular, the design tutorials. The design theme of the exam was not evaluated. Participation was voluntary and all data analysis was carried out by a staff member who was not part of the course to ensure impartiality. Ethical permission from the university's Human Research Ethics Committee was sought and given. A total of 83 students responded of which 8 chose to not have their opinion linked to their results.

Course Participation

Students were asked about their participation in the various offerings of the course. The results are listed in table 1 below. Participation in the partial tests is the highest, followed by lectures. The design tutorials are also regularly attended by more than half the respondents. However, 29 respondents did not take part in the exam. Reasons for not taking part in the exam have not been investigated.

Table 1. Self-reported participation percentages in the course.

Lectures	N = 83	Design Tutorials	N= 83	Help Sessions	N = 81	Partial Tests	N = 81
< 3	3.6%	None	15.7%	None	69.1%	None	1.2%
4-7	9.6%	1-3	24.1%	Before exam only	6.2%	1	2.4%
8-11	16.9%	4-5	22.9%	Before tests only	22.2%	2	12.0%
12-14	69.9%	All 6	37.3%	All sessions	2.5%	All 3	81.9%

In a number of open questions, students were asked for their reason for not participating in the lectures, design tutorials or help sessions. Most predominant reasons given for not attending lectures were other obligations including work, clashes with other courses and bad planning.

For design tutorials, the reasons given for non-attendance were other priorities, not useful, did not like set up or being too far behind. With regard to the help sessions, most students indicated they did not need them, and a small number of students cited other obligations or unawareness of the existence of help sessions. Finally, when it came to reasons for not or no longer participating in the partial tests the predominant reasons given were: lack of confidence, scheduling conflicts and illness.

Evaluation of the design tutorials

When asked why they attended the design tutorials, most students indicated that saw it as an opportunity to learn more about designing, practice the material and prepare for the exam. They also indicated they attended because they found the design tutorials useful, preparing for their professional future and fun. When asked what they liked the most about the design tutorials the students indicated they really liked the application of the material to a real-life design problem, exchanging either with peers and working in groups, the design freedom and the more structured approach after the 'hostile takeover'. Finally, when asked what students

thought that needed to be improved about the design tutorials, they overwhelmingly indicated that they would prefer to have more guidance and less freedom at the beginning with increasing design freedom as the weeks go on, as opposed to the way the tutorials were organized this time. Students also would like more support to be available during the session and work out a better way to create groups. Some students also expressed the desire to understand better how all the tasks fit together.

Relation between course results and participation in design tutorials

The results, as listed in table 2, appear to show that the students who attend more than half the tutorials appear to do better on average on the partial tests and the exam compared to students who attended less than half. They also do better than the total student population. A Pearson's Chi-squared test was carried out to see if a significant relationship exists between passing the course and attending more than half the tutorials. It was found that $\chi 2(1) = 4,405, p < 0.05$, which means a significant relationship exists. The odd ratio was subsequently calculated and this showed that students who attend more than half of the design tutorials are 3.6 times more likely to pass the course than those do not.

Table 2. Mean test and exam scores compared between different groups of students. Note: A 10-point scale is used and a passing grade constitutes a grade of 6.0 or higher.

	Test 1		Test 2		Test 3		Exam		Final grade	
	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n
Respondents that attended < 4 tutorials	7.0	22	6.4	17	4.7	13	4.4	19	5.0	19
Respondents that attended 4 or more tutorials	7.3	43	7.3	27	6.1	27	5.5	28	6.4	28
All students	6.6	456	6.4	406	5.2	303	5.1	422	5.2	422

REFLECTION & CONCLUSIONS

As a general whole the course ran well although the lecturers did experience some logistical hiccups in the process. With a large number of students putting off this course or having to re-sit this course and no mandatory enrolment system present, lecturers are confronted with an unknown quantity of students leaving them with guestimates as to how many students to expect and to design the course for. This also affects the quality of the scheduling and allocation of lecture theaters. During the first lecture, the theatre was too small, and this may have contributed to students deciding to not follow the course or only follow it via recorded lectures which requires self-discipline and may lead to students dropping the course. The design exercise attendance was also affected by the availability and size of the theatre, the initial large design freedom and the unwillingness of students to work with different students in each design session resulting in entire groups dropping out. The lecturers decided to address the freedom by staging a 'hostile take-over' but do feel that being confronted with a large design

uncertainty is also a fact of practical engineering life students should learn to live with early on in their education.

Unfortunately, the logistical issues described above are not so easily solved in terms of the systems and procedures for enrolment currently in place within TU Delft. As a result, it will remain a risk for future iterations of the design exercise. One of the biggest impacts of these logistical problems was the sporadic makeup of the individual groups from week to week. This had a major impact on the continuity of activities throughout the year and was voiced as a demotivating factor in the exercise. Some students found themselves without any of their group members showing up in a given week, and thus either had to work on their own, or join another group whose design may have been quite different from the lone team member's. To address this in future iterations of this exercise, rather than allowing each group to build upon their own design throughout the whole course, groups will vote on the best concept/design development from all of the groups from that particular session to form the common basis for the beginning of the next design exercise. Additionally, to combat some of the students' feelings of not knowing where to start in their design, it is intended to align the exercise with a design and construction project from the 1st year of the bachelor program. In that project, students designed and constructed a metallic wingbox with a large number of restrictions. The design exercise will examine this wingbox design, but remove many of the constraints, introduce a change from metal to composite material, and require multiple load cases to be considered. It is hoped that this will provide some confidence and familiarity with the design, but provide ample opportunity for challenging their initial design decisions with the new theory and concepts learned within the course. As an added bonus, students will be provided the opportunity to build their design after the course and test it at the end of the year when the 1st year students test their metallic wingboxes.

It is also worth noting that the design exercise had a very positive effect on the AeroDelft student project. The student group experienced a large interest from students within our course in participating in the project. Many of them indicted that the design exercise made them aware of what could be actually accomplished with what they were learning in class and motivated them to seek out more opportunities to apply their knowledge.

The design-themed exam was a larger success. Students generally seemed to appreciate the interconnection between the questions in terms of critical reflection of their own answers. Some students did complain about the length of question descriptions as the additional context necessitated more information to be provided, so this aspect will be kept in mind in future exams to attempt to strike the right balance between facilitating and over-burdening the students. One idea for the next iteration of the course is to publish the design context that will be used on the exam one week prior to the exam. This may spark discussions amongst students about the context, possible relevant question types that could be asked in such a context, and may provide a motivating context for their studying.

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DESIGN AND OUTCOME OF A CDIO SYLLABUS SURVEY FOR A BIOMEDICINE PROGRAM

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ABSTRACT

The CDIO Syllabus survey has successfully been applied to the Bachelor's and Master's programs in Experimental and Medical Biosciences, within the Faculty of Medicine and Health Sciences at Linköping University, Sweden. The programs are and have been, subject to considerable redesign with strong influence from the CDIO framework. One of the main drivers for the redesign is a shift concerning the main job market after graduation, from an academic career to industry and healthcare. One of the steps in the development process has been to carry out a Syllabus survey based on an adapted version of the CDIO Syllabus. The survey was sent out to students and to various categories of professionals, and in total 87 responses were received. The adapted version of the Syllabus and the design, execution, and outcome of the survey is presented.

KEYWORDS

CDIO Syllabus, curriculum design, stakeholders, Standards: 1, 2, 3,12.

INTRODUCTION

The biomedicine program at Linköping University was initiated around 20 years ago by pure academic needs. The program had a high number of applicants, and it was rewarded with a good success rate with regards to students completing the program as well as the graduating students' employment situation following completed studies. However, there have been drastic changes in the need from the life science sector as well as the health care system during the last years, and therefore the program is in the process of a thorough redesign. The first group of students, following the redesigned program, began their studies in fall 2018. It is the first international Bachelor's program, i.e. taught entirely in English, at Linköping University. The redesigned program has been named "Bachelor's program in Experimental and Industrial Biomedicine". As previously stated, the primary goal is to prepare students for employment outside academia as well as continued studies at advanced and research level. This includes motivation of students for active learning by a strong professional identity. Through project-driven courses based on typical situations/problems from academia, healthcare and industry, students will be provided with a multidisciplinary base, the latest approaches in project management, and an understanding of bio-entrepreneurship. The

intention is that the program will train the students to be able to identify, assess and implement biomedical ideas, and to understand how these concepts can be developed into products in the wider biomedical field. The program aims to integrate in-depth knowledge of medical biology with the latest experimental methods in biomedical research. Throughout the program, the students will receive practical experience in project management, laboratory techniques, as well as in data analysis, report writing and presentation techniques. Students will also meet industrial collaborators where they will be trained to translate biomedical knowledge into biomedical applications, to prepare for further work in academia, healthcare or business. Students will have the opportunity to spend a semester at an academic or industrial actor in Sweden or abroad.

An important step in the redesign is to ensure that the new program meets the needs, in terms of knowledge and skills, of the future profession. In that process, it is important to give the stakeholders the opportunity to take part in the development process. This has been accomplished by several means, such as conferences and meetings of different types. Another valuable tool is the CDIO Syllabus survey, which has been applied to a set of stakeholders consisting of both students and professionals, and this is the topic of this paper. The outcome of the survey can be used to confirm the steps already taken in the redesign and to guide the revision of the later parts of the program.

The CDIO framework was designed for engineering education, but there are a few examples of extensions and applications of the framework to disciplines outside engineering. Fahlgren et al. (2018) was probably the first example of application within the biomedicine field. Another interesting publication is Malmqvist et al. (2016), where various examples, from different disciplines and countries, of applications of CDIO outside engineering are presented. An additional example is given in Martins et al. (2017).

The paper is organized as follows. It will start by a brief introduction to the CDIO framework in general and the key components of the framework followed by a short description of how the Syllabus survey has been used within the engineering field. The next section describes how the CDIO Syllabus has been adapted to suit education programs within the biomedicine field, and this is followed by a section where the design and execution of the survey are described. The next section contains a summary and analysis of the results, and this is followed by the conclusions.

THE CDIO FRAMEWORK

The CDIO framework is a powerful and widespread tool for design and management of engineering education. A thorough introduction to the framework is given in Crawley et al. (2014) and the web site: The CDIO Initiative (2019). In the engineering context, the framework consists of four key components:
- A definition of the role of an engineer.
- Clearly defined and documented goals for the desired knowledge and skills of an engineer (The CDIO Syllabus).
- Clearly defined and documented goals for the properties of the engineering education program (The CDIO Standards).
- An engineering approach to the development and management of education programs.

However, provided it is possible to describe the intended role of the graduates from an education program in some other field it should be possible to apply the CDIO framework also there. According to the CDIO framework, see Crawley et al (2014), page 50, the goal of engineering education is that every graduating engineer should be able to:

Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.

An initial challenge in the work is hence to formulate a corresponding statement for graduates from the biomedicine program, and this work is carried out in collaboration with various stakeholders of the education program. Provided a formulation of the role of the graduates has been stated the next steps will be to investigate to what extent the fundamental documents the CDIO Syllabus and the CDIO Standards need to be adapted to the new context.

The CDIO Syllabus was first presented in Crawley (2001), and it is one of the two fundamental documents of the CDIO framework. The document, together with revised and translated versions of it, can be found via the CDIO web site: CDIO Initiative (2019). The document is the basis for formulation of the learning outcomes of both individual courses and the entire program. The CDIO Syllabus consists of four main sections with corresponding sub-sections and sub-sub-sections.

I - Disciplinary knowledge and reasoning.
II - Personal and professional skills and attributes
III - Interpersonal skills: Teamwork and communication.
IV - Conceiving, designing, implementing and operating systems in the enterprise, societal, and environmental context – The innovation process.

When applying the CDIO framework to the new field the main efforts will be on adapting the document to the new type of education and intended profession. In addition to introducing the CDIO Syllabus, Crawley (2001) presents the first examples of the application of the Syllabus survey. This was later followed by, e.g. Bankel et el (2003), and that publication presents the outcome of the Syllabus survey from the four original collaborating universities in the CDIO Initiative. A thorough description of how the survey is designed is given in Crawley et al. (2014). In the survey, a selected set of stakeholders are asked to, from their perspective, rate the expected levels of proficiency of the graduates in the CDIO Syllabus knowledge and skills, according to a proposed scale. As in, e.g. Crawley (2001) and Bankel et al. (2003), the focus has been on Sections 2, 3, and 4 of the CDIO Syllabus. It should be stressed that there are numerous other examples of applications of the survey, and it is not the intention to give a complete overview here. Further examples can be found via the link Knowledge library of the CDIO web site.

ADAPTATION OF THE CDIO SYLLABUS

Since the CDIO Syllabus was designed for engineering education a first step in the process was to split Section 4 into two slightly different versions reflecting the two main career paths of the graduates, i.e. academia or industry. Section 4 is hence more directed to a career in industry, while Section 5 is focused on an academic career, Sections 2 and 3 are almost identical with the corresponding sections on the CDIO web site, but in order to help the reader to interpret the data below also Sections 2 and 3 are given below. Hence, the four sections, subsections, and sub-subsections are:

Section 2 – Personal and professional skills and attributes

2.1. Analytical thinking, reasoning and problem solving: Problem identification and formulation. Modelling. Estimation and qualitative analysis. Analysis with uncertainty
2.2. Experimentation, investigation and knowledge discovery: Hypothesis formulation. Survey of print and electronic literature. Experimental Inquiry. Hypothesis test and defense

2.3. System thinking: Thinking holistically. Emergence and interactions in systems. Prioritization and focus. Balance in resolution

2.4. Initiative and willingness to make Decisions in the face of uncertainty. Urgency and will to deliver. Creative thinking. Critical thinking. Self-awareness and knowledge integration. Curiosity and lifelong learning. Time and resource management

2.5. Ethics, integrity and social responsibility: Professional behavior, Responsibility and accountability. Professional behavior. Proactively planning for one's career. Staying current on the world of biomedicine

Section 3 – Communication and teamwork

3.1. Teamwork: Forming effective teams. Team operation. Team growth and evolution. Team leadership

3.2. Communications: Communications strategy. Communications structure. Written communication. Electronic/multimedia communication. Graphical communication. Oral presentation and interpersonal communications

Section 4 – To conceive, design, implement and operate systems in the enterprise and societal context

4.1. External and societal context: Roles and responsibility of a biomedical professional. The impact of biomedicine in society. Society's regulations of biomedicine. The historical and cultural context. Contemporary issues and values

4.2. Enterprise and business context: Appreciating different enterprise cultures. Enterprise strategy, goals, and planning. Bio-entrepreneurship

4.3. Understand and identify the need for biomedical products and systems: Setting system goals and requirements. Defining function, concept and architecture. Modelling of the system and ensuring goals can be met. Development. Project management.

4.4. Designing new biomedical products and systems: The design process. The design process phasing and approaches. Utilization of knowledge in design. Disciplinary design.

4.5. Implementing new biomedical products and systems: Designing the implementation. Process hardware manufacturing process. Software implementation. Process hardware software Integration. Test, verification, validation, and certification. Implementation management.

4.6. Operating new biomedical products and systems: Designing and optimizing operations. Training and operations. Supporting the system. Lifecycle system improvement and evolution. Disposal and life-end issues. Operations management.

Section 5 – Research and development projects in a scientific and societal context

5.1. Societal terms and conditions: Individual responsibility. Knowledge of societal and environmental effects. Rules and regulations. Global development. Sustainability and the need for sustainable development.

5.2. Financial terms and conditions: Understanding financial and economical tools for control. Planning, strategies, and goals for knowledge development. Knowledge-based entrepreneurship. Working in an organization. Working in an international organization. Development and evaluation of acquired knowledge.

5.3. Identification of research need: Specify project aim(s). Define project function, components and delimiters. Organize project components according to project aim(s). Lead the project during the planning phase.

5.4. Implementation of the research project: Knowledge of the project´s phases and methods. Knowledge of projects within one´s field and of translational projects. Knowledge of a sustainable work process. Experimental design and research planning. Interaction between theoretical and experimental knowledge. Testing and verification of results. Leadership and follow-up during implementation.

5.5. Presentation and evaluation: Present knowledge in a scientific manner. Present knowledge using layman-terms. Implementation of acquired knowledge. Evaluation of the work process.

DESIGN AND EXECUTION OF THE SURVEY

To a large extent, the design of the syllabus survey follows the description in Crawley et al. (2014). The first step is to identify relevant stakeholder groups for the program. In this case, the stakeholder groups included students and professionals (both alumni and non-alumni), and the professionals were from academia, health care or industry. In some of the previous uses of the syllabus survey also a group of faculty members was included, but this was not the case here. The survey was done using a web interface, and the participants were contacted via e-mail, or through social media by the Facebook alumni group, in which the background and the purpose of the survey were described.

The survey used the grading scale that is proposed in Crawley et al. (2014) i.e.
1. To have experience or been exposed to.
2. To be able to participate and contribute to.
3. To be able to understand and explain.
4. To be skilled in practice or implementation.
5. To be able to lead or innovate in.

The participants were informed that they will perform the survey regularly during the education program. They were also asked to be aware of the limited time for an education program and hence avoid putting the highest score on all items in order to leave access to progression. (A possibility would be to maximize the total sum of the grades given. This possibility was discussed, but the limited time did not allow the implementation.) In total 87 answers were obtained, and the distribution over the different stakeholder categories is shown in Table 1. Comparing with the results in Bankel et al. (2003), the total number of responses is of the same order of magnitude. Also, the number of responses from professionals, i.e. 58, is even higher than the corresponding categories for several of the participating universities in Bankel et al. (2003). Notably, faculty was included in Bankel et al. (2003) but, as mentioned above, not in the study presented here.

Table 1. The number of responses in the different stakeholder groups.

Participants	Response (n)
Students (n=29)	
BSc old	6
BAc new	7
MSc	16
Alumni (n=41)	

	Academia	16
	Healthcare	8
	Industry	17
Non-alumni (n=17)		
	Academia	13
	Healthcare	2
	Industry	2

SURVEY RESULTS AND ANALYSIS

The mean value for each item averaged over all answers is given in the diagram in Figure 1.
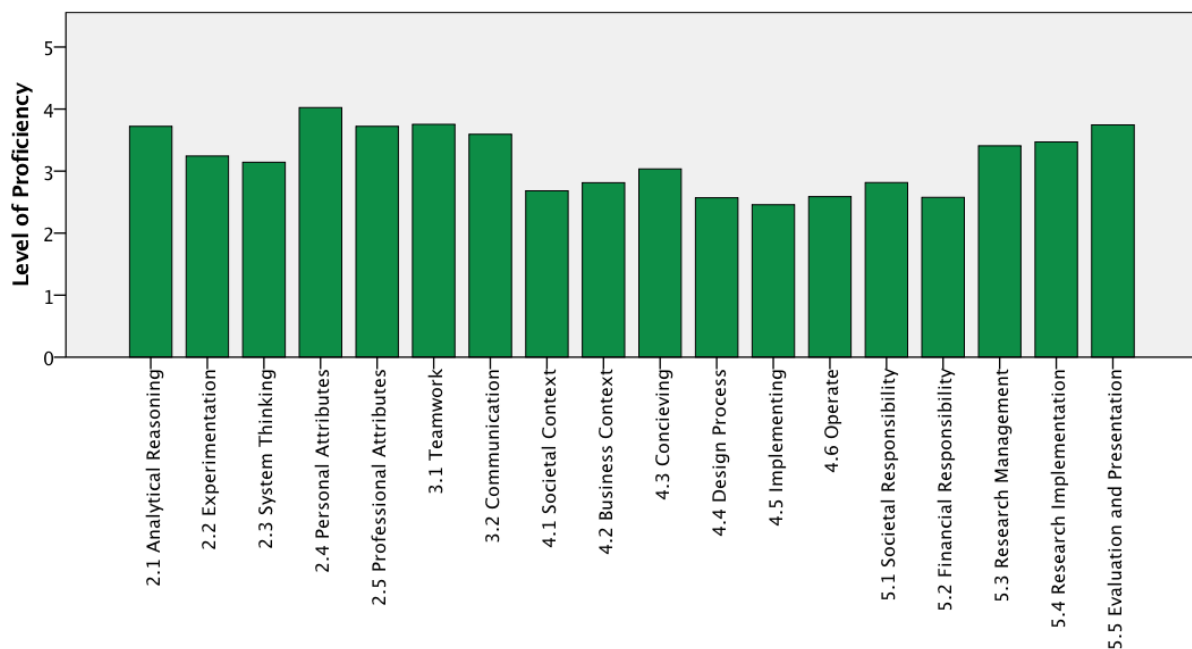
Figure 1. Mean values over all 87 responses. For a detailed description of the items in the adapted Syllabus see above.

First, it can be noted that the variation of the mean values is relatively small and that they range between 2.4 and 4.0. Figure 1 shows that the highest scores are given for items 2.1 (average 3.7), 2.4 (average 4.0), and 2.5 (average 3.7) respectively, connected to the personal and professional skills. Furthermore, items 3.1 (average 3.8) and 3.2 (average 3.6) about teamwork and communication get high scores. Also, item 5.5 (average 3.8), presentation and evaluation, is given a high score. It can also be seen that items 5.x, i.e. corresponding to the academic career, in most cases are given higher scores than the corresponding items in section 4.

Comparing with e.g. Figure 3.9 in Crawley et al. (2014), showing the results for MIT professionals (including both faculty and industry), it is found that items 2.1, 2.4, 3.1, and 3.2 are given relatively high scores. One noticeable difference is found for section 4 were the MIT results show a big difference between the different items. Items 4.1 and 4.2 get very low scores, 2.0 or lower, while the other items, particularly 4.3 and 4.4, get larger scores. In Figure 1 the average scores of the different items in section 4 have a flatter distribution.

Figure 3.10 in Crawley et al. (2014) shows a comparison between alumni from MIT and Queens University in Belfast (QUB). The QUB alumni also put comparatively high scores for 2.1, 2.4, 3.1, and 3.2, but the distribution of the items of the section looks more like the one in Figure 1.

Figure 2 shows the mean value for each item when the responses have been split into the two groups of students (29 answers) and professional (57 answers). The student group includes both Bachelor's and Master's level students, and the professional's group include both alumni and others.
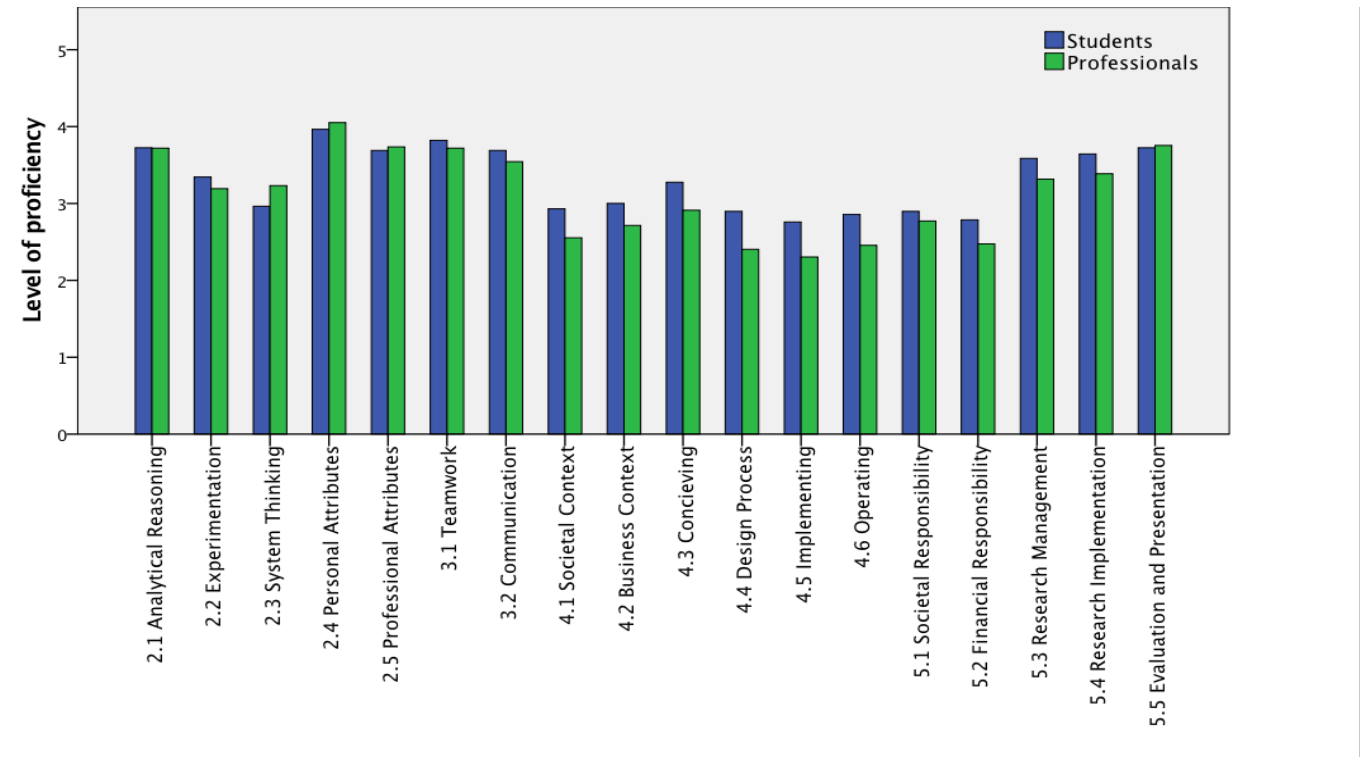
Figure 2. Mean values for the 29 students and the 58 professionals respectively. For a detailed description of the items in the adapted Syllabus see above.

The main observation in Figure 2 is that there is no big difference in the results between the two categories. The students seem to choose somewhat higher scores, but in general, the distribution over the sections and the items are similar.

Figure 3 shows the mean values of the scores for professionals split into the groups; industry (19 responses), healthcare (10 responses), and academia (29 responses) respectively.
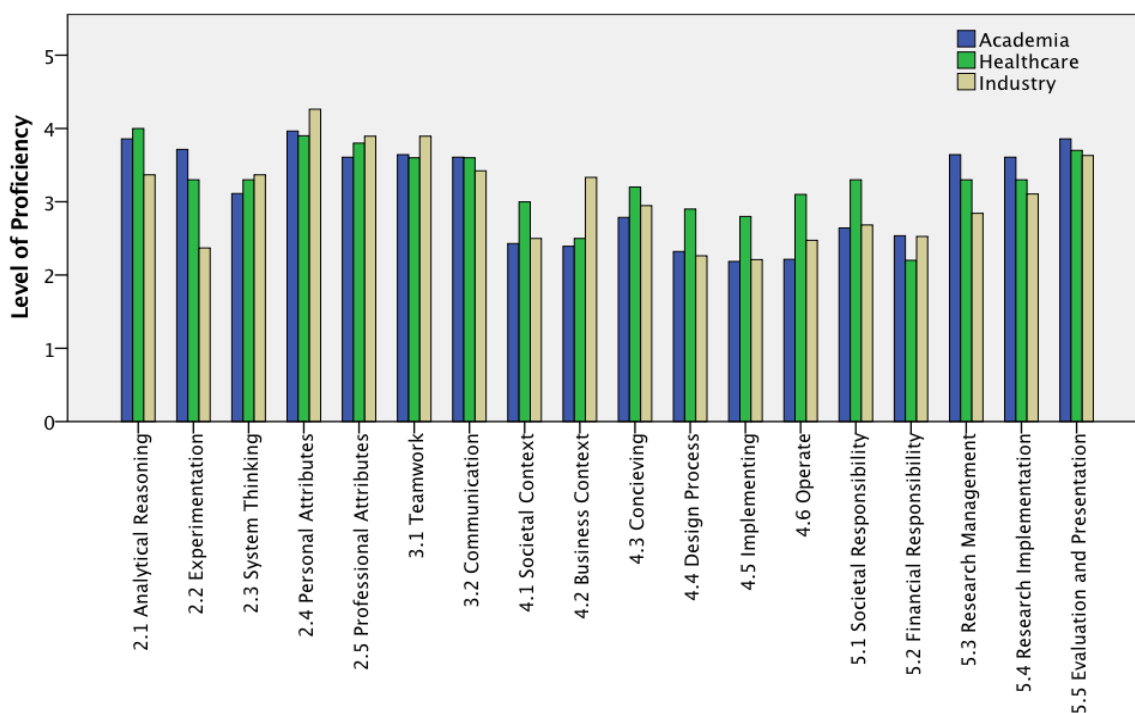
Figure 3. Mean values for the different categories of professionals; industry, healthcare and academia. For a detailed description of the items in the adapted Syllabus see above.

Keeping in mind that there are relatively few responses in some of the groups some interesting observations can be made using Figure 3. For section 4, which is more focused on an industrial career, the healthcare group gives the highest scores. The exception is 4.2, i.e. Business context, for which the group industry has put the highest score. Item 4.2 includes keywords such as bio-entrepreneurship and enterprise strategy, and it is hence reasonable that this is rated high by the group industry. The high scores from the healthcare group for items 4.2 – 4.6 can be understood by considering the typical role for a biomedicine graduate in the healthcare sector. For section 5, which has a research focus, the acedemia group has the highest average score, which also is reasonable. It is notable that the highest score of all is the given by the group industry for item 2.4, i.e. personal attributes.

CONCLUSIONS

The paper has presented an application of the CDIO Syllabus survey to the Bachelor's and Master's programs in Experimental and Medical Biosciences, within the Faculty of Medicine and Health Sciences at Linköping University, Sweden. The programs have been, and are, subject to considerable redesign with strong influence from the CDIO framework. One of the steps in the development process has been to carry out a Syllabus survey based on an adapted version of the CDIO Syllabus. The survey was sent out to students and various categories of professionals, and in total, 87 answers were given. The main conclusions of the results are:

- Like engineering education, see, e.g. Bankel et al. (2003), the items Analytical Reasoning (2.1), Personal Attributes (2.4), Teamwork (3.1), and Communication (3.2) are given the highest scores.
- There is no dramatic difference in the answers between students and professionals.
- For the three groups of professionals there are similarities but also differences in the responses, e.g. Experimentation (2.2) - less needed in industry, and this will be the topic for further investigations.

The outcome of the survey supports the steps already taken in the redesign of the program and provides very useful guidance for the ongoing work dealing with redesign of the later parts of the program. In addition, the results in the paper show that the CDIO framework is applicable and very useful also for a program within the biomedicine field and that the Syllabus survey is a convenient and systematic tool for getting stakeholder input in the processes for program management and development.

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THE COLLABORATION BETWEEN ACADEMIA AND INDUSTRY FOR ENHANCING EMPLOYABILITY AND FACULTY DEVELOPMENT

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ABSTRACT

The aim of this paper is to share an academia-industry collaboration experience at a Soil and Water Engineering (SWE) Program, the Department of Agricultural Engineering (AE), Faculty of Engineering, Rajamangala University of Technology Thanyaburi (RMUTT), Thailand. The program has been launched since 2003. The program committee has a high ambition to popularize this program for relevant Thai agricultural-based industries. In 2015, the program name was changed to Irrigation Engineering and Water Management (IRE). The department has adopted the CDIO framework, especially CDIO standard 3, 5, 7, 9 as a strategic plan for creating collaboration with the industry.

A system of academia-industry collaboration at SWE and IRE has 5 steps. The first step is a university visit. The department invites managers/key persons from companies as guest lecturers, invited speakers and project co-advisors. The second step is to send SWE and IRE students for an industry internship at those companies. The university offers a 2-month on-the-job training (OJT) and a 4-month co-operative education (Co-op) courses for all students. The third step is an industry visit by the faculty member while the students are having their internship. This visit allows the faculty members to share their expertise with real-life problems the industry is facing. The fourth step is an industry-based co-research where the faculty members work closely with the industry to solve specific problems, form a research group, enhance professional skills, and transfer real-world experience to students. The fifth step is to co-create curriculum development for SWE and IRE to better educate future engineers entering the industry.

The result of this collaboration enhances student employability after graduation. Most of them receive job offers from those companies immediately. From 2012-2017, 52 students had co-operative education in 6 companies, and 17 of them (32.70%) were recruited. Moreover, academia-university collaboration has enhanced the faculty professional development regarding the knowledge and skills required to work successfully in the industry. In addition, the collaboration also reveals the knowledge and skills that graduates should have that resulting in revising curriculum supporting the industry's needs.

KEYWORDS

Academia-industry collaboration, soil and water engineering, irrigation engineering and water management program, standards: 3, 5, 7, 9.

INTRODUCTION

Soil and Water Engineering (SWE) program has started since 2003, considered as the first and the newest program in Thailand at that time. It is an undergraduate program at the Department of Agricultural Engineering (AE), Faculty of Engineering, Rajamangala University of Technology Thanyaburi (RMUTT). The program objectives are:

      1) To produce SWE graduates
      2) To design and implement farm irrigation system techniques and
      3) To fulfill the industry's needs on SWE engineers

Since it was a new program, the program committee has a high ambition to popularize it to serve Thai agricultural-based industries. This paper aims to share an academia-industry collaboration experience that benefits both parties. Participating companies contribute their human resources; such as managers, key-persons, engineers, to be guest lecturers, invited speakers and project co-advisors. Examples of delegates from the industry are the Director of Ground Water Department, the CEO of Kongsanguan-Engineering Co., Ltd. and a lecturer from Sukhothai Thammathirat Open University. In addition, the participating companies accept SWE students for 2-month on-the-job (OJT) training. The students are required to work at a public or private organization in order to get experience according to SWE. Examples of participating companies are Kongsanguan-Engineering1993 Co., Ltd., Power Engineering Trading Co., Ltd, and Inter Tech Consultants Co., Ltd. Usually, the graduates are employed as consultants, hydroponic entrepreneurs, irrigation engineers, sale engineers and government officers.

Kuptasthien et al. (2014) presented that RMUTT, as the first CDIO collaborator in Thailand, has started introducing and applying the Conceive-Design-Implement-Operate (CDIO) Framework for Re-Thinking Engineering Education since 2013 through a collaboration with Singapore Polytechnic (SP), supported by Temasek Foundation International (TFI). The institution is fully committed to the adoption and implementation of CDIO framework. RMUTT has established the quality management framework with CDIO as a foundation to produce hands-on professional graduates. Currently, 12 programs from 5 faculties: Engineering, Business Administration, Mass Communication Technology, Architecture and Thai Traditional Medicine College, have fully adopted the CDIO framework. The Industrial Engineering was the pioneer program to adopt CDIO. Tangkijviwat et al. (2018) discussed the CDIO principal was presented and promoted to all faculty members in the annual seminar in 2014 at the faculty of Mass Communication Technology. In 2015, the Soil and Water Engineering (SWE) program was modified into Irrigation Engineering and Water Management (IRE) program. The AE department has adopted the CDIO framework, especially CDIO standard 3, 5, 7, 9 as a strategic plan for creating a collaboration with the industry. The integrated curriculum (CDIO standard 3) design ensures that the new graduates meet the industry expectation. There are courses that enhance the student's experience on design and build (CDIO standard 5) project. The integrated learning experiences (CDIO standard 7) with 2-month OJT and 4-month co-operative education (Co-op) strengthen the linkage with the industry. Lastly, faculty members enhance their competencies (CDIO standard 9) by working closely with the industry.

A number of literatures show that many universities apply CDIO framework in enhancing the collaboration between faculty and industry. Male et al. (2016) stated that the CDIO standards provide an excellent framework for the engagement of industry stakeholders in the development and operation of professional engineering degrees. The principal found from the consultation with industry are very strong drivers for engagement in terms of industry and

company visibility for recruiting and brand promotion, internal staff development, relationship development, and social (corporate and professional) responsibility. Kamp and Verdegaal (2015) reported that an internship enables the university to include authentic practical experience (CDIO Standard1) and make an integrated curriculum (CDIO Standard 3) with an intensive integrated learning experience (CDIO Standard 7). The intern is able to experience how it is to work as an engineer in the industry and develops a good sense of ethical accountability and social responsibility. Moreover, Mejtoft (2015) summarized that a higher level of engagement from both the students and the industry and actual valuable results can be achieved by integrating the teaching of professional skills into the curriculum. Active learning in a real context of design-implement-test projects make the students more aware of actual problems, work harder and have a more professional attitude towards the project and the results.

Several literatures show that there are various types of industry/university collaborations, for example, student internships, faculty exchanges and industry capstone projects to complete a degree program (Mead et al., 1999). Lee (2000) examined the sustainability of the collaboration experience by focusing on the actual "give-and-take" outcome between university faculty members and industrial firms. This study found that faculty members collaborating with industry bring with them a set of personal objectives for which they are willing to commit time, energy and intellectual resources. Liévana (2010) presented the relationship between industry and universities by reviewing the historical development of research and development labs in order to classify the linkages and strengths that emerged between universities and industry. Guimon (2013) reviewed that the most appropriate approach to promoting university-industry collaboration depends on the country's technological and institutional endowment. The challenge for government is to select policy programs to support university-industry collaborations in developing countries.

Further, Pittayasophon and Intarakumnerd (2016) investigated the influence of firm characteristics on the decision to collaborate with universities and collaboration modes. The study findings have crucial implications for stimulating university-industry collaboration.

Based on the information above, the CDIO framework is one of the strong tools which can be used to manipulate the program effectively. Most of the collaboration between faculty and industry were considered in this study.

ACADEMIA-INDUSTRY COLLABORATION PROCESS

Collaboration between academia and company is important for skills development (education and training), acquisition, job offers, improvement of knowledge (innovation and technology transfer), promotion of curriculum and promotion of entrepreneurship. AE Department has set up an academia-industry collaboration system. There are 5 steps; namely, 1) university visit 2) student internship 3) industry visit 4) industry-based co-research and 5) co-create the curriculum development as shown in Figure 1.

Figure 1. AE-RMUTT academia-industry collaboration system

University Visit

In order to start an industry-university collaboration, the first step is to introduce the department to the industrial companies. Managers and key persons from selected companies are invited to contribute as guest lecturers, invited speakers and project co-advisors. This step allows the industry to get familiar with the SWE and IRE programs, as well as the faculty members. Recently in a seminar course, "Modeling for Irrigation System and Water Management Project in Thailand" lectures were given by a senior engineer whose expertise is an irrigation system from Southeast Asia Technology Co., Ltd. and a CEO from InterTech Consultants, Co., Ltd. respectively. Moreover, the department invited a guest lecturer from the Royal Irrigation Department (RID) to give a lecture in the Water Resource Development subject. Figure 2 shows photos taken from those events.

Figure 2. University visits from the industry

Student Internship

The second step is to send SWE and IRE students for internships at partner companies. There are more than 30 companies in the suggestion list preparing for students. RMUTT provides 2 types of internship to the student, as following:

Co-operative Education (Co-op)

Practice in a government organization, a state enterprise or a company in the relevant field of engineering as a temporary full-time employee with certain responsibility, under assigned job supervisor who will advise the student during the entire period of the training, required at least 16 weeks. The training will be also advised, followed up, and evaluated systematically by co-

op advisor and/or co-op staff to assist students to gain direct experiences, realize their capacity, and develop themselves before graduation.

On-the-job Training (OJT)

Practice in a government organization, a state enterprise or a company in the relevant field of engineering for at least 270 hours to realize working experiences before graduation.

Table 1 shows numbers of companies and students participated in the internship from 2012-2017. There are 6 companies that continuously offer an internship to RMUTT students. The number of students and the name list of those 6 companies is shown in Table 2. For the academic year 2018-2019, the process has not completed yet.

Table 1. Number of companies and students for internship program from 2012-2017

Year	Number of Companies	Number of Students taking Internship
2012	9	16
2013	12	30
2014	12	21
2015	11	20
2016	4	5
2017	16	31

Table 2. Name list of company for co-operative education of academic year 2012-2017

Company	Number of students	Number of students who were recruited after graduated	Number of Alumni who are still work at the company
Kongsanguan Engineering 1993 Co., Ltd.	6	4	8
Power Engineering Trading Co., Ltd.	8	3	5
InterTech Consultants Co., Ltd.	11	2	5
Paragon Engineering Consultants Co., Ltd.	10	4	7
Southeast Asia Technology Co., Ltd.	8	2	3
Cholnawat Co., Ltd.	9	2	4
Total	52	17	32

Industry Visit

The third step is an industry visit by the faculty member while the students are having their internships at partner companies. This visit allows the faculty members to share their expertise in real-life problems with the industry. At the same time, the students have realized the linkage between the knowledge they acquired at the university and how to implement it in the working environment. Figure 3 shows faculty members of the IRE program visiting the company.

Figure 3. IRE program committees visit partner companies

Industry-based Co-research

The forth step is an industry-based co-research where the faculty members work closely with the industry to solve specific problems, form a research group, enhance professional skills, and transfer real-world information to students. There are several ways of linking research to teaching and transferring knowledge to students, i.e. research-oriented and research-based teaching. This step provides good opportunities for the student to explore real problems and develop a competency to conduct research. Table 3 shows the co-research titles and courses that integrate the knowledge into classrooms. Figure 4 also represents the program committee works closely with the industries.

Table 3. Co-research projects and related courses

Company / Year	Project Name	Lecturer	Expertise	Related Course
InterTech Consultants Co., Ltd./ (2015)	Environmental Impact Assessment (EIA), Mae Nung Reservoir, Lampang Province	Sanidda	Hydrology Specialist	• Engineering Hydrology • Water Resource Engineering • Geographic Information System Application for Engineers
		Supachai	Water Resource Specialist	
		Apirat	GIS Specialist	
United Analyst and Engineering Consultant Co., LTD. (2017-2018)	Environmental Impact Analysis of the Bangkok Airport Development: Don Mueang Airport Development Project	Sanidda	Hydrology Specialist	• Engineering Hydrology • Irrigation Engineering and Water Management Pre-Project
Cholnawat Co., Ltd. (2017)	Project Development of Water Information System at the Sub-district Level	Sanidda	Hydrology Specialist	• Engineering Hydrology • Water Resource Engineering • Geographic Information System Application for Engineers
		Supachai	Water Resource Specialist	
		Apirat	GIS Specialist	
Cholnawat Co., Ltd. (2018)	The Feasibility Study and Environmental Impact Assessment of Flood Relief in Chumphon Province	Sanidda	Hydrology-Water Balance Specialist	• Engineering Hydrology • Water Resource Engineering • Irrigation Engineering and Water Management Pre-Project
		Supachai	Water Resource Specialist	
Cholnawat Co., Ltd.	Preliminary Environmental	Sanidda	Hydrology Specialist	• Engineering Hydrology

(2018)	Impact Assessment of the Royal-initiated Huai Mae Khian Reservoir Project, Ngao District, Lampang Province	Supachai	Water Resource Specialist	• Water Resource Engineering • Irrigation Engineering and Water Management Pre-Project

Co-develop Curriculum

The fifth step is to co-develop SWE and IRE curriculum to better educate future engineers entering the industry. The staffs from the company were invited to criticize, validate and give comments on the development of a new curriculum. There are some suggestions on adding knowledge on basic computer, creative thinking and English communication skills. Therefore, the program outcome can meet the industry's expectation on graduate's knowledge, skills, and competencies.

Figure 4. The program committee work closely with the industries

RESULT OF COLLABORATION

Not only the university and industry can strengthen the collaboration, but also enhance the student job opportunity and employability after graduation. Many of the students got job offers from internship companies immediately. As shown in Table 2, 52 students had co-operative education in 6 companies, and 17 of them (32.70%) were recruited.

Other benefits from this academia-industry collaboration can be listed below:
1) Promoting the SWE and IRE curriculum
2) Expanding the collaboration with the industry
3) Validating the curriculum and receiving feedback for curriculum development
4) Student Internship
5) Co-research between industry and the program members
6) Sharing of knowledge, expertise and experiences
7) Providing professional development training to partner companies' employees to update and up-skill the knowledge and competencies
8) Job opportunity for the student

These benefits are conforming to Mead et al. (1999); Lee (2000) and Liévana (2010), mentioning that benefits from academia-industry collaboration are importance to develop education and fulfill requirements of curriculum outcome. Mead et al. (1999) summarized these partnerships also resulted in increasing potential revenues among the partners and expansion of contacts and resources from both sides of the partnerships. Moreover, students also earn benefits from this collaboration as the following:

1) Learning the industry working styles
2) Learning how to solve an urgent problem
3) Applying the knowledge from university to the real work
4) Experiencing job supervision
5) Practicing presentation and communication
6) Coordinating with another agency

For further improvement the academia-industry collaboration, the following steps should be considered 1) Memorandum of Agreement signing between the AE department and the companies, 2) funding support from the industry and 3) continuously part-time job at the company after students go back the university. However, the sustainability of the collaboration is the challenge faced in implementing the academia-industry collaboration.

CONCLUSION

In this study, the application CDIO is able to enhance the competency of graduates and program committee to meet stakeholder requirement. Moreover, academia-university collaboration has enhanced the faculty professional development regarding the knowledge and skills required to work successfully in the industry. In addition, the collaboration also reveals the knowledge and skills that graduates should have that resulting in revising curriculum supporting the industry's needs. The above results indicate that there is a need to use the CDIO framework in a curriculum. Moreover, the results of the study provided valuable information that could help or give direction in a system of academia-industry collaboration that would eventually benefit the graduates and program committee in the Agricultural Department. For further study, it should survey the perception of student and satisfaction of industry. Moreover, the linking of teaching, research and community service will be considered.

ACKNOWLEDGMENTS

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COMPARISON OF DIFFERENT TYPES OF ACTIVE LEARNING IN A COURSE OF INDUSTRIAL ENGINEERING

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ABSTRACT

In accordance to CDIO, active learning methods engage students directly in thinking and, currently, the application of innovative learning tools in the engineering courses are becoming mandatory. The selection of the most appropriate methodology for each course is a challenge. Once CDIO adopts that assessment of student learning is the measure of the extent to which student achieves specified learning, the outcomes from the assessment can be adopted as one indicator giving the direction to the better choice of methodology. In this research, three innovative methodologies were applied with a group of 81 undergraduates belonged to an industrial engineering course. During one semester were collected the outcomes data of the assessment applying to the group using: Team-Based Assessment, Peer Assessment and Project-Based Assessment. The data were treated using ANOVA, Tuckey multiple comparisons and the paired t-test in order to validate the hypothesis that the average grade of the group after each type of assessment would be the same considering the three methodologies. The findings were discussed and presented. The work was concluded and opportunities for further researches were suggested.

KEYWORDS

Assessment, team assessment, peer assessment, industrial engineering course, project-based learning, standards: 7,8,11.

INTRODUCTION

As students are not all alike and have different expectations regarding their higher education experience, the school should provide different learning processes somehow adapted the students' profiles. Nevertheless, there are several constraints:

1. School's internal pedagogical regulations, which strongly limit the existence of different assessment paths in a course.
2. Outcomes-based program accreditation processes, which require that a minimum set of outcomes must be the same for every student. Thus, different learning processes must have the same outcomes.
3. Students usually prioritize their effort, so coursework that does not contribute to the course's grade is usually given a very low priority or left undone.

Removed from CDIO standards (standard 11): "Assessment of student learning is the measure of the extent to which each student achieves specified learning outcomes. Instructors usually conduct this assessment within their respective courses. Effective learning assessment uses a variety of methods matched appropriately to learning outcomes that address disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills. These methods may include written and oral tests, observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment. If we value personal and interpersonal skills, and product, process, and system building skills, and incorporate them into curriculum and learning experiences, then we must have effective assessment processes for measuring them. Different categories of learning outcomes require different assessment methods. For example, learning outcomes related to disciplinary knowledge may be assessed with oral and written tests, while those related to design-implement skills may be better measured with recorded observations. Using a variety of assessment methods accommodates a broader range of learning styles and increases the reliability and validity of the assessment data. As a result, determinations of students' achievement of the intended learning outcomes can be made with greater confidence." (CDIO, 2016).
Regarding this, we thought that Integrated Learning Experiences (standard 7), Active learning (standard 8) must be dominant in a CDIO program.
Also, different things to different people, so that it would be useful to have a reference/catalog for active learning methods. Based on this, methodologies as Team-based learning (TBL), Peer (standard 11) (PA) and Project-based learning (PBL) are being applied by the universities worldwide.

TEAM-BASED LEARNING (TBL) AND TEAM-BASED ASSESSMENT (TBA)

Team-Based Learning is an evidence-based collaborative learning teaching strategy designed around units of instruction, known as "modules," that are taught in a three-step cycle: preparation, in-class readiness assurance testing, and application-focused exercise. A class typically includes one module.

TBL has been adopted by schools, in order to develop the students' abilities to solve engineering problems (Borrego et al., 2013), as well as the development of transversal skills (Conway et al., 1993).

Maynard and Sanchez (2013) used a Crazy Machine with teamwork and verified that the experience gave students the opportunity to develop professional skills and learn about the design embedded system, encouraging students to reflect more in their learning and how it happened (or not).

Truong et al. (2014) using data collected during the deployment of CDIO's Capstone Projects, measured, assessed and analyzed the maturity levels of the student's teamwork capabilities. Based on their "in-house" rubric, which addressed key aspects of teamwork capabilities along five dimensions of (1) Shared leadership, (2) Team orientation, (3) Effort redundancy, (4) Learning results and (5) Team's autonomy.

In this research work, one of the applied assessment methods was the TBA, where the students had an examination conducted in a group with a maximum of six members regarded to the theoretical concepts of the discipline. In the group, each student had one different examination from the others and they had helped themselves to address the examination questions.

PEER ASSESSMENT (PA)

Peer assessment, in which students evaluate each other's work, has been defined as an arrangement for individuals to consider the amount, level, value, worth, quality or success of peers' learning products or outcomes (Topping 1998).

Peer assessment is a reflexive learning activity. It increases the students' time to the task and can help them consolidate, reinforce and deepen their understanding by letting them experience reviewing, summarizing, clarifying, giving feedback, diagnosing misconceived knowledge and identifying missing knowledge (Wengrowicz, Dori & Dori, 2017).

Thomson, Spooner & Chalashkanov (2015) presented evaluations of the performance of students on multiple peer review projects over their curriculum and also surveys students' perceptions and experiences on the use of peer assessment among students.

In this work, PA was conducted considering that individual student had to evaluate their peer' outcomes. The outcomes were regarded to assimilation of the content of the discipline.

PROJECT-BASED LEARNING (PBL) AND PROJECT-BASED ASSESSMENT (PBA)

The teaching role in PBL is changed. The teacher is no longer the expert lecturer, facts provider, and director of instruction but rather a resource provider, learning environment shaper, how-to-learn teacher, advisor, tutor and colleague (Buck, 2018). Krajcik, Czerniak and Berger (1999) suggest three possible advantages for the teacher. Firstly, the teacher may find the work enjoyable, interesting and motivating, since teaching will vary every year, as he/she will be exploring new projects with each new group of students. Secondly, in project-based teaching, the teacher continually receives new ideas, thus becoming a 'lifelong learner'. Thirdly, classroom management is simplified because when students are involved, they are likely to cause fewer disciplinary problems.

Frank & Barzilai (2004) described in their work that three challenges were experienced by the students when they were submitted to PBL methodology: coping with conflict situations in the teamwork, investing a lot of time and efforts, and coping with new contents in a learning environment which is neither structured nor organized in advance.

In general, students and teachers have been satisfied with the new learning process. Students think that the projects have now better "real working life feeling" than before. The new process is more meaningful, and its clear description tells who shall do what and when. Students particularly like the new way of setting learning goals for the project together with the project group instead of each student filling in a learning diary monthly (Määttä, Roslöf & Säisä, 2017). In our research work, PBA was conducted in the same groups of six members, where each group had to presented the final project to be evaluated, delivered one scientific article based on the project and one member from each group was randomly drawn to realize one examination about questions regarded to their group projects.

This paper aims to validate the hypothesis that the results originated from the assessment from the three methodologies, TBA, PA, PBA, were the same.

The results were quantitatively analyzed and commented, followed by suggestions for further researches.

APPLICATION AND FEEDBACK

TBA, PA and PBA has been applied, to eighty-one students, during one semester in one Industrial Engineering Course, having The Plant Design as the subject discipline. When the teacher understood, theoretical classes were conducted.

Research procedures

To apply these methodologies, the students were divided into groups with a maximum of six students.

First, the teacher presents the project, the assessment procedures, the content and importance of some meetings and the weighting of the final grade.

Second, under the teacher supervision, they define a timetable of the Project with the activities, responsibilities, date for begin and end of each part of the project.

To follow up on the project throughout the semester, there are meetings with the teacher throughout the semester.

During the semester, we apply:

1. **TBA assessment**: They work together, but each member has a different exam;
2. **PA assessment**: After one month of the previous assessment (TBA), each student is assessed individually by his peer;
3. **PBA assessment**: Here, the students present the final project. The assessment consists of presenting a report in the format of a scientific paper (50% of the final PBA grade), followed by presentation by the group (30% of the final PBA grade) and defense of it by one of the members, randomly drawn, of the group (20% of the final PBA grade).

FINDINGS AND DISCUSSIONS

We want to know if there is a significant difference between the averages obtained by the students, depending on the three methods used (TBA, PA and PBA).

For this, a Variance Analysis (ANOVA) was used, with classification and samples of the same size.

The null hypothesis to be tested, of equality between the three means and the alternative hypothesis, can be presented as follows:

H_0: $\mu_{TBA} = \mu_{PA} = \mu_{PBA}$
H1: there is at least a different average

The summary of results and the table of analysis of variance are presented in Table 1 and Table 2, respectively:

Table 1. Summary of ANOVA results

Groups	Count	Sum	Average	Variance
TBA	81	607	7,49382716	3,36558642
PA	81	676,5	8,351851852	3,402777778
PBA	81	645	7,962962963	1,561111111

Table 2. ANOVA test results

Source of Variation	Sums of Squares	Degrees of freedom	Mean Square	F-Values	P-Value
Between groups	29,9033	2	14,9516	5,3851	0,0052
Within groups /Error	666,3580	240	2,7765		
Total	696,2613	242			

The P-value found is much lower than the usual significance levels. This indicates the existence of a significant difference between the 3 methods.

The ANOVA identified a difference between means, but the question remains: which average (s) should be considered different from what other(s)? In principle, the PA method seems to be the largest and the TBA method is the smallest, but it is necessary to continue the analysis because it can be concluded from the difference among the three means or two or two partial differences. To do so, we decided to use two methods: the Tuckey multiple comparisons and the paired t-test applied between the samples, two by two.

Because the samples are the same size, the Tuckey method is efficient. This method uses critical values of the standardized amplitude, denoted by q. The literature provides critical values of q in the case of a normal population. If we want to compare k samples, each of them with n elements, the procedure recommends considering the means μ_i e μ_j as distinct:

$$\left| \bar{x}_i - \bar{x}_j \right| > q_{k,v,\alpha}\sqrt{S_R^2/n} \,, \tag{1}$$

Where: α is the desired level of significance, $v = k(n-1)$ e S_R^2 is the residual variance.
For the case under analysis, we have: n=81; k=3; S_R^2=2,78. And adopting the significance level of 5%, we must use q_(3,240,5%)=3,33. Averages of more than 0.62 should, therefore, be considered different. The results are:

$$\left| \bar{x}_{TBA} - \bar{x}_{PA} \right| = 0,86$$
$$\left| \bar{x}_{PA} - \bar{x}_{PBA} \right| = 0,39 \tag{2}$$
$$\left| \bar{x}_{PBA} - \bar{x}_{TBA} \right| = 0,47$$

That is, the averages of the TBA method and the PA method are considered different from each other. Better: the average PA is bigger than the TBA. In addition, taken two by two there seem to be no significant differences: between PBA and TBA and between TBA and PBA.

But by this method, it is not possible to know from what level of significance it can be said that there is a difference between these means. For this, the t-test was applied, with paired samples, two by two. Student identity is the criterion for matching the data. The t-test is used to compare two means with each other.

When the data from two samples are paired, it makes sense to calculate the di differences corresponding to each pair of values and test the hypothesis that the difference between the means of the two paired populations is equal to a certain Δ value. This is equivalent to testing the hypothesis that the mean of all differences for populations is equal to Δ.

That is, we will simply test the hypothesis H0: μ_d = Δ against an H1 alternative that may correspond to a unilateral or bilateral test, depending on the interest. The test value will be the Student t test that will be compared with the critical value of Student t obtained as a function of the level of significance with n - 1 degree of freedom. Or a complementary procedure that is to analyze the p-value corresponding to Student's t experimental. It is therefore calculated:

$$t = \frac{\bar{d} - \Delta}{S_d/\sqrt{n}} \tag{3}$$

at where:
$(\bar{d})$ is the mean of the sample of differences,
Δ is the tested value of the mean of the differences in populations, which will be zero when testing equality
S_d is the sample standard deviation of each method
n is the sample size of the differences
Summary, we have the desired and realized tests, thanks to the pairing of the data, which are shown in Table 3.

Table 3. Conducted t-tests

Test initially desired	Test performed, thanks to pairing of data
H0: $\mu_{TBA} = \mu_{PA}$ H1: $\mu_{TBA} \neq \mu_{PA}$	H0: $\mu_{d1} = 0$ H1: $\mu_{d1} \neq 0$
H0: $\mu_{TBA} = \mu_{PBA}$ H1: $\mu_{TBA} \neq \mu_{PBA}$	H0: $\mu_{d2} = 0$ H1: $\mu_{d2} \neq 0$
H0: $\mu_{PBA} = \mu_{PA}$ H1: $\mu_{PBA} \neq \mu_{PA}$	H0: $\mu_{d3} = 0$ H1: $\mu_{d3} \neq 0$

The t-tests were performed using Microsoft Excel ® software, using the "t-test: two paired samples for averages", available in "Data analysis". The summary of results is shown in Table 4.

Table 4. t-tests results

	H0: $\mu_{TBA} = \mu_{PA}$		H0: $\mu_{TBA} = \mu_{PBA}$		H0: $\mu_{PBA} = \mu_{PA}$	
	Team	Peer	Peer	PBL	PBL	Team

average	7,4938	8,3518	8,3518	7,9629	7,9629	7,4938
variance	3,3655	3,4027	3,4027	1,5611	1,5611	3,365
observations	81	81	81	81	81	81
difference hypothesis	0		0		0	
degrees of freedom	80		80		80	
Student's t experimental	-3,204347501		1,898141506		1,883127441	
p-value uni-caudal	0,000972467		0,030642028		0,031658786	
t critical uni-caudal	1,664124579		1,664124579		1,664124579	
p-value bi-caudal	0,001944935		0,061284056		0,063317572	
t critical bi-caudal	1,990063421		1,990063421		1,990063421	

From these results, especially by analysing the p-values, one can conclude that the data are compatible with the mean difference, with strong or moderate evidence, as summarized in Table 5.

Table 5. Summary of t-tests results

	PA	PBA
TBA	Single p-value = 0.0010 Two-tailed p-value = 0.0019 It is concluded that the results are compatible with the difference between the averages (strong evidence)	Single p-value = 0.0317 Two-tailed p-value = 0.0633 We conclude that the results are compatible with the difference between the means (moderate evidence)
PA		Single p-value = 0.0306 Two-tailed p-value = 0.0613 We conclude that the results are compatible with the difference between the means (moderate evidence)

It is seen that such results are always compatible with the difference between the three means, although in different degrees of intensity in the certainty of these conclusions.
The results obtained by the two methods (Tuckey method and two-two t-test) are compatible and can be synthesized as follows:

$$\mu_{PA} > \mu_{PBA} > \mu_{TBA} \tag{4}$$

CONCLUSIONS

The purpose of this research work was reached by the demonstration that the average of the outcomes obtained from the assessments data from the TBA, PA and PBA was not the same, which demonstrated that the hypothesis H0 was not true.
As a practical implication, this work can be used as a guide for professors who are looking forward to applying one of these three innovative methodologies as an alternative to the conventional assessment approach.
This research work presents limitations as (1) The results were obtained from Industrial Engineering Course only, as well as from one specific discipline, (2) The significance value adopted was 0.5% to reach the F-Critical value which can change if a higher significance value would be adopted, changing the results.

As further researches it is recommended that the same approach using the three methodologies could be applied in a different course, for example, Business Administration, and ANOVA, Tukey and t-test analysis could be conducted for the comparison of the results, adding one more significant value to reach the F-Critical in order to validate or not the H0 hypothesis.

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CDIO IMPLEMENTED PROJECTS IN A COMPUTER AIDED DESIGN COURSE

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ABSTRACT

Instruction of a Computer Aided Design (CAD) Course usually involves topics from three major disciplines: geometric modelling, computer graphics and engineering design. The traditional lecture-based instruction focuses on the analytical and theoretical portions of these disciplines, which has helped the students build a strong knowledge base of these disciplines. However, it also leads to the fact that many students may still lack the experiences to handle real engineering problems even after taking this crucial course. This paper discusses how to adopt the CDIO-implemented projects to a third year CAD course and help students to achieve their learning goals. It also discusses how to use the outcome based assessment tools to evaluate the attributes of the learners, which include design and creativity, communication and collaboration, proficiency of using engineering tools, project management skills and self-learning capability. The study has found that stressing and implementing active learning experiences through these projects can significantly improve the learning outcomes.

KEYWORDS

Computer Aided Design, CDIO Standards: 2, 5, 6, 7, 8, 11.

INTRODUCTION

In the University of Ontario, Institute of Technology (UOIT), Computer Aided Design is an engineering core course offered to all students in the programs of mechanical engineering, automotive engineering and manufacturing engineering. The major contents covered by the course include the topics such as geometric/solid modelling (e.g. curves, surfaces and solids), computer graphics, finite element analysis, CAD and CAM integration, product lifecycle management, virtual engineering as well as design optimization.

The author has taught this course since 2011 and has noticed that the traditional lecture-based instruction methods have played important roles on improving the analytical and theoretical skills of the students, which are very helpful to the students if they plan to continue the graduate studies or conduct R&D work in the future. However, aside from these capabilities, the

industries usually prefer the engineering students to have many market-oriented skills, such as communications skills, capabilities to use the engineering tools, collaboration and teamwork, knowledge of engineering economics and project management, self-learning capabilities etc.

Since 2012, the Canadian Engineering Accreditation Board (CEAB) has required all the Canadian Universities to implement their engineering programs so that students graduated from these programs will possess certain graduate attributes (e.g. knowledge base, problem analysis, design, investigation, and use of engineering tools etc.). At the same time, many educators have pointed out that a systematic reform of engineering education is necessary (Crawley et al., 2007), and CDIO based approaches are recommended for implementing the engineering education (Lynch et al. 2007). Many educators around the world have adopted CDIO standards to plan their curriculum (Hallenga-Brink et al., 2017) and prepare the assessment tools. (Lantada et al., 2017) Studies have shown that implementation of CDIO standards to the engineering design courses can effectively combine the design theory, lectures with various hands-on learning activities (e.g. sketching, CAD/CAE, fast prototyping), and provide much richer learning experiences to the undergraduate students. (deWeck et al., 2005) It has been found that to most engineering design courses, one of the critical issues about CDIO implementation is the skill evaluation system. (Munoz-Guijosa et al., 2016)

With more than five years' teaching experiences on the Computer Aided Design course, the author and his colleagues find that the sole dependence on the traditional lecture-based instruction method (illustrated in Figure 1) no longer works and the traditional evaluation tools such as paper-based exams can no longer accurately assess the students' performance. To achieve the teaching objectives, the instructor has specified the following course outcomes for a Computer Aided Design course: (CDIO standard 2)

1) Understand basics of geometric/solid modelling, computer graphics and feature modelling; e. g., represent curves and surfaces using parametric equations; understand the roles of a CAD/CAM/CAE system in the context of the product cycle; (CAD Knowledge)
2) Demonstrate the capability to analyze engineering problems with or without CAD/CAM/CAE tools; (Engineering Analysis)
3) Demonstrate the capability to conduct an investigation with given design specifications; (Investigation)
4) Demonstrate proficiency with product design and development processes; (Design)
5) Demonstrate proficiency with the application of CAD/CAE tools; (Use of CAD Tools)
6) Demonstrate strong communication skills to discuss, explain, present and promote engineering projects; (Communication Skills)
7) Demonstrate successful collaborations with peers and teammates; (Teamwork)
8) Demonstrate the capability to conduct simple project management and economic analysis, understand key issues in CAM and the data associativity benefits of CAD/CAM systems; (Economics and Project Management)
9) Have the capability to conduct self-learning for a commercial CAD/CAM/CAE system and to be a life-long learner. (Life Long Learning)

The terms shown in the brackets in the above are CEAB graduate attributes required in a Canadian engineering curriculum, and this paper will discuss how to use CDIO implemented projects to evaluate these attributes.
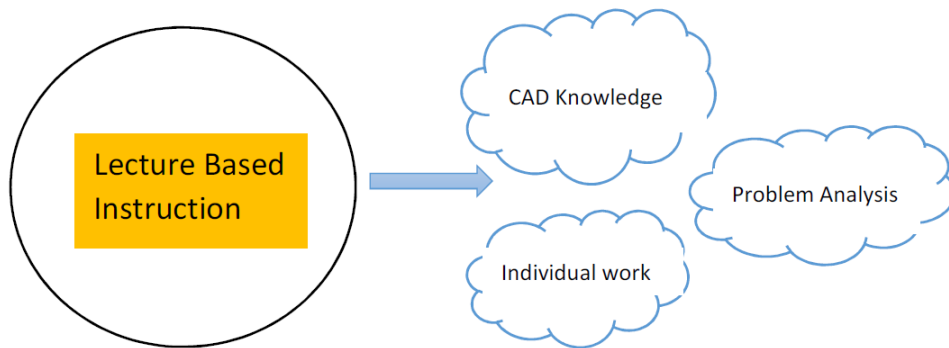
Figure 1: Traditional Instruction Method for CAD course
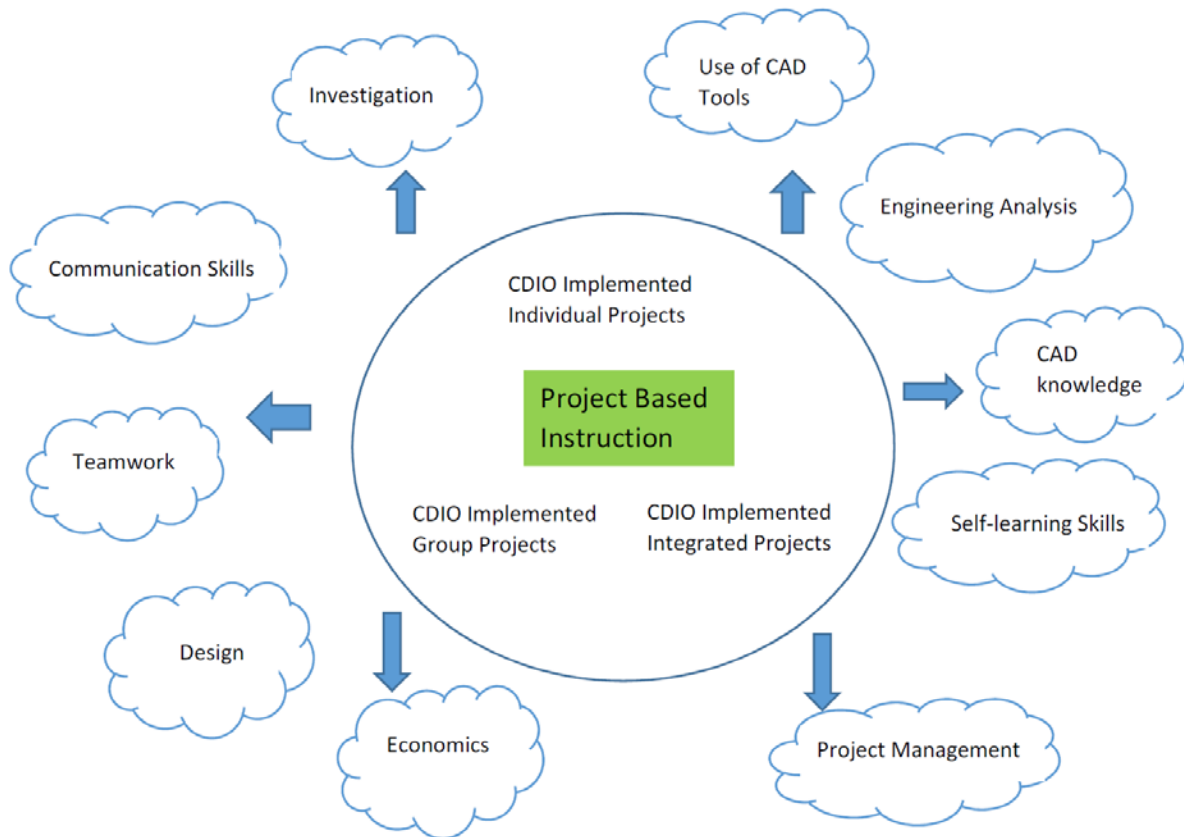
Figure 2: Project-Based Instruction Implemented with CDIO Standards

Since 2014, the instructor has initiated a Project based, CDIO implemented method to teach Computer Aided Design course. (Shown in Figure 2). The main feature of this teaching method is that aside from delivering the traditional lectures to the students, the instructor has developed three different types of projects that form the backbone of the course, and through them, the instructor expects the students will learn how to:
1. Design and develop products
2. Analyze and solve the engineering problems
3. Conduct technical investigations and market research
4. Manage the engineering projects
5. Collaborate with peers.

CDIO Implemented Projects

Table 1 shows the main characteristics of these different types of projects, which are all CDIO implemented.

Table 1 Comparison of Three Different CDIO Implemented Projects

Project Types	Group Size	Prototype Requirements?	Presentations Requirements?	Project Duration	Peer Review	CDIO standards
Individual Projects (Type I)	Individual	No	No	6 weeks	No	CDIO standard 2, 5, 8
Group Projects (Type II)	4-5 members per group	Yes	Yes	4 weeks	No	CDIO standard 2, 5, 6, 7, 8
Integrated Projects (Type III)	Up to 8 members per group	Yes	Yes	8 weeks	Yes	CDIO standard 2, 5, 6, 7, 8, 11

The individual project (type I project) is assigned right after the lectures, during which the instructor has introduced new theories or new concepts. (E.g. NURBS algorithm) It requires the students to follow the steps of Conceive, Design, Implement and Operate to develop a new product. It is an individual assignment, although it does not restrict the students from discussing with their peers. To complete this project, students must conduct some patent survey or literature research first and then generate the concepts with brainstorming. Students need to create technical sketches of the product and eventually complete a CAD model of it. To build the CAD model, students must teach themselves a new graphics software chosen by the instructor. (E.g. Rhinoceros) Finally, the students are required to write an essay to make comments about the CAD software and share their learning experiences accumulated through this project.

The instructor assigns different group projects (type II project) to the students as well. These projects have different storylines and the students call them "Case Studies". Although these projects cover different engineering topics, the instructor designs them carefully to achieve the following goals:

1) All the projects must be completed in groups so that students can gain integrated learning experiences (CDIO standard 7). While doing these projects, students not only need to review and practice the topics that the instructors have delivered in the lectures but also need to collaborate with their classmates, which require interpersonal skills. In addition, all the groups must present their projects in front of the classes and it is mandatory for the rest of the class to ask them questions after presentations. Through these interactive activities, the instructor expects students to learn how to apply their knowledge to the engineering practices, how to address their concerns and how to respond to the doubts or criticism in a professional manner.

2) These group projects require students to go through an active learning process (CDIO standard 8). The instructor does not offer direct guidelines to the students. Instead, he will offer a list of technical resources (e.g. software, books, articles, equipment) that may be helpful to the students. Through group discussions and meetings, students make their own decisions about how to use these resources. Students usually explore these resources through self-learning and teamwork, but if necessary, the instructor or teaching assistants will provide some suggestions.

3) Through these projects, the instructor help students understand and solve real engineering problems. Although topics of these projects are different, students' works still focus on the major aspects of the product development life cycle: market research, industrial design, engineering analysis and manufacturing. Students will gain design and build experiences (CDIO standard 5) through these projects.

4) Students can complete their projects through CDIO implemented workspace (CDIO standard 6). UOIT has regular CAD laboratories, which host more than 60 desktop terminals with more than 100 different software systems. In addition, every UOIT engineering student has a laptop assigned from the school, with the installation of all the required software systems. In 2017, the Engineering Faculty of UOIT opened a new Design Studio. This design facility has equipment that students can use with no costs (e.g. 3D scanner, 3D printers etc.) Two machine shops are also available for undergraduate engineering students.

The third type of projects is the integrated project (Type III). It is comprehensive and similar to an industrial project. It not only requires students to develop a product system but also requires them to conduct customer surveys, organize the meetings, create the budgets and execute a business model. Each project group could have a size of up to eight members. Based on their backgrounds and academic preferences, group members can assume their different roles in the team, such as project manager, industrial designer, engineering analyst or manufacturing specialist. This comprehensive project has specific requirements for collaboration and each member must fill the peer evaluation for their group work. The whole class will have the same project topic and it serves as a comprehensive tool to assess students' performance. (CDIO standard 11). The grade of this project includes the students' performance at four different areas: written project report, final presentation, prototype demonstration, and peer review. The

instructor not only assess the students' achievements based on their paper-based submission and oral presentations, but also the physical prototype they build as well as feedback from their peers.

Assessment Rubrics

These CDIO implemented projects have offered a rich portfolio of assessment tools to evaluate the students' performance, which includes project reports, sketches, drawings, rendered pictures or images, CAD models, prototypes, oral presentations, review essays, peer evaluations etc.

Table 2 shows the detailed rubrics which the instructor has used to assess the nine major course outcomes: CAD knowledge, engineering analysis, investigation, design, use of CAD tools, teamwork, communication skills, economics and project management and self-learning skills.

The rubrics have followed the outcome-based CEAB accreditation criteria (Kishawy et.al, 2014) as well as the dossier of the Computer Aided Design course in UOIT (Yang, 2016). The rubrics specify four different levels of course outcomes, with the highest level as Level3 (students achieve a grade of 80% or higher) and the lowest level as level0 (students achieve a grade of 50% or lower). Level2 (students achieve a grade of 60% to 80%) suggests a student performance level which meets the expectations from the instructor. (Popiiev, 2015)

Some of the CEAB graduate attributes have been measured with only one or two types of projects. For example, for the CAD knowledge, only Type I project is used for assessment. This arrangement could give the instructor some flexibility while preparing the project topics.

The integrated project (Type III project) has been used for assessing most course outcomes and it has served as the most important assessment tools of the course (weight of 25% of the full course grade). Type I and II projects have their specific focuses due to their assignment sizes and project lengths while serving as an assessment tool. (E.g., type I project mainly serves for assessing the CAD knowledge, design and self-learning skills)

Results and Discussions

Figure 3 shows the results of the assessments from three classes (sections) opened in Fall 2018. There are 240 students in this course and they are from three different programs: mechanical engineering, automotive engineering and manufacturing engineering. They are divided into three separate lecture sections and students from different programs have been mixed within different sections. The instructor conducted three hours of lectures per week for each section, and there are two weekly CAD lab hours offered to the students as well.

For each course outcome, Figure 3 has shown the number of students corresponding to different performance levels. The author has found that for all the course outcomes, the majority of the students have met or exceeded the expectations, and for some course outcomes such as communications and teamwork, students perform extremely well.

However, for the course outcomes such as knowledge base and self-learning skills, there are up to 15% of students who either fail or marginally meet the expectations. The author has noticed that both of these two-course outcomes have been assessed only with type I project, which requires individual work.

Table 2: Assessment Rubrics for CDIO Implemented Course Outcomes

Outcomes	Level 0 0-50% *Fails to meet expectations*	Level 1 50-60% *Minimally meets expectations*	Level 2 60-80% *Adequately meets expectations*	Level 3 80-100% *Exceeds expectations*
CAD Knowledge (Assessed with Type I Project)	Poor competence in geometric modelling and computer graphics	Students demonstrate limited understanding of geometric modelling and computer graphics.	Students demonstrate the ability to apply the fundamental theories of geometric modelling and computer graphics to explain the schemes and algorithms commonly used in a CAD system.	Students demonstrate the ability to apply the theories of geometric modelling and computer graphics accurately to explain, modify and develop the schemes and algorithms used in a CAD system.
Engineering Analysis (Assessed with Type III project)	Inability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems.	Students demonstrate limited ability to identify the type and primary objectives of the engineering problems, understand the methods used to solve the problems.	Students demonstrate the ability to decompose complex problems into relatively simple sub-problems and solve them with little errors.	Students demonstrate the ability to follow the scientific and engineering principle to analyze engineering problems and execute the solutions efficiently and accurately.
Investigation (Assessed with Type III projects)	Inability to conduct investigations of complex problems.	Students demonstrate limited ability to state an engineering problem or review of previous work.	Students demonstrate the ability to apply appropriate methods for data collection, select appropriate methods for implementation and use the results from previous work to draw a conclusion.	Students demonstrate the ability to analyze the results of previous work, summarize the limitations and implications and finally draw the conclusions and execute a successful plan for problem-solving.
Design (Assessed with Type I, II and III projects)	Inability to design solutions to the assigned open-ended problems.	Students demonstrate limited ability with product design and development process.	Students are proficient with product design and development process.	Students demonstrate impressive creativity and conduct product design and development proficiently

Use of CAD Tools (Assessed with Type I, II and III projects)	Inability to use common CAD tools to solve fundamental problems.	Students demonstrate limited capability to use common CAD tools to solve engineering problems, need external help while handling problems that require advanced skills.	Students demonstrate proficiency with the application of common CAD/CAE tools and could complete advanced problems with little external help.	Students demonstrate a high degree of proficiency with common CAD/CAE tools; become experts of one or two CAD tools.
Teamwork (Assessed with Type III projects)	Inability to work effectively as a member of a team.	Students demonstrate a limited appreciation of teamwork but still can work with another member fairly.	Students demonstrate the ability to contribute to a team, show the responsibility and help manage and organize the team.	Students demonstrate excellent collaborations with peers and show the leadership in a team
Communication Skills (Assessed with Type II and III projects)	Inability to deliver or describe complex engineering concepts. Inability to communicate with peers and colleagues.	Students demonstrate limited communication skills to discuss, explain, present and promote engineering projects;	Students demonstrate strong communication skills to discuss, explain, present and promote engineering projects;	Students demonstrate the ability to communicate with colleagues, and demonstrate the ability to present engineering concepts creatively
Economics and project management (Assessed with Type III projects)	Inability to apply the principles of economics and business practice, and inability to manage the engineering activities.	Students demonstrate limited ability to conduct basic engineering economics analysis and to manage engineering activities.	Students demonstrate the ability to conduct simple project management and economic analysis, understand key issues in CAM and the data associativity benefits of CAD/CAM systems.	Students demonstrate the ability to conduct moderate project management and economic analysis, understand key issues in CAM and the data associativity benefits of CAD/CAM systems.
Self-learning Skills (Assessed with Type I project)	Inability to conduct self-learning for a commercial CAD/CAM/CAE software.	Students demonstrate a limited ability to conduct self-learning for a commercial CAD/CAM/CAE system.	Students demonstrate the ability to conduct self-learning for a commercial CAD/CAM/CAE system and to be a life-long learner.	Students demonstrate the ability to develop a strategy to identify and address gaps in knowledge, undertake self-learning, and advance knowledge through research and other means.

Figure 3: Course Outcomes Assessed with CDIO Implemented Projects in UOIT (for all Fall 2018 semester)

The feedback from the students about these CDIO implemented projects are generally positive. Many students like the facts that the group projects (type II) and integrated projects (type III) allow them to learn actively. Compared with the traditional lecture-based instruction, these projects push them to learn through the collaboration and many students have improved themselves because they have been inspired and encouraged by their peers.

For the individual projects (type I), some students like it since it presses them to work independently. Many of them have pointed out that the challenges originated from this project actually have forced them to conduct active learning due to their desires to learn the software quickly and use it to solve the problems. However, there are also students who point out that they did not perform very well because of fact that this kind of project (type I) does not provide a platform where they can share their learning experiences; instead, they have been asked by the instructor to submit an essay describing their self-learning experiences.

The instructor has also collected the feedbacks from his teaching assistants and colleagues. The general agreement is that these projects have significantly enhanced the active learning experiences for the students. They also point out that one of the advantages of these CDIO implemented projects is that these projects can be used for assessing many course outcomes that traditional paper exams can't evaluate. However, these projects should not be used as only measurement tools for some course outcomes, such as knowledge base and use of CAD software. A combination with a traditional paper exam or an operational CAD lab exam could be a good solution.

LIMITATIONS AND CHALLENGES

Modifications and refinements are definitely required for these CDIO implemented projects, and the author identifies the following limitations and challenges:

The first challenge is about the accuracy of the assessment tools, especially for the group projects (Type II and Type III projects). Although each group assignment has been marked with cautions, and the mark of each team member has been adjusted through peer evaluation, there are still many factors that may lead to the errors. For example, the instructor has noticed some kind of mark inflation in the peer evaluations of group projects, and this can explain why course outcomes heavily affected by peer evaluations such as "communication skills" and "teamwork" have a much better performance compared with course outcomes such as "self-learning skills" and "knowledge base". As pointed out earlier, "self-learning skills" and "knowledge base" are only assessed with individual assignment (Type I project), without being affected by the peer evaluations at all.

The other issue is about the workload of the instruction. The marking and assessment of these projects need more teaching assistants to help the instructor. In addition to the traditional marking works such as marking the project reports and lab reports, more works hours now are required for consultations, prototype demonstrations as well as evaluating the project presentations and discussions.

The third challenge is about the size of the class. The instructor noticed that the optimum class size is about 40 -60 students. If the class size is too large, it is hard for the instructor to control; while if the class size is too small, although the instructor may spend more time on each student, it will limit the flexibility for the instructor to select project topics.

In the future, more implementations are required to address the above issues. For example, the instructor considers using a double-blind peer evaluation process for the integrated course project. (E.g. invite students from parallel classes or previous classes to evaluate the group projects)

CONCLUSIONS

Through the above results and feedbacks, it can be concluded that the active learning (CDIO standard 8) has played a very important role in these CDIO implemented projects and has essential contributions to improve the performance of the students. These projects can push the students to learn through collaboration and self-learning. The data collected through these projects have shown that the students did very well in many courses outcome categories such as "Investigation", "Design", "Communications Skills", "Teamwork" and "Economics and Project Management". The author also believes that other CDIO standards, such as integrated learning (CDIO standard 7), design-build experience (CDIO standard 5) and CDIO implemented workspace (CDIO standard 6) have formed the foundation of these projects. The feedback from the students and colleagues regarding these projects are general positive. However, modifications and refinements for the implementation of these CDIO standards are crucial to achieve the continual improvements of this course.

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BIOGRAPHICAL INFORMATION

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BOOSTING FOREIGN-LANGUAGE COMMUNICATION CONFIDENCE THROUGH A SHORT-TERM ICT-BASED INTERNATIONAL WORKSHOP

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ABSTRACT

This paper outlines a short-term Information and Communications Technology (ICT)-based international exchange program co-organized by Hokkaido Information University (HIU), Japan, and Rajamangala University of Technology Thanyaburi (RMUTT), Thailand. Participants in this program generally are non-fluent speakers with lower levels of proficiency. The program provides a context and goal that necessitate the use of English as a common language, or *lingua franca*, between Thai and Japanese students and instructors. The main part of the program consists of two workshops: one at HIU and one at RMUTT. Throughout the workshops, students work in teams of four to produce web pages, short films and computer programs, all in English and using English as their common language. At the end of the workshops, students present their work in groups to peers and teachers in all-English presentations. In order to assess how participation in the program affects students' attitudes toward using English and interacting with an international community, a 24-item survey was designed, adapted from previous surveys on communication apprehension (CA) and willingness to communicate (WTC). The survey was given to all participating Japanese students before and after the workshops. For comparison, it was also given to a group of Japanese students not involved in the HIU-RMUTT program. Preliminary statistical treatment of student response data suggests significant differences in CA and WTC among program participants compared to non-participants, with more moderate differences between a pre-program survey and a post-program survey. Considerations for future research are offered at the end.

KEYWORDS

International collaboration, ICT, communication skills, learning outcomes, design implement experiences, integrated learning experiences, active learning, Standards 2, 5, 7, 8.

SHORT-TERM STUDY-ABROAD PROGRAMS: ARE THEY WORTH IT?

University students who want to go overseas are often limited by time and money. Traditional programs that run for a semester or a year are too expensive for many students. Further, in longer-term programs, students formally enroll in and attend classes at an overseas university. This requires a foreign language proficiency level that many students do not readily possess.

On the other hand, the experience of visiting a foreign country, even for a short period, is valuable. In order to bolster an international-mindedness of Japanese university students, Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT), in tandem with the Japan Student Services Organization (JASSO), a support entity, are working to promote and fund shorter-term overseas programs, which are more accessible to a larger number of students. In Japan, the number of short-term study-abroad programs at universities has been increasing. According to McCrostie (2017), 60 percent of university students who study abroad do so on programs that last less than one month.

There is abundant literature supporting the linguistic benefits of study abroad with respect to gains in oral proficiency and communicative competence (DiSilvio, Diao, & Donovan, 2016). Davidson (2010) points out that along with an increase in students participating on short-term programs, there has been an accompanying uptick in the amount of research devoted to analysing language gains according to a variety of factors. However, the prevailing concern seems to be with how much students gain in terms of foreign language (L2) proficiency or fluency. The assumption is that "more is better," which Dwyer (2004) and Dwyer and Peters (2004) argue is true. From this, however, it is easy to draw the inverse conclusion that "less is not worth it." This assumption helps fuel institutional resistance to provide more funding support for short-term overseas programs (Collins & Davidson, 2002).

Llanes and Muñoz (2009:354) observed that "Studies about language gains in a stay abroad context have frequently analysed subjects who spend three or more months abroad, the assumption being that shorter periods may not produce any significant change in subjects' second language proficiency," but reported significant gains in listening comprehension, oral fluency and accuracy among participants on 3-4 week immersion programs. As the number of students participating in short-term programs increases, so will the literature that evaluates them, and similarly, positive results will likely emerge.

At the same time, it will be helpful to measure not only changes in linguistic proficiency but in cultural proficiency as well. With respect to short-term programs that offer English language experience, there has been a shift from English-as-a-Second Language (ESL) environments, (for example Japanese studying short-term in the United States) toward English-as-a-Lingua-Franca (ELF), environments (for example Japanese studying short-term in Thailand). Because of their cost-effectiveness, the number of these ELF-environment programs is expected to rise. Therefore, research that examines the benefits of these short-term programs to participants and stakeholders, both in terms of linguistic ability as well as intercultural awareness, will be helpful in advocating for their continued financial support by stakeholding institutions.

Further research into the benefits of short-term exchange programs will also contribute to the ability of institutions to grant credit to participating international students. Efforts to coordinate university credits internationally are already underway (see e.g. European Commission website (2019): European Credit Transfer and Accumulation System (ECTS); ASEAN

University Network website (2019): ASEAN Credit Transfer System (ACTS). If institutions can officially grant credits to international students on short-term exchange programs, their appeal is increased. Such research will, therefore, be instrumental in promoting the adoption of a thirteenth CDIO standard, Internationalization & Mobility (Campbell & Beck, 2010; Malmqvist, Edström, & Hugo, 2017). This proposed Standard 13 is a nod toward programs and organizational commitment that expose students to foreign cultures and promotes the transportability, transferability, and transparent recognition of credits, curricula, qualifications, and joint awards across international borders. The HIU-RMUTT International Collaboration program is, we believe, a step in the direction of fostering global-mindedness, intercultural appreciation and international mobility.

HIU-RMUTT PROGRAM STRUCTURE

Conceived in 2011, the short-term international collaboration program between HIU and RMUTT seeks to foster the development of four things:

1. C-D-I project-based learning using ICT skills;
2. English ability and confidence;
3. Intercultural understanding; and
4. International friendship

The program has four stages (see flow chart in Appendix B, and Anada et al., 2018, for more details):

      Stage 1: Selection. At each university, between January and June, hopeful participants—working individually or in teams—create and submit web pages, short films, and computer applications for entry into the international contest. Projects are created in their native language, although some guidance is given to the effect that successful entrants will include work that is easily transferable to another language—for example, work that keeps
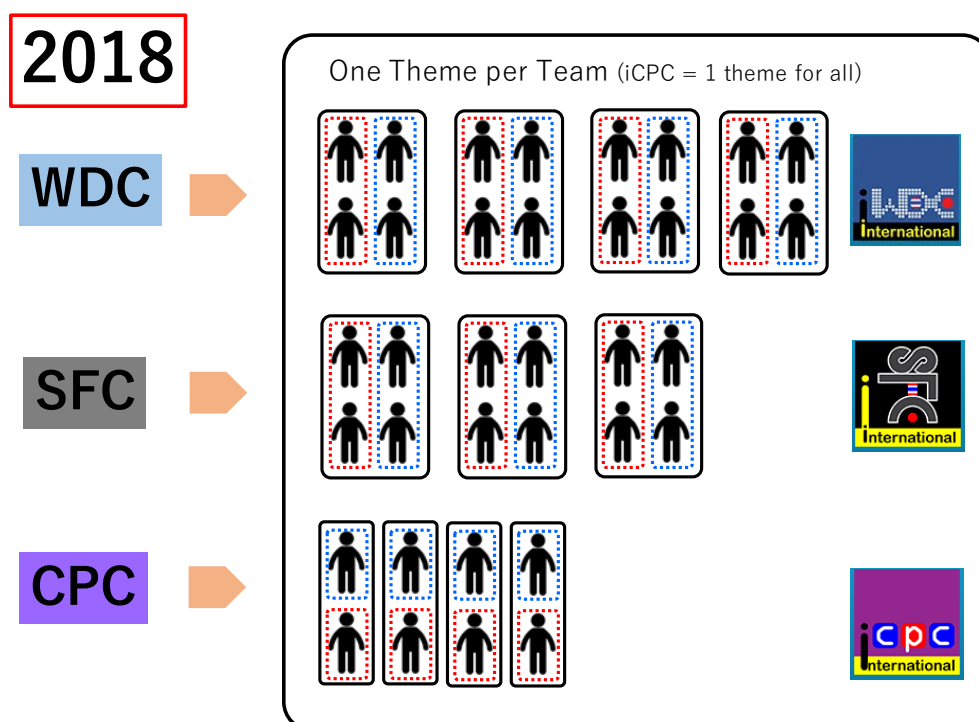

Figure 1. 2018 Team structure (red = Japanese students, blue = Thai students)

difficult language to a minimum, and is internationally themed. The best of these submissions are chosen by participating faculty at each institution. Students who are financially and academically (in principle, applicants must have a GPA of 3.0 or better) able to participate are chosen from the winning entrants. Currently, a total of 18 students from each university is chosen annually: 8 Web Design students; 6 Short Film Students, and 4 Computer Programming students (see Figure 1).

Stage 2: Competition. Students chosen to participate in the program are informed. Through a series of pre-program (workshops 1 & 2) training classes, students convert their work from native Japanese or Thai into English. These projects are later evaluated by participating faculty and awarded prizes at the end of the next Stage 3 (Collaboration). During this phase, students are also prepared for their overseas experience, which includes presenting proposals to their international peers for new collaborative projects that they will construct and implement in Stage 3 (Collaboration).

Stage 3: Collaboration. Students visit each other's countries and institutions over a course of two active-learning workshops. Each workshop lasts about eight days. At the beginning of this stage, they present proposals for new Web pages, short films, and computer applications to be constructed during the two workshops. Groups of four, each with two Japanese and two Thai students, are chosen. At the end of the workshops, groups give short presentations (in English) of the final products of their collaboration to the entire body of students and faculty. In implementing their product, the students develop their skills in Web programming, digital film editing, C language, and so on. It should be noted that these final products are evaluated and given grades for credit purposes; there is not enough time at the end of the program for evaluation and preparation of awards. The evaluation process for projects submitted for the previous Stage 2 (Competition) occurs during Stage three, and the award ceremony for these Stage 2 entries is given at the end of Stage 3 (Collaboration).

Stage 4: Sharing. In their native languages, participants write reports and give short presentations at their local institutions about their projects and about their experience on the program. This sharing is aimed at a broader audience of local faculty and prospective student participants in the following year. This program is a core course for the integrated curriculum of communication in English (CDIO Syllabus 3.3.1) at each institution.

RELATIONSHIP TO THE CDIO INITIATIVE

With regard to the CDIO initiative, we believe this program provides an excellent example of an education-based setting rather than an engineering-based one. Overall the program involves conceiving, designing, and implementing ICT-based projects, primarily in a foreign language. Students present their work and proposals for new projects to an audience of participants [CDIO Syllabus 3.3.1], take part in pre-program lectures and preparation sessions that help students systematically design their projects [CDIO Syllabus 4.3.4], and communicate with each other cooperatively over distance [CDIO Syllabus 3.1, 3.2], employing SNSs, online translation, and other modern technology. At the end of the workshops (Stage 3: Collaboration), groups of students make final presentations in English to a larger audience of peers and faculty, using a variety of multimedia, in order to showcase their projects and the skills they acquired through producing them [CDIO Syllabus 3.2.4, 3.2.5, 3.2.6, 3.3.1].

Furthermore, there is a distinct focus on design-implement experiences (Standard 5) through a collaborative teamwork approach, which is driven through active learning strategies (Standard 8). Learning outcomes (Standard 2) are central to the realization of the model and are aligned with the purpose of the program and set at appropriate levels. The program is constructed around learning outcomes and activities that integrate personal skills with disciplinary knowledge (Standard 7), in this case, actualized by teamwork carried out in a non-native language, and by utilizing and developing acquired knowledge and skills.

Much of the program is based upon the belief that the rights and responsibility to learn should be returned to the students and guided, rather than directed and controlled by, the teachers. While the focus of the program is not purely on engineering education per se, it embraces the vision of CDIO as proposed at Delft in October 2018, and sees the target of CDIO "is a worldwide collaboration to deliver re-engineered education (Leong, 2019)." Teachers need to stimulate students' initiative, which is done by ensuring that teaching, and the curriculum is learner-centered. This is actualized through the project-based learning approach, capitalizing on cognitive learning, interdisciplinary learning and collective ownership. Furthermore, the program incorporates the proposed new Standard 13: Internationalization & Mobility (Malmqvist, Edström & Hugo, 2017), which helps students develop requisite skills in a true global environment.

The learning objectives of the program are the knowledge, skill, and attitude targets that come from making the students' learning cooperative and collaborative. The learning outcomes focus on determining to what extent the student has acquired the knowledge, skills and appropriate mindset.

ROLES OF ENGLISH IN THE HIU-RMUTT PROGRAM

There are three principal roles of English as a lingua franca on the HIU-RMUTT program. English is used for:
   (1) general communication among students and faculty;
   (2) contents of student projects: (a) Web pages, (b) short films, and (c) computer applications; and
   (3) short presentations by students to peers and instructors at the beginning and end of the workshops (Stage 3: Collaboration).
Rian (2016) points out that problems with English arise as a result of low proficiency levels among students from both universities. This tends to result in an over-reliance on machine translation (online translation sites) for project contents, as well as presentation delivery (i.e., the mechanical delivery of presentations in the form of reading scripts that are, in worst cases, a verbatim copy-paste regurgitation of machine-translated output). Some of these problems can be ameliorated through training during the pre-program workshops that students attend before working with each other in person (Stage 1: Selection), as well as during the in-person workshops (Stage 3: Collaboration).

SURVEY: COMMUNICATION APPREHENSION (CA) & WILLINGNESS TO COMMUNICATE (WTC)

Since the beginning of the program, the faculty felt it was essential to monitor outcomes and to identify potential benefits and areas needing improvement. Stage 3 (Collaboration) is the most interactive-intensive part of the program, where students and faculty are interacting with each other daily in workshops under tight deadlines. However, because this stage lasts for a period of less than three weeks, and because there are no formal English language classes as part of the program, it was thought that, as some of the literature suggests (Llanes & Muñoz, 2009), linguistic skills cannot be expected to improve measurably.

As an alternative, faculty wanted to know if, as a result of participating in the program, students' attitudes toward communicating in English and toward interacting with an international community were improved. Most participants are lower-level proficiency and have little experience communicating in English, and are therefore assumed to harbour an apprehension to communicating. In 2014 and 2015 a 7-item ad-hoc in-house questionnaire was constructed

and given to students before and after they participated. Results showed increases for most items. However, because it was not created with reference to any previous research on communication apprehension, it suffered from several design flaws that compromised the validity of the results.

Based on the original 7 items, a new survey was constructed based on surveys on communication apprehension (CA) by McCroskey (1997), and subsequent surveys by Yashima (2009) with respect to willingness to communicate (WTC). A total of 24 Likert-style items were adapted from these surveys. Also adapted were four categories, or constructs, with six items each. These constructs are:

(1) ***Intergroup approach/avoidance tendency***, or the degree to which people seek to approach interacting with an international community;
(2) ***Interest in international vocation or activities***, or the degree of interest in working or volunteering overseas or for overseas-related activities;
(3) ***Communication Apprehension—Interpersonal conversation context***, or the degree of apprehension one has toward conversing with others in a foreign language.
(4) ***Communication Apprehension—Presentation context***, or the degree of apprehension one has toward making a presentation in a foreign language.

The entire 2017-2018 survey appears in Appendix A.

We wanted to know how participation in the program affected each of these constructs, specifically, (1) whether responses for participants and non-participants were different, as well as (2) whether there were differences in responses among participants before the program and after the program. The survey was given to 136 non-participating students in 2017, as well as to all 18 participating Japanese students in 2017 and 2018, once before and once after the program. The questionnaire was given to Thai students once before and once after as well. Rian (2018) provides a broader discussion about the construction of the newer survey as well as raw data. However, a statistical treatment of this data had not been attempted until now. Results of a statistical application are discussed below.

First, we ran Cronbach's Alpha for all responses (n=172) to evaluate whether the six items in each of the four categories are a good fit for each category. Cronbach's Alpha yielded a near-average of 0.8 over the four categories. This suggests all items solicit reliable responses for each category.

Second, we ran two tests to see whether there was statistically significant positive difference in item responses between (1) non-participants and participants, and (2) participants before and after the program.

For non-participant versus participant responses (2017), we assumed the null hypothesis: "The mean of the distribution of responses by program participants is greater than the one of non-participating students," and then carried out the following tests:

(1) one-sided, non-pairwise T-test (reasonable if responses to items follow a normal distribution pattern); and
(2) one-sided, non-pairwise Wilcoxon signed-rank test (reasonable if responses do not follow a normal distribution pattern).

Histograms of responses for each item showed the possibility that it does not necessarily follow a normal distribution. For simplicity, we have shown the number of statistically significant items for each category in Table 1. The numbers indicated by an asterisk in each cell of Table 1 are predominant positive change (three or more of six maximum) in comparison with others.

Table 1. Non-participant group vs 2017 pre-program and 2017 post-program group (Japanese)

Category	Non-participant group (n=136) versus…			
	2017 pre-program (n=18), number of items with significant positive change (max. 6)		2017 post-program (n=18) number of items with significant positive change (max. 6)	
	Non-pairwise T	Non-pairwise Wilcoxon	Non-pairwise T	Non-pairwise Wilcoxon
(WTC) Intergroup approach/avoidance tendency (Q1-6) Cronbach α＝0.8	1	2	*5**	*5**
(WTC) Interest in international vocation or activities (Q7-12) Cronbach α＝0.78	0	0	*3**	*5**
(CA) Communication Apprehension—Interpersonal conversation context (Q13-18) Cronbach α＝0.8	1	1	2	*5**
(CA) Communication Apprehension—Presentation context (Q19-24) Cronbach α＝0.87	*3**	*4**	*6**	*6**

Compared to the 'control' group of Japanese students who did not participate in the program (n=136), there is an apparent distinction in responses by Japanese students who participated in the program (n=18) across all categories. This suggests that participation in the program improves willingness to communicate (WTC, categories 1 & 2) and reduces communication apprehension (CA, categories 3 & 4). We note, however, that a reduction in CA in the presentation context (category 4) was already apparent before the main part of the program, Stage 3: Collaboration began. During Stage 3, participants are given training for and execution of final presentations. It is possible that these positive responses were influenced by briefer self-introduction presentation training that occurs during Stage 1: Selection. These pre-program lectures and workshops help prepare students for participation in the subsequent stages of the program.

Next, we looked at differences between 2018 pre-program responses and 2018 post-program responses (Table 2). For this case, we assumed the null-hypothesis: "The mean of the distribution of responses by students after the program had finished is greater than the one by students before the program began" and then carried out the same tests as mentioned above:

(1) one-sided, non-pairwise T-test (reasonable if responses to items follow a normal distribution pattern); and

(2) one-sided, non-pairwise Wilcoxon signed-rank test (reasonable if responses do not follow a normal distribution pattern).

As with Table 1, we have shown the number of statistically significant items for each category in Table 2. The numbers indicated by an asterisk in each cell of Table 2 are predominant positive change (three or more of six maximum) in comparison with others.

Table 2. Pre-program groups vs post-program groups, 2017 & 2018 (Japanese)

| Category | 2017 & 2018 pre-program groups (n=18) versus… | | | |
| | 2017 post-program (n=18), number of items with significant positive change (max. 6) | | 2018 post-program (n=18), number of items with significant positive change (max. 6) | |
	Pairwise T	Pairwise Wilcoxon	Pairwise T	Pairwise Wilcoxon
(WTC) Intergroup approach/avoidance tendency (Q1-6) Cronbach α＝0.8	1	1	2	2
(WTC) Interest in international vocation or activities (Q7-12) Cronbach α＝0.78	2	2	1	1
(CA) Communication Apprehension—Interpersonal conversation context (Q13-18) Cronbach α＝0.8	*4**	*4**	*5**	*5**
(CA) Communication Apprehension—Presentation context (Q19-24) Cronbach α＝0.87	*4**	*3**	*5**	*5**

Comparing responses by pre- and post-program groups (2017 and 2018, each n=18), we see statistically significant positive changes in responses to half or more of the six items in each category (indicated by asterisk). Although this sample is small, the results tentatively suggest that participation in the program yields improvements especially in terms of communication apprehension in a foreign language (English), both in the context of communicating face-to-face with others and in the context of giving presentations in English before a group of teachers and peers.

For contrast, we also ran a provisional T-Test on Thai student data, who completed the questionnaire for the first time in 2018. The result is shown in Table 3.

Table 3. Pre-program group vs post-program group, 2018 (Thai)

| Category | 2018 pre-program Thai students (n=18) versus… |
| | 2018 post-program Thai students (n=18), number of items with significant positive change (max. 6) |
	Pairwise T
(WTC) Intergroup approach/avoidance tendency (Q1-6) Cronbach α＝0.8	2
(WTC) Interest in international vocation or activities (Q7-12) Cronbach α＝0.78	*3**
(CA) Communication Apprehension—Interpersonal conversation context (Q13-18) Cronbach α＝0.8	*3**
(CA) Communication Apprehension—Presentation context (Q19-24) Cronbach α＝0.87	*4**

Responses by Thai students to an average of half of the six items in each category were positive. Of interest to us is the similarity to responses by Japanese (HIU) students to categories 3 and 4 (CA). The implication is that participation in the program reduces apprehension with regard to conversing and presenting in a foreign language.

Collectively the results offer nominal support that participation in the program increases willingness to communicate (WTC) with, and reduces communication anxiety (CA) toward

interacting with, an international community using a lingua franca that they (a) are generally not very proficient at and (b) do not have much practical experience with, beyond what experience they may have received through compulsory English classes. Broadly, then, we can say that the program is worthy of continued support and research, and by extension, other similarly short-term exchange programs.

LIMITATIONS, IDEAS FOR FUTURE RESEARCH

While a statistical analysis of the survey data for 2017-2018 has yielded incremental but tentatively encouraging results that the HIU-RMUTT program helps to boost confidence among participants with respect to using English to interact with a foreign community, further and broader examination is needed in order to more conclusively assert successful results.

Limitations of this study include:
(1) it involves a small data set (limited number of participants per year). This seems to be the case in other surveys on short-term exchange programs (Rees & Klapper, 2008) This number could be doubled with a better-coordinated incorporation of responses from Thai student participants.
(2) the mandatory nature of the questionnaire. While it is common for studies to involve instructors researching participants from their own institutions (Kinginger, 2009), providing students with a choice to opt in or opt out of offering program feedback would be a polite gesture.
(3) it employs only numbers. A treatment of student comments is beyond the scope here but would be beneficial to include in a future publication.

As the number of short-term overseas programs increases, further research into their effectiveness as promoters of foreign language and foreign culture will be helpful to further their cause. For future research, we offer the following ideas:
- Closer examination of the literature on short-term programs that involve ELF rather than ESL.
- Treatment of student commentary, including open-item comments in surveys as well as testimony in final presentations at the end of Stage 3 (Collaboration) and Stage 4 (Sharing).
- Proficiency pre-program and post-program interviews (see e.g. Kang, 2014).
- Stimulated recall interviews with volunteer students.
- Longitudinal follow-up with past participants.
- Examine gains in speaking (see e.g. D'Amico, 2012; Hernández, 2016).
- If further Likert-style survey data is used, Rasch analysis could improve item/construct quality (Apple, 2013).
- Closer consideration of CDIO guidelines with respect to the curriculum in which short-term exchange programs such as the one between HIU and RMUTT exist.

CONCLUSION

The number of short-term study-abroad programs at universities is increasing, and so is the amount of research into these programs. However, there is as yet a dearth of studies that examine (a) short-term programs in an ELF context, where English is a common foreign language between speakers of two different languages, rather than ESL contexts, where English learners stay in English-speaking countries, as well as (b) in contexts that provide no formal English classes during the training, where speakers just get together and manage with what they have in order to complete some collaborative task.

Our statistics-aided approach offers the following suggestions: (1) Both Thai and Japanese participants in the program reported noticeable reductions in apprehension toward communicating and presenting in English with an international community as a result of participation in the program. This result encourages us to continue supporting this program. Meanwhile (2) while there appear to be improvements in students' WTC, that is, to their tendency to approach and interact with a foreign community, these responses are not as pronounced. Worthy of future research attention is particularly the improvement in communication apprehension.

We believe the continuation of this program will provide valuable opportunities for continued research into short-term study-abroad programs that are financially and academically accessible to a broad number of students—especially those who, under different circumstances, may not have the opportunity to experience what it is like to travel abroad.

APPENDIX A: 2017-2018 Survey

6-point Likert-style response format, 6 = strongly agree, 1 = strongly disagree.
* = reverse-coded item.
NOTE: Order of items was randomized on survey given to students.

Intergroup approach/avoidance tendency (based on Yashima, 2009)
1. I want to make friends with international students studying in Japan.
2. I would talk to an international student if there were one at school.
3. I want to participate in local volunteer activities that help foreigners living in Japan.
4. I wouldn't mind sharing an apartment or room with an international student
5. *I try to avoid talking with foreigners if I can.**
6. *I would feel somewhat uncomfortable if a foreigner moved in next door.**

Interest in international vocation or activities (based on Yashima, 2009)
7. I want to work where many people from other countries work.
8. *I plan to live in Japan/Thailand my whole life.**
9. I'm interested in doing volunteer work overseas.
10. *I think what's happening overseas is not related to my daily life.**
11. I'd like to try working in a foreign country.
12. *I'd rather not have a job that sends me overseas frequently.**

Communication Apprehension—Interpersonal conversation context (based on McCroskey, 1997)
13. *I would feel very nervous participating in a conversation in English with a new acquaintance.**
14. I would enjoy having a conversation in English.
15. *If I tried to have an English conversation, I would be at a loss for words.**
16. I am not afraid of participating in an English conversation.
17. *Even the idea of having a conversation in English makes me nervous.**
18. I would be confident if I had a conversation in English.

Communication Apprehension—Presentation context (based on McCroskey, 1997)
19. *Giving a presentation in English would make me terribly nervous.**
20. *Even the idea of giving a presentation in English makes me afraid.**
21. *If I gave a presentation in English, I would quickly lose my calm.**
22. I would not mind speaking in English before a group.
23. I am not afraid of giving a presentation in English.
24. I would be confident if I gave a presentation in English.

APPENDIX B: HIU-RMUTT International Exchange Program flow chart

WDC = Web Design Contest, SFC = Short Film Contest, CPC = Computer Programming Contest

Stage 1: Selection
**HIU Local (In-School) Contest
(WDC, SFC, CPC)**

From among competing HIU teams, participating HIU staff choose:
- Best submissions: Web pages, short films, computer programs
- *International Contest* candidates from among winning team members.

Stage 1: Selection
**RMUTT Local (In-School) Contest
(WDC, SFC, CPC)**

From among competing RMUTT teams, participating RMUTT staff choose:
- Best submissions: Web pages, short films, computer programs
- *International Contest* candidates from among winning team members.

HIU: Local Pre-Program Workshops
- Overview of program by HIU staff
- Introduction to Thailand and Thai culture, tips on international travel
- Advice on English for communication and presentations
- Assistance converting project contents to English

RMUTT: Local Pre-Program Workshops
- Overview of program by RMUTT staff
- Introduction to Japan and Japanese culture, tips on international travel
- Advice on English for communication and presentations
- Assistance converting project contents to English

Stage 2: Competition
International Contest (iWDC, iSFC, iCPC)

From among competing HIU and RMUTT teams, HIU and RMUTT staff choose best submissions: Web pages, short films, computer programs. Awards presented at end of Stage 3

Stage 3: Collaboration
International Exchange Program (Collaborative Production)
- Participant students and staff spend eight days each in Thailand (RMUTT) and Japan (HIU). Order of 1st and 2nd country visited alternates every year.
- Most interaction in English, with Japanese and Thai assistance from staff as necessary.

Workshop 1 & Workshop 2:
- Teams for each of iWDC, iSFC, iCPC chosen. Students give presentations of their project proposals to each other, and students choose which team interests them. Each team has two Thai and two Japanese members, and each works together on project of their choice for the duration of the program. Workshop 2 continues activities in Workshop 1, but in the other country. Activities include many field trips to local attractions. Students use these field trips as part of their projects, such as filming locations for short films.
- At the end of Workshop 2, each team gives a final presentation on the product of their project in front of all staff and participants.

Stage 4: Sharing
- Local award ceremony, post-program reflection.
- Students write reports on their projects and experiences with foreign culture, give presentations to next year's prospective students.

Stage 4: Sharing
- Local award ceremony, post-program reflection.
- Students write reports on their projects and experiences with foreign culture, give presentations to next year's prospective students.

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A DEVELOPMENT AND OPERATIONAL PRACTICES OF STUDENT-CENTERED CLASSROOMS

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ABSTRACT

The modern student-centered classrooms in the Faculty of Engineering, Chulalongkorn University, were modeled after the SCALE-UP platform, a total disruption approach from the previously gradual improvement of classrooms. The first pilot room was completed in 2014 with five more fully equipped and two semi-equipped large classrooms in the next three years. The rooms were only allocated to courses with active learning only; lecturers who requested to use the classroom had to pass through the training. By the end of 2016, the classrooms were used around 48% of the working hour for regular courses, and 14% of all lecturers passed through the utilization training. While the classrooms were very popular, the invested resource and effort were equally high in order to meet the demand of the stakeholders. While the conception and infrastructure development was quite challenging due to financial regulation and bureaucratic practices, the real tests were the strategic deployment and operational practices for the room utilization, management, maintenance, and continuous development.

KEYWORDS

Change Management, Learning Environments, Faculty Development, Standards: 6, 8, 10.

INTRODUCTION

Learning environment influenced learning quality. Previous classroom developments in the Faculty were incremental; user experiences in existing classrooms, e.g., the visibility (Singhanart et al., 2012), were studied and the room layouts were modified accordingly. While classrooms were indeed improved, they were still very much teacher-centered. For the envisioned roadmap for engineering education (Sripakagorn & Maneeratana, 2013), the classrooms that better suited student-centered instruction models as well as promote active and collaborative learnings were needed. In short, the situation required a disruptive change.

The SCALE-UP was a part of the outstanding success in the development of the interactive, collaboratively based instruction (Beichner et al., 2000). It was found in previous studies that students were generally more engaged, and performances could be improved under the combination of the resulting active-learning instructional model and the supporting environment (Dori & Belcher, 2005). The developers' network setup up a website for assimilating the knowledge at http://scaleup.ncsu.edu from which the concept was adopted. To better accommodated the local learning experiences, identified needs included the

discussion and interaction between students, tables' space for laptop computers as well as the ability of teachers to circulate to engage students. Classrooms were refurbished in three phases with were distinctive for round tables for students to work in groups and the instructor station at the center.

To improve the quality of engineering education (Sripakagorn & Maneeratana, 2013), the curricular were to incorporate the CDIO platform to raise the overall educational quality (Lee et al., 2015). To facilitate the CDIO Standards 4-8: Introduction to Engineering, Design-Implement Experiences, Engineering Workspaces, Integrated Learning Experiences, and Active Learning, the Learning Corridor was envisioned and implemented into the new Engineering Centenary Building (Figure 1). There were classrooms for Conceive & Design on the fourth floor, the engineering workspace on the mezzanine floor for the Design & Implement, and the ground floor concourse was for exhibition and demonstration.

(a) The Centenary Building (b) The Learning Corridor
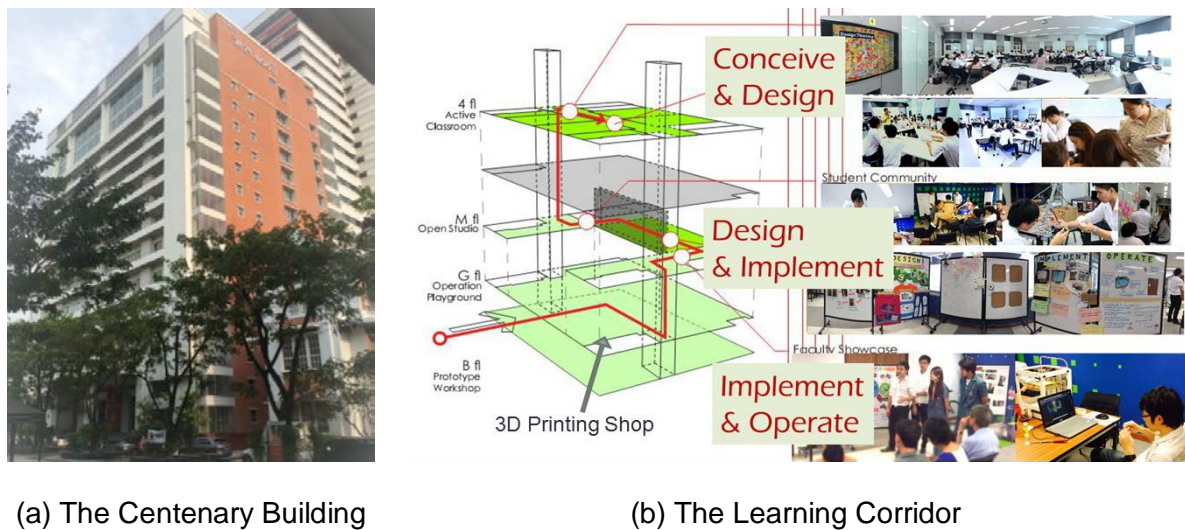
Figure 1. The learning space for CDIO Implementation

Concerning the classrooms for active learning, the developer selected the SCALE-UP classrooms and registered as a site member to gain additional information. However, the adoption and implementation in the local contexts and constraints required much effort. This paper described the experiences, pitfall, and lessons learned from this exercise.

INFRASTRUCTURE DEVELOPMENT

Starting the conceptual design in April 2013, examples of the SCALE-UP-type classrooms were studied in details. The existing rooms were surveyed while the available furniture, electronic equipment such as televisions, smartboards, signal controllers and software in the market were reviewed. The initial imposing of the classroom format involved many components, including the writing space, lighting, air conditioning, video signal, and audiovisual systems. After the room requirement was outlined, a mock-up room, using borrowed furniture and televisions was set up for a demonstration to test both the instructional practice and potential donators' reaction during the 2013 alumni reunion event sound out the potential donation.

Then, details of the system and the required resources were refined. The architecture and outlook of the planned classroom were digitally rendered (Figure 2). The brand name iSCALE was chosen, the SCALE recognized the SCALE-UP platform while the suffix i denoted the word intania which was the nickname for the Faculty of Engineering. The initial project consisted of the total refurbishment of the rooms on the fourth floor of the Centenary Building, involving four large and two small classrooms.
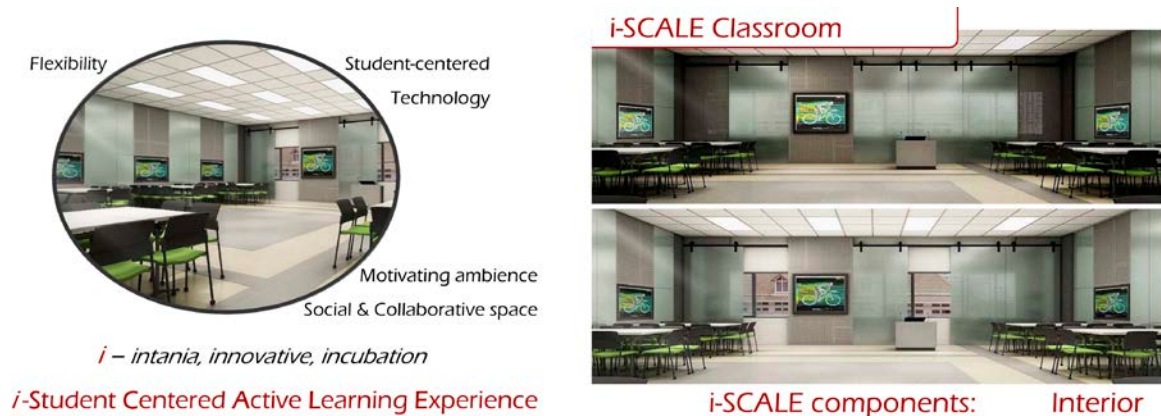

Figure 2. The architectural render for the first iSCALE room for fundraising purpose

With the full support of the then Dean of Engineering, Assoc. Prof. Boonsom Lerdhirunwong, the project was pitched to Chevron (Thailand) in August 2013; the company sponsored a large room and a small room. The second set of large-room sponsors were the Thai industrial conglomerates, the SCG, PTTEP, and PTT Global Chemical. The donation came as a lump sum for the sponsored room. The first pilot room was completed in early 2014, just in time for the cascade training session of the first batch of the Thai CDIO master trainers (Figure 3). The next three rooms went into full operation in 2015.

Figure 3. The inaugural activity for the iSCALE: CDIO cascade training on 24-27 June 2014

After the first iSCALE rooms became a success, the Learning Innovation Center (LIC), which was responsible for promoting educational quality in the Chulalongkorn University, took up the practice and started to co-funding similar rooms throughout the University (Table 1). The LIC paid for the sets of computers, television, interactive whiteboard, projector, video signal equipment, tables, and chairs while faculties were responsible for the rest of the room refurbishment, including wiring, writing board, audio equipment, acoustic system, air

conditioning systems, and other accessories. The Faculty of Engineering received the co-funding of two such rooms in 2015 and 2016.

Table 1. The list of LIC-sponsored classrooms between 2015-2018

Faculty/Offices	Numbers		Involvement	
	Rooms	Seats	Procurement	Site training
Allied Health Sciences	1	32	✔	✔
Architecture	1	64	✔	
Arts	2	80	✔	✔
Commerce & Accountancy	1	64	✔	
Communication Arts	1	64	✔	
Dentistry	2	64	✔	✔
Economics	1	48	✔	✔
Education	1	64	✔	
Engineering	2	128	✔	✔
Law	1	64	✔	✔
Medicine	1	64	✔	
Pharmaceutical Science	1	64	✔	
Political Science	1	64	✔	
Psychiatry	1	64	✔	✔
Science	2	128		
Veterinary Science	2	96	✔	✔
Petroleum & Petrochemical College	1	32		
Language Institute	1	32		
General Education Office	1	32	✔	

The rest of the classrooms on the 5th floor were semi-furbished with new tables and chairs. The portable whiteboards that were provided for discussion could be used as partitions and poster stands. The available iSCALE rooms (Figure 4) became sufficient in numbers such that they might have a substantial impact on the learning environment in the Faculty. Also, the LIC sponsored the Design Workspace (Chancharoen & Maneeratana, 2016) on the mezzanine floor which completed the integrated Learning Corridor for CDIO in 2016 (Figure 1).

Figure 4. The floor plan and available iSCALE classrooms

The processes of procurement and infrastructure development provided another insight into the management system. For the first four rooms, an education technology company, TRINiTech was responsible for all implementing works. The company collaboratively worked with the iSCALE developers in the co-creation of knowledge, providing much-needed expertise

on interior design, electronic equipment selection and installation, acoustic absorption, and other finer points of room refurbishing. The company had since provided services in implementing active learning classrooms in universities around the country.

On the other hand, the LIC, that provided partial funding to many faculties, procured equipment and furniture in large batches. While this approach was better in terms of discount and the custom furniture, designed from the users' feedbacks, there were many problems with product and service specification. Unexpected problems included the lack of the compulsory standard for furniture and a visit by officers from the Office of the Auditor General of Thailand due to a complaint by a fail bidder who misunderstood the process. The coordinating for room development was much more difficult due to the lack of a professional interior designer and the arrival order of equipment, installation, and services. With such a small amount of works in each stage, it was very difficult to find good contractors. The atmosphere and color schemes of the rooms were not as elegant as the previous rooms as well.

In reflection on the infrastructure development, the expectation of stakeholders had been getting higher as they became accustomed to highly polished commercial products and services in increasing prosperity of the country. High-quality services were valued; drab government facilities were no longer satisfied. The development of the iSCALE followed similar practices for the famed development of the Engineering Library (Vorasaiharit & Thawesaengskulthai, 2016). The practice and potential benefits had to be well researched. Planning required professional services of architects and interior designers; the fundraising activities enticed potential donators with attractive vision as well as returned benefits of either tax deduction or public relation opportunities.

However, the normal due process in a public university had not been keeping up. The government strictly regulated the fiscal and spending procedure in an attempt to fight corruption. It was hard to employ professional services that were perceived as unsuitably extravagant – such as the architects, interior designers, procurement and inspection specialists as well as the service managers – that allowed the possibility of truly outstanding quality.

The procurement practices were equally outdated. The current norm was to rely on lecturers and supporting staff for writing the technical specification of rapidly changing technology and products. They had to participate in the bidding and purchasing processes as well as for the acceptance procedure. This required personnel to face enormous challenges on both the technology and bureaucratic practices that were not their core duty. The steep learning curve could be somewhat overcome but never be sufficient good for notable achievements. Either training existing personnel as specialists for operating in a university-wide scale or, more likely, allowed more outsourcing might be the way forward, but the path was still very much in doubts (Upping & Oliver, 2012).

IMPLEMENTATION AND PRACTICE

Due to the technology-intensive in iSCALE classrooms, the users had to be trained so that they could operate the equipment in proper manners. The utilization manual and training video clips were provided; any persons who applied to use the room regularly had to complete the certification process (Figure 5). The training on instructional practice and techniques were conducted in separate projects. Lecturers and other users had to declare the instructional method and use of active learning in order to book the room. For group teachings, at least one

lecturers had to be certified. The most crucial point was to use software to control signals, use the free connectors that were provided at the podium or under each television and to avoid using hardware controls on equipment and detaching cables for direct connection at all cost. It was noted that due to different visual signal controls in the early and later development, the certification for these two sets of rooms had to be separately conducted.
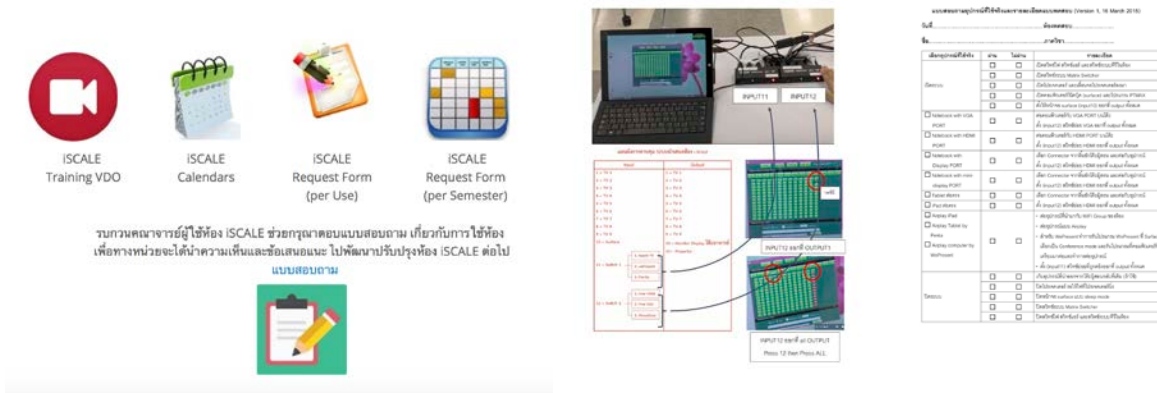

Figure 5. Room booking and user training media and documents

With the iSCALE rooms, lecturers that pioneered and implemented innovative instructional models were empowered with the ecology that much better suit to their needs (Figure 6). It was noted that the room and technology utilization were tracked for continuous developments. Instructional practices and problems were recorded such that the problems would be addressed in the development process of the next room. This design and equipment were continuously fine-tuned and matched with the usage modes and current technology in the never-ending cycle.

As the room configuration was not friendly to teacher-centered lectures, it was hoped that the environment would force some lecturers to change their teaching to be more active. However, it was found that if the lecturers really wanted to lecture, they would do so regardless of the environment. Some might even arrange the tables into rows as in the typical classroom. These study cases further supported the operational need to ensure that that only courses with suitable instructional models were able to use the rooms.

Lecturers and students were surveyed on the utilization of the iSCALE classrooms. Lecturers were very satisfied with the comfortable and clean environment for discussion and group works, the compatibility with different OS system and multiple screens for presentation. The main complained was the old projectors as well as some unreliability of the video signals and the internet access, particularly the University's wifi network. Despite multiple wireless microphones in each room, the numbers were considered too few, and there was occasional interference from the adjacent rooms. Frequently, natural light was too bright, and the disposable such as markers and battery were not readily available.

For students, the initial pro opinion of the classroom that were most frequently mentioned, from ascending order, were the ease of discussion & interaction, the television screens & ease of presentation, good atmosphere, good working condition with computer & electronic equipments with lots of electric sockets, easily moved table & chairs, and the built-in board for writing. The most common dissatisfaction was the screen visibility, particularly for the table at the center which was far away from the nearest television. There were also complaints about

the lighting and too bright natural light, the crowdedness near the wall and entangled chair, too few microphones and electric sockets as well as minor problems in the operation and supplies. There were also requests to use the room for students' extra-curricular and club activities.

Figure 6. Examples of active learning activities in iSCALE classrooms

In 2015 and 2016, 41 lecturers, equivalent to 14% of all academic staff, passed through the training (Table 2). However, when the distribution across the departments was considered, the level of expressed interested varied from as high as 30% to negligible. The early-adopters data helped the planning of lecturers' training in order to ensure core numbers of active-learning practitioners. Also, a lecturer of Architecture was also trained to use a room for a general education course.

Concerning the room utilization, around 65-67 courses using the room regularly every semester, accounting for 48% of the standard 8-hour days. Besides, the rooms were used for courses that requested occasional usage as well as other activities (Table 3) which clearly showed the popularity of the rooms. Concerning investment, the depreciation value of the durables in the rooms per usage hour was no more than 600 Baht (about 19 USD) according

to a most conservative estimation using the maximum depreciation rate of governmental financing regulation. The operation costs, particularly the electricity bills, were not much different from regular classrooms.

Table 2. The number of trained personnel between 2015-2016

Department/Offices	Lecturers		No. of Staff, & TAs
	Numbers	Percentage	
Mechanical Engineering	9	29.0	
Computer Engineering	9	25.0	4
Civil Engineering	8	24.2	
Survey Engineering	2	18.2	
Water Resources Engineering	1	16.7	
International School of Engineering	2	16.7	4
Nuclear Engineering	1	11.1	
Electrical Engineering	5	10.4	2
Metallurgical Engineering	1	8.3	
Environmental Engineering	1	4.8	
Industrial Engineering	1	4.0	
Chemical Engineering	1	2.8	2
Mining and Petroleum Engineering			
Faculty Offices			8
Total	41	14.0	

From the operation and surveyed feedbacks, the utilization of the iSCALE rooms had two main concerns, the operation, and maintenance. With intensive incorporated technology, it was easy for instructors to slip and unable to operate the equipment and signals despite the training. Most of the times, the problem was minor but might results in a long delay while the users could quickly get frustrated. The most severe problems were the I/O control of audio-visual signals by the matrix software. Students frequently did not want to wait for the video signals to be switched by the software or tested whether their output signal was sufficient good for the matrix signal channeling. Many went on directly connected their notebooks to the television's screen. The forced move of the built-in screens and cable disconnection easily caused the wear and tear on the hardware which, in turn, further exacerbate signal problems.

Table 3. Non-regular extracurricular activities during the second semesters of 2015

Activities	Activity Numbers	Total Time (hr)
Industrial liaisons & workshops	7	99
Internal workshops & trainings	5	17
Educational visits	14	40.5
Student activities	8	49.5
Total	34	206

Secondly, the maintenance routine was much more intensive than typical classrooms. Accessories and battery supplies had to be regularly checked and restocked. The infrastructure had to be kept in good condition or had a short downtime. The rooms were costly with a steep decline in values of the incorporated electronic equipment; it was necessary for the rooms to be heavily used to justify the expenses.

The key response to these two problems was to have a supporting staff in the nearby office such that if any problems arose at any time, there would be a one-stop service that could solve minor problems for the lecturers while coordinating with other offices or the support centers.

SUSTENTION AND EXPANSION

Since the first iSCALE room became operational, there were many interests in the rooms. There were regular requests for the visit and use from inside and outside the University (Figure 8). The classrooms became a compulsory stop for the tours of the Faculty's learning showcases – the Library, Workspace and iSCALE (Table 3).

Figure 7. A workshop by the Faculty of Architecture (left) & science teachers' training by the Faculty of Science (right)

With the success of the first four pilot classrooms in the Faculty of Engineering, the Learning Innovation Center (LIC), started to co-sponsor the rooms in various faculties (Table 1 and Figure 8) as described in the previous section. The iSCALE classrooms were used as the demonstrative rooms for interested lectures to visit and experienced first-hand in addition to the uses in training on teaching and learnings. For the room development, details with incorporated lessons were adapted to suit specific needs. The on-site training was mostly conducted by the growing crops of iSCALE operators.
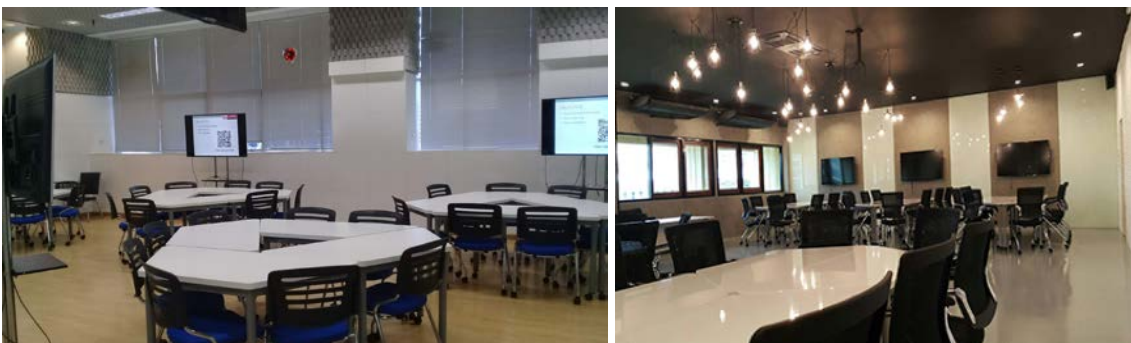
Figure 8. Expansion to other Faculties: Faculty of Law (left) & Faculty of Economics (right)

As the classroom operation was perceived to be stable, the operation was absorbed into the standard hierarchy within the Faculty of Engineering. The duty of the on-site staff was handed over in 2018 to the Academic Offices for booking, the Building Operational Office for the regular

operation and the Audiovisual Unit and the Infrastructure Office for maintenance. As this procedure was causing several mishaps, the practice transfer and long-term operational performance and effectiveness had to be evaluated.

CONCLUSIONS

The iSCALE classrooms at the Faculty of Engineering, Chulalongkorn University, could be considered a successful adaptation of the SCALE-UP environment into a Thai public university as an integrated component of the CDIO adaptation. The availability of facility empowered and encouraged changes of instructional models on educators who either had changed or inclined to change.

During the implementation and the operation since then, the iSCALE adoption could be seen as a harbinger of new practices. With the high expectation on the level of services in the modern economy, the stakeholders of iSCALE – staff, students and donators – expected high-quality services, not the most economical option as in the previous generation.

The infrastructure development was just the beginning. The critical items for success thus far were the course selection, room management system, lecturers', on-hand operational supporting personal, continuous development and understanding of the administration and administrative offices. Also, the gained extrinsic and intrinsic knowledge had to be passed on and instilled in the regular operation.

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FLIPPED LEARNING IN A PROGRAMMING COURSE: STUDENTS' ATTITUDES

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ABSTRACT

Student-centred learning (SCL), which puts the student at the centre of the educational process, has been gaining focus in recent years. This is due to doubts that teacher-centred learning (TCL), which puts the teacher in the primary role in the learning process while students take a more receptive role, is the best way for students to learn. SCL is related to active learning, team-based learning (TBL), flexible learning, experiential learning, digital learning, flipped learning (FL), and blended learning. In this paper, it stands for a learning environment where students have more choices and control over their learning and are active participants in the educational process. We introduce an implementation of a novice-programming course that was completely reorganized according to SCL, TBL and FL, using online videos, online exams, and group work, with a minimal formal presentation from the teachers. In the course, Canvas was used as the Learning Management System, Piazza as a question and answering system, and Mimir Classroom as a system for assignments, projects, quizzes and exams. As the course setup was new for the students, a survey was conducted to assess how they perceived the educational process. We discuss the results in relation to the CDIO standards 1 and 8, program philosophy and active learning. In short, the students felt that the course was overall good learning experience and liked the online resources, especially the videos.

KEYWORDS

Student-centred learning (SCL), flipped learning (FL), team-based learning (TBL), novice-programming course, online learning, CDIO Standards: 1, 8.

INTRODUCTION

Teaching methods and organization of a course are essential for the learning process and have an impact on students' engagement and the outcome of their educational work. Teachers are the central performers in educational change (Fullan, 2001; Sarason, 1990; Shulman, 2004; Fullan, 2007; Hargreaves & Shirley, 2009) along with school authorities. Educational changes take time and as Fullan (2007) says: "success it not just about being right; it is about engaging

diverse individuals and groups who are likely to have many different versions about what is right and wrong" (p. 40). Teachers can choose between numerous diverse methods of how to provide study materiel and how to organise their courses. In recent years, with more and better opportunities of online educational options, many teachers have looked into how they can implement those new options and how they should layout their courses in a different and even new way. The purpose of this study was to look into students' attitudes towards a new organization of a novice-programming course, built on the student-centred learning (SCL) approach, using flipped learning (FL) and team-based learning (TBL). Overall, there has been a growing understanding of the significance of students' attitudes towards their educational environment, the content and layout of courses, and use of information and communication technology (ICT) (Marshall & Cox, 2008; Matthíasdóttir, 2015).

How to teach novice students programming has been debated over the years, both the layout of teaching, teaching methods and what programming languages to teach (Marion, 1999; Matthíasdóttir & Geirsson, 2011; Kunkle & Allen, 2016; Hendrix & Weeks, 2018). C, C++ and Java have been the most used languages in both industry and academia, but Python has gained more popularity over the recent years (Ben Arfa Rabai, Cohen & Mili, 2015). ACM/IEEE teams on computing curricula do not recommend any particular programming language and the industry is still using programming languages with background in the late sixties/early seventies (C), and variations thereof (C++, Java). Therefore, it is up to academia to take the lead and use languages that best assist students to master programming (Ben Arfa Rabai, Cohen & Mili, 2015). In the first-semester programming course discussed in this paper, it was decided to change from C++ to Python, as it was believed to be a much more convenient development environment for novice programming students.

Teaching methods are important and the SCL approach has gained more interest due to doubts that teacher-centred learning is the best way to teach. The driving force has also been the changing nature of the student population (Lea, Stephenson & Troy, 2003), where technology is now, in fact, an integrated part of students' lives. All the new online options available with the use of ICT and technology-enhanced learning (TEL) give teachers new opportunities to adapt SCL in their courses.

Cannon and Newble (2000) provide a useful definition of SCL as "ways of thinking and learning that emphasize students' responsibility and activity in learning rather than what the teachers are doing. Essentially SCL has student responsibility and activity at its heart, in contrast to a strong emphasis on teacher control and coverage of academic content in much conventional, didactic teaching." (p.16). Here SCL is viewed as a learning environment, where students have more choices and authority over their learning and are actively participating in the learning process. SCL can be used with the support of different teaching methods like flexible learning, experiential learning, digital learning, and blended learning.

Educators have recognized FL as an effective and inventive educational approach where traditional instruction is changed by switching in-class instruction time with out-of-class practicing time. The students' out-of-class learning plays a central role for students and teachers in-class work, and it is important that students prepare out-of-class so they can take active part in in-class work (Mason, Shuman & Cook, 2013). FL is not only about providing students with videos to watch before class, it is also about teachers guiding and assisting them to think, reason and discuss, and to enhance learning with communication, good feedback and problem solving (Hwang & Wang, 2015).

TBL is a convenient instructional approach especially for the purpose of practicing teamwork skills. In TBL, the student is at the centre, where the teacher directs the instructional method as the students are divided into small teams of five to seven aiming at solving problems. Traditional lectures are not provided as the students are assumed to be acquainted with the content out-of-class. When attending class, the students take an individual multiple-choice test and then discuss in groups the same test and get feedback on the group answers. The teacher then clarifies what the students have struggled with and they then continue working in groups on relevant problems and discuss their solution with other groups in the class under the teachers' facilitation (Dolmans, Michaelsen, van Merriënboer, & van der Vleuten, 2015).

Technology-enhanced learning (TEL) is here aligned with Laurillard, Oliver, Wasson, Hoppe (2009), where technology is used to encourage new types of learning experiences, but at the same time to increase current learning settings. Online material, especially videos, are the learning material format that has recently gained most interest and distribution by students. The availability of online educational videos is a fast-growing fact that students can make use of with or without teachers' guidance. This gives the teacher many opportunities to use ready-made videos by other professionals and, in a way, it can be stated that videos are not only a substitute for the teacher's lecturers but also the new book for the students.

Evaluation of students' work is essential to guide students through their study and to add to their educational process (Ardid, Gómez-Tejedor, Meseguer-Duenas, Jaime Riera, & Vidaurre, 2015). Use of different assessment methods gives a better overview of students learning. Online exams and quizzes, with immediate scoring, can be useful and versatile. They are good options for students to receive instant feedback and for the teachers to use continuous assessment without overloading their work. Readiness Assurance Tests (RATs) are a good way of using online multiple-choice tests and they have proved to be a good way of preparing students for tests (Bartlett Ellis, Carter-Harris, & MacLaughlin, 2016). RATs are an integrated part of a TBL layout in classes, where students first take a test individually (I-RAT) and then with a team (T-RAT) (Gullo, Ha & Cook, 2015).

Novice-programming course

In this paper, we describe the results of a survey conducted among students in a 12-week novice-programming course in the Department of Computer Science at Reykjavik University. The course was completely reorganized using the SCL methodology, TBL and FL, and using online materials, like videos and tests, but with no formal conventional lectures from the teachers.

The 325 students in the course were divided into seven sections and then into groups of 5-6. Each section had a class twice a week for 4*45 minutes each day, where they were assisted and guided by one teacher and one teaching assistant. The students were expected to come prepared to the class by reading a chapter in the course textbook and watching short YouTube videos selected by the teachers. The videos were mainly demonstrations of the textbook material.

In line with TBL and RATs, most class hours started with a short individual online test, but before the test, the students could ask questions related to the content of the day. After the individual test, the students worked in groups to solve the same test again (both the individual test and the group test counted towards the course grade). Then the groups worked on short programming problems, for which each student had to hand in his/her own solution at the end of the class, or no later than four hours later.

Weekly larger programming projects were also assigned for the students to work on out of class, and additionally, two midterm exams. At the end of the course, there was a three-hour final exam taken in the same environment as students had been working in during the course. The programming language was Python, the university learning management system (LMS) was Canvas (www.canvalms.com), Piazza (www.piazza.com) was used for questions and answers as it has been used in the department for several years, and Mimir Classroom (www.mimirht.com) for administrating projects and exams. The leading instructor of the course was responsible for the organization and six instructors were tutoring the sections with one teaching assistant each.

The main research question in this study was: What do the students believe that matters most regarding their experience in the SCL and TBL approach of the novice-programming course?

METHOD

Participants
An online survey was e-mailed to 325 students in the introductory programming course. In total, 178 (55%) students answered, 114 (64%) males and 65 (36%) females. The participants' average age was 24.4 years, ranging between 18 and 46 years. Most students, or 148 (83%), were first-semester students, 119 (67%) rated their programming skills very little or little before they entered the course, and only 14% (24) rated it as great or very great.

Measures

The online survey consisted of twenty-three questions, designed especially for the purpose of the study. Three are background questions about gender, age and semester, and one question is about the participant's programming skills before he or she started the course: "How much computer skills do you consider you had before you started the course?", rated on a five-point Likert scale, ranging between "Very little" and "Very great". The term programming skills was not defined in the questionnaire and the participant could only select one single answer.

Fifteen questions ask about the course and the student's learning experience. They were all rated on a five-point Likert scale, ranging between "Totally disagree" and "Totally agree". The questions are as follows.

- Six questions are about the organisation of the course, class hours, the YouTube videos and the exams: "*The organization of the course is good", "The class hours each week are useful to me", "The book of the course helped me in my study", "The videos in the course helped me in my study", "I like the organization of the short exams at the beginning of class"* and *"I like the arrangements of the midterm exams".*
- Four questions are about communication with the teachers and fellow students: "*Communications with teachers in class help me to study", "To discuss with fellow students helped me to study", "To discuss with fellow students outside the class hours helped me study"* and *"I like to work in a group with fellow students".*
- Five questions are about the students' use of online resources and the textbook: "*I usually read the book before class", "I usually watch the video in the course before the class", "I liked to use Canvas in my study", "I liked to use Piazza in my study"* and *"I like to use Mimir in my study".*

One question asked about the students' attitudes towards the course: "*This course is overall a good learning experience*". This question was used as the outcome variable in the main analysis (linear regression) and rated on a five-point Likert scale, ranging between "Totally disagree" and "Totally agree".

Three additional questions were asked: "*I feel the course is lacking traditional lectures", "I have done well in this course*" and *"Group work is time-consuming*". They were rated on a five-point Likert scale, ranging between "Totally disagree" and "Totally agree".

Procedure

The survey was put online in the system Free Online Surveys (https://freeonlinesurveys.com) and a link was sent to the students by e-mail in the 10th week of the course. Data analysis was carried out in Excel and the Statistical Package for the Social Sciences (SPSS).

RESULTS

Figure 1 shows the mean scores on the fifteen questions about the students' behaviours in the course and their attitudes towards its layout, communication and learning resources. The students seem to be most active in using the videos, Canvas (the learning management system) and Mimir Classroom, and value both communications with the teachers and their fellow students. The textbook did seem only moderately helpful and not frequently read before class.
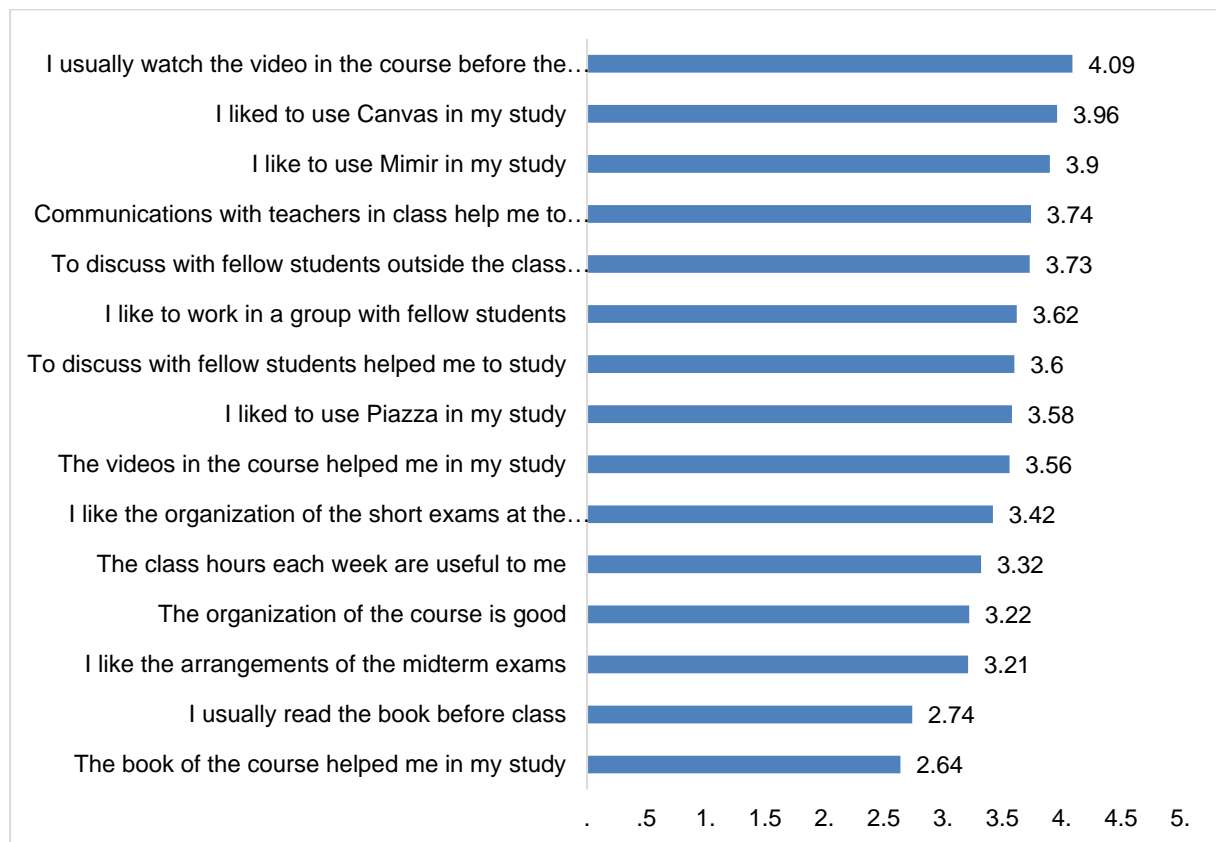
Figure 1 The mean scores on the 15 questions (scale 1-5).

To investigate the relative contribution of fifteen predictor variables described in Table 1 to the variance of the outcome variable, „*This course is overall a good learning experience*" (mean score 3.53) linear regression was carried out (force entry method). The fifteen variables were entered into the regression in three blocks. The first block included six variables related to the organisation of the course, class hours, videos and exams, the second block included four variables related to communication with the teachers and students, and the third block included five variables related to the students' use of the online resources and the textbook. Eight of the fifteen predictor variables shown in the table explained 62% of the variance in the final model, the first block explaining the largest part or 54%, and the second and the third block adding another 2% and 9%, respectively. In the final block, the weekly class hours (β=0.39) was the strongest single predictor, followed by the organisation of the corse (β=0.24), the use of Piazza (β=0.23), the online videos (β=0.23) and using the videos (β=0.21).

Table 1 Linear regression, with the question "*This course is overall a good learning experience*" as an outcome variable.

	Block 1		Block 2		Block 3	
	β	t	β	t	β	T
The organization of the course is good	0.31	4.66***	0.29	4.36***	0.24	3.75***
The class hours each week are useful to me	0.35	5.31***	0.35	4.67***	0.39	5.64***
The book of the course helped me in my study	0.13	2.30*	0.12	2.20*	0.16	2.43*
The videos in the course helped me in my study	0.15	2.48*	0.15	2.44*	0.23	3.69***
I like the organization of the short exams at the beginning of class	-0.04	-0.65	-0.04	-0.71	-0.04	-0.76
I like the arrangements of the midterm exams	0.15	2.80**	0.14	2.58*	0.12	2.25*
Communications with teachers in class help me to study			-0.03	-0.42	-0.06	-1.01
To discuss with fellow students helped me to study			0.16	1.80	0.08	0.97
To discuss with fellow students outside the class hours helped me study			0.02	0.25	0.02	0.30
I like to work in a group with fellow students			-0.15	-2.06*	-0.16	-2.42*
I usually read the book before class					-0.10	-1.53
I usually watch the video in the course before the class					-0.21	-3.77***
I liked to use Canvas in my study					0.01	0.23
I liked to use Piazza in my study					0.23	4.30***
I like to use Mimir in my study					0.02	0.37
Adjusted R	0.54		0.54		0.62	
R2 Change	0.55		0.02		0.09	
ANOVA F-value (df)	33.50 (6.163)***		21.08 (10.159)***		19.58 (15.154)***	

*p<0.05, **p<0.01, ***p<0.001

Half (89; 50%) of the students claimed they had done well in the course (so far), nearly half (88; 49%) found the course lacked traditional lectures, and 52 (29%) claimed group work was time-consuming.

DISCUSSION

This study investigated student´s experiences in a SCL, TBL and FL designed novice-programming course at the university level. The aim was to gain a deeper understanding of the issues related to what options students use and like in their studies. It is a complex matter due to the many options teachers can use to support SCL, TBL and FL, and the different views people have of the implementation and usefulness of ICT in education.

The importance of understanding students' perception of their learning experience is one of the central essentials in the development of effective learning environments. For FL, TBL and RAT to be successful, the students need to come prepared to class. If they are not prepared, they cannot take active part and do not get the most out of the educational work that goes on. Thus, students' use of learning recourses and their attitudes towards the course affordance and organisation is important for their learning experience. It is clear from the results that the students do not value the textbook as a support to their study, but they like the videos and claim to use them. Our findings suggest that videos in programming education get students´ attention and encourage them to prepare for class. Research has shown that images are usually processed and remembered better than when reading or hearing material (Shorter & Dean, 1994) and videos are more pleasing compared to traditional lectures to students Bhadani, Stöhr, Hulthén, Quist, Bengtsson, Evertsson, & Malmqvist, J. (2017). The popularity of watching videos among young people's today offer teachers the opportunity to reach out to students and use instructive videos more frequently.

The fifteen predictor variables entered in the linear regression explained 62% of the variance of the students' learning experience in the course. The results indicate that the students relate their learning experience mostly to the weekly class hours, the use of Piazza and the organisation of the course as well as the videos.

It is of concern that the students did not find the textbook helpful and did not use it to prepare for class. This raises the question, how do we get students to understand that they need to be active, take part and prepare for class to be successful? They come to university after 13-14 years in the educational system so they have developed their study style that for some of them may not be a successful one when at the university level. One way to change this situation could be to emphasise the students' learning style at the beginning of a course so that they realise how they need to work in a SCL environment.

Technology will continue to be a motivating force for designing courses built on SCL, TBL and FL. Organising a course with this methodology can activate the students and encourage them to identify for themselves what and how they learn and increase their motivation for successful learning. This is in line with the CDIO standard 8, teaching and learning based on active experiential learning methods and could be an option for educators that are working with the CDIO vision for engineering education.

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Innovative engineering project from engineering design to implementation-base on CDIO model

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ABSTRACT

In the past, the higher education in Taiwan aimed to create elites in the field of engineering. However, the conventional subjects and curriculum taught were mainly focusing on the introduction and understanding of theories. So students who only accept professional theories, the technology developed is not necessarily the needs of the industry, hence affecting the competitiveness of the country. The importance of "Creative Education" was mentioned in many research papers around the world when discussing how to enhance national competitiveness. Feng Chia University is devoted to promote "The Project of Innovative Engineering". By borrowing the experience of innovative education from Purdue University and combining it with the CDIO model, Feng Chia University created a systematic process for the project of innovative engineering. This allows students to discover and define problems, analyze and simulate actual situations, conceive and invent products, and in the end, achieve product evaluation and innovation development.

This paper introduces the procedure of how Feng Chia University integrated the CDIO framework into innovative education, and how, they through curriculum development, encourages students to engage in active learning and gather learning experiences rather than passive note-taking. The results of the current two semesters have shown that by transforming industrial design into a project of innovative engineering really does enhance students' motivation for active learning. The learning goal and process created based on Bloom's taxonomy is set to start with "creativity". Under this guideline, students are willing to learn the contents related to "analysis", "assessment" and "application" more actively, leading to an outcome of the enhanced ability to "memorize" and "comprehend". Moreover, by using the CDIO framework to create the project of innovative engineering, it allows teachers to overcome

the time limitations which existed in the system before, and at the same time enhances the depth of learning for the students significantly.

KEYWORDS

Practical skills development, Project-based learning, Self-determination theory, Bloom's taxonomy, Standards: 1, 2, 3, 4, 7, 8.

INTRODUCTION

Now a day, international competition is still increasing, which most of the medium and large enterprise keep expanding or maintaining their global market share aggressively. On the other side, the sense of internationalization is now a very popular concept for the younger generation in Taiwan, and also many developed countries in Asia. For the higher salary and better social welfare, to study or be employed abroad in Europe, North America or Australia are one of the important milestones in their life planning. How to cultivate student with certain international competitiveness during the higher education is the topic that university attaches great importance to.

Generally, higher education in university is the last step of professional knowledge and ability development before students entering the society in Taiwan, which the net enrollment rate of higher education is about 73 % in age 20 in 2017 (Educational statistics, 2017). Therefore, University is playing a very important role in connecting 12-year basic education and employment successfully.

From the report of the National Association of Colleges and Employers (NACE) published in November 2018 (NACE Job Outlook 2019, 2018), the survey results of attributes employers seek on a candidate's resume indicate that the top 5 attributes are communication skills, problem-solving skills, ability to work in a team, initiative, and analytical/quantitative skills. On the other side, about the career readiness competencies, critical thinking/problem solving, teamwork/collaboration and professionalism/work ethic are the top three of the weighted average rating, which is 4.66, 4.48 and 4.41, respectively under a 5-point scale. From the above report, employers attach much importance to the soft skills/ability of candidates. However, during the 12- year basic education in Taiwan, most of our students are educated to pay attention to memory knowledge only. In most of the cases, the score of examinations is the only key performance indicator of student learning effectiveness. Many of Taiwanese students lacked practical experience, and become disjointed with the real world requirement of human resource because of the monotonous and rigid teaching strategy.

The main causes of this problem are the way of classroom management. In Taiwan, Learning environment are usually created as a very traditional teacher-centered classroom. In the teacher-centered learning environment (Emaliana, I. (2017), Garrett, T. (2008)), the teacher is the sole leader who plays important roles in the learning process and evaluation. On the other hand, students are viewed as learners who receive knowledge passively with the "right answers" only. Under the monotonous teaching strategy with "one answer questions", it is easy to cause our students to lose the ability of judgment/critical thinking. The low motivation for learning is also easily become the by-product of this kind of learning environment.

To avoid the same problem that continues to occur, this paper aims to build up a new hybrid teaching strategy which including both the teacher-centered and student-centered learning environment with the idea of CDIO process. The strategy was designed from the idea of

innovative education of Purdue University, who pay more attention to the balance between soft skills and professional knowledge, and is redesigned with a combination of CDIO structure as a new teaching strategy for FCU students. The module "Innovation project - foundation" is implemented for first-year university students in the International school of technology and management, Feng Chia University.

COURSE DESCRIPTION & CDIO ARRPOACH

On the design of "Innovation project - foundation", students will have the rudiment of engineering and how to become an engineer. The teaching and training goals are focusing on:

1. Innovation concept – understand the definition and meaning of innovation. (C, D)

2. Innovative accomplishment – learn professional skills and tools using. (C, D, I)

3. Need finding & Problem scoping – ability to Figure out the real world problem & challenges, and define problems/pains and the background in detail. (C)

4. Idea generation and innovative thinking– Idea generation fluency and become an informed designer. (D)

5. Realize & implement–build up prototypes or models of the solution. (I)

6. Self-evaluation–confirm the value proposition of the solutions and the ability of competitiveness. (O)

7. Professional communication–presenting the problem statement, challenge, solution, and the unique value proposition in a formal way via oral or writing. (O)

The design of course roadmap with the innovation process and abilities training is represented in Figure 1.
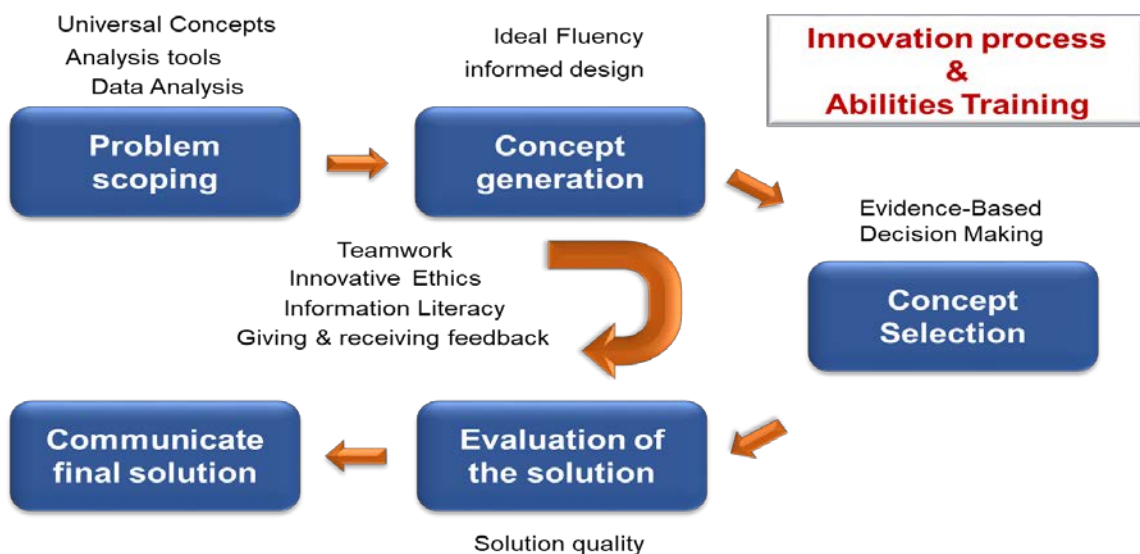
Figure 1. The roadmap of "Innovation project - foundation" module with training abilities

During the course, students learned four categories of abilities training objectives, which are: (1) engineering tools using & analysis, (2) engineering professional skills (soft skills), (3) modeling & problem solving, and (4) innovation & Design. It is believed that a successful engineer requires well training of the following 14 abilities (Figure 2.). The step by step abilities training objectives with detailed description is shown in Table 1.

Figure 2. Four categories of learning goals with 14 abilities objectives

Table 1. Learning goals and the objectives of abilities training

Goals Category	Learning goals	Abilities training objectives
Engineering tools using & analysis	Engineering tools (ET): using software, apparatus or prototypes to support your engineering calculation, analysis, modeling and presenting your results.	ET01-Use built-in cell referencing and functions of MS Excel for the efficiency of calculations
		ET02-Select appropriate graphical representation of dataset based on data characteristics such as numerical (discrete or continuous) or categorical (ordinal or nominal)
		ET03-Justify graphical representation based on data characteristics.
		ET04-Prepare chart or table for technical presentation with proper formatting (headers, units, meaningful decimal points, appropriately scaled axes, appropriately sized marker and axis labels)
		ET05-Create a histogram with a meaningful number of bins and width/sizes.
		ET06-To collect trustworthy information, literature or data from the internet.
		ET07- Use tools or modeling package to test or simulate the engineering design. For example MS Excel, CAD software.
	Data analysis (DA): to study and finding the meaningful/useful	DA01-Describe, with calculations, the central tendency of data using appropriate descriptive statistics (mean, median, and mode).

	information from pre-existing or new data set.	DA02-Describe, with calculations, the variability of data using statistical methods (standard deviation, variance).
		DA03-Make accurate statistical comparisons or analysis across grouped data with two or more variables.
		DA04-Given independent and dependent variables, interpret or predict the performance of a solution.
		DA05-Given two variables, describe the relationship and/or calculate the strength of the correlation between these variables.
		DA06-Interpret the distribution of data in a graph.
	Universal Concepts (UC): prepare and present the information/results in a simple and direct way for clear understanding, including appropriate text description, tables or diagrams with captions.	UC01-Demonstrate an understanding of conservation principles (mass, energy, momentum, and/or charge) in a boundary system
		UC02-Describe systems or processes using schematic diagrams with inputs and outputs.
		UC03-Define systems or processes with mathematical models with simulation results.
		UC04-Calculate efficiency of a system, product, or process as it relates to cost, energy, or other engineering factors
Engineering professional skills	Teamwork (TW): to work in a synergistic way to improve efficiency and productivity and reduce mistakes. Teamwork skills include division of labor, effective communication, giving and receiving feedback and so on.	TW01-Evaluate the unique knowledge, skills and abilities of each team member
		TW02-Document all contributions to the team performance with evidence that these contributions are significant.
		TW03-Develop strategies to support interactions between teammates and learn from one another.
		TW04-Develop expectations with high-quality work and timely completion of team projects.
	Information Literacy (IL): seek, find, collect, evaluate and apply information appropriate from a variety of trustworthy sources.	IL01-Ask questions to determine what new information is needed to scope and solve a problem.
		IL02-Include citations within the text (in-text citations) that show how the references at the end of the text are used as evidence to support decisions.
		IL03-Gather information from reliable sources and being able to evaluate the quality of evidence.
		IL04-Support all claims made with evidence that is either generated or found.
		IL05-Format reference list of used sources that is traceable to original sources (APA or MLA are recommended)

	Professional communication (PC): communicate engineering concepts, ideas, decisions and professional advice in multiple ways including written, oral, visual and digital communication.	PC01-Use professional communication (written, visual, and oral), free of grammatical or spelling mistakes and in a formal tone, appropriate for engineering school and workplace.
		PC02-Make clear and complete arguments or statements by fully addressing all parts of the assignment.
		PC03-Present all visuals with captions (e.g., Figure number, table number, and brief description)
		PC04-Professionally present all visuals representations (Figures, images, sketches or prototypes) to clearly convey meaning by labeling key components to show their form and function.
	Engineering Ethics (EE): recognize how contemporary issues as part of cultural, economic and environmental factors impact engineering design and practice, and what are the obligations and responsibilities of an engineer.	EE01-Justify decisions based on the recognition that such decisions involve not only technical factors but also cultural, economic, environmental and other applicable considerations.
		EE02-Predict/identify the potential ethical dilemmas and consequences that result from implementing solutions.
		EE03-Make connections between classwork and contemporary issues that impact or are impacted by engineering practice.
	Giving & receiving feedback (GRF): giving specific and objective information for improvement; open mind to receive the idea or suggestion to improve yourself.	GRF01- Give useful and meaningful objective information for helping others to improve, including by point out blind spots, honest mistakes and misconceptions.
		GRF02- Evaluate objectively the information received, evaluate if it is reasonable, and take appropriate action.
Modeling & Problem solving	Be able to develop a clear statement of the problem, including environment, stakeholders, criteria, constraints and so on.	PS01-Explain the problem based on the synthesis of the client, user, and other stakeholder needs.
		PS02-Justify why the problem is important to solve by making reference to relevant global, societal, economic, or environmental issues.
		PS03-Explain key specifications (in terms of criteria and constraints) that address what the client wants and what the user needs.
		PS04-Identify potentially competing or conflicting needs or requirements.
		PS05-Expand or revise problem statement based on evidence found during later stages of the design process.
	Evidence-based decision making (EBDM): Use	EBDM01-Test prototypes and analyze results to inform a comparison of alternative solutions.

	evidence to develop and optimize solution. Evaluate solutions, test and optimize chosen solution based on evidence.	EBDM02-Identify assumptions made in cases when there are barriers to accessing or collecting information related to a problem.
		EBDM03-Clearly articulate reasons for answers with explicit reference to data to justify decisions or to evaluate alternative solutions.
		EBDM04-Justify chosen metrics and the corresponding assigned weights to evaluate potential solutions, based on stakeholder needs.
		EBDM05-Present findings from iterative testing or optimization efforts used to further improve the aspect or performance of a solution.
	Process awareness (PA): Reflect on both personal and team's problem solving/design approach and process for the purpose of continuous improvement.	PA01-Identify strengths and limitations in one's problem solving/design approach.
		PA02-Identify potential behaviors to improve the approach in future problem solving/design projects.
Innovation & Design	Engineering design (ED): addresses issues of creating and delivering innovative, useful, reliable and economical technical solutions to meet client wants or needs. Also, the ability to plan and schedule works, build up and test prototype and redesign based on interim evaluations.	ED01-Define the problem, criteria, constraints, and requirements.
		ED02-Be able to brainstorm multiple ideals and designs as the solutions in response to the problem statement.
		ED03-Plan and schedule the proceeding of development works
		ED04-To build up prototypes for you design.
		ED05-Test the properties of prototypes for further improvement. Sometimes, redesign is required.
	Idea Fluency (IF): to generate ideas fluently. Take a risk when necessary.	IF01-Generate a wide range of solutions including ideas not readily obvious or combinations of ideas in new ways. Explicitly use and document two or more ideation strategies (biomimicry, brainstorming, exploration of prior art, etc.) to generate ideas.
		IF02-Generate testable prototypes (physical, visual or conceptual) for a set of potential solutions.
	Solution quality (SQ): to present a high-quality solution (or design) for an engineering problem, including a detailed description, feasibility, risk, and other supporting materials, evidence, information, etc.	SQ01-Use appropriate, scientific, mathematical, and/or technical concepts, units, and/or data in solutions.
		SQ02-Justify design solution based on how well it meets criteria and constraints.
		SQ03-Justify qualities of a solution and recognize any limitations and be able to explain the trade-offs made to arrive at a final solution.

IMPLEMENT METHODOLOGIES AND CASE STUDIES DISCUSSION:

In order to cultivate freshman with the effectiveness of innovation process, soft skills/abilities with our designed CDIO teaching strategy, a series of case study were selected in different training stages, as shown in Figure 3. During the course, several teaching methods and models have also engaged in improving student learning efficiency, as following:

Self-determination theory (SDT) – as mentioned before, the lack of motivation is one of the most serious problems of students in Taiwan. How to frame motivational studies for our student is the top challenge for course design and applying CDIO structure. SDT is a motivational theory of personality, which including both intrinsic and extrinsic motivation (Deci, E. L. and Ryan, R. M. (2015)). In the meta-theory of SDT, three basic psychological needs of students are *Autonomy* - have a chance of selection but receiving orders from instructors only; *Competence* - to know that they have ability to success, sense of accomplishment is a strong driving force for autonomic learning; *Relatedness* - interact with instructors or classmate but receiving information passively.
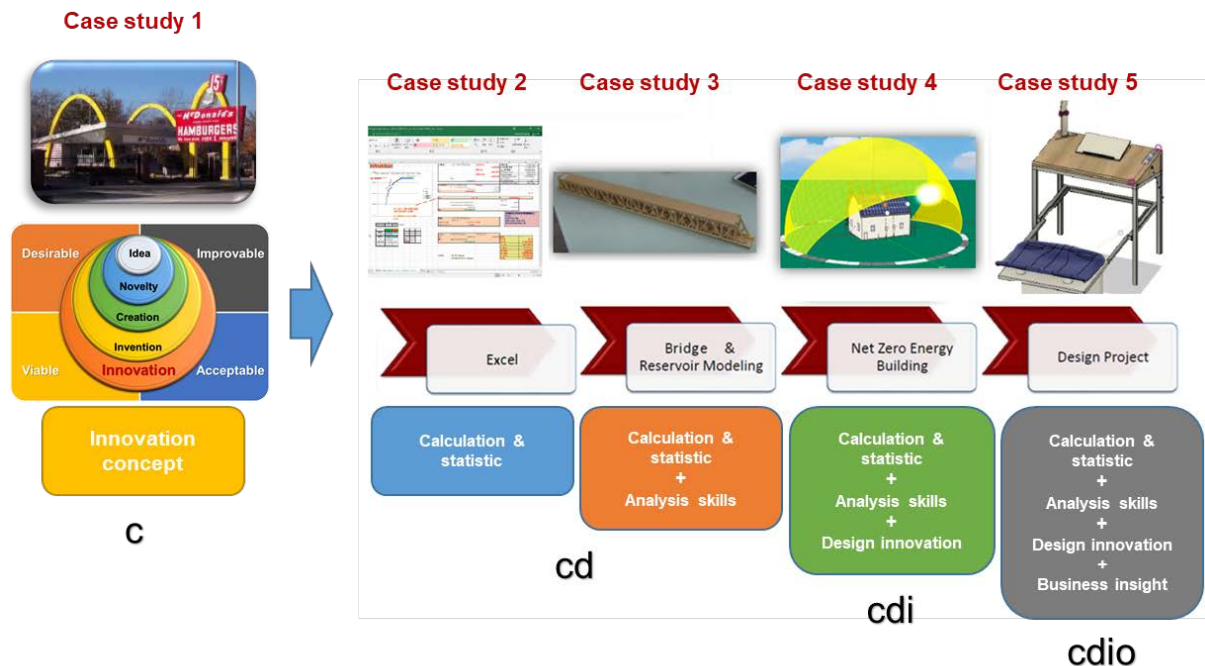
Figure 3. A series of case study for own designed CDIO teaching strategy

Bloom's taxonomy – 5 levels of learning achievements in the taxonomy are; remember, understand, apply, analyze, evaluate and create. However, from both the feedbacks of graduate students and supporting companies/industries, application ability to learned knowledge is relatively weak in our students. In the traditional teacher-centered classroom, paper examination is the most common way to evaluate the outcome of students with the level of remembering and understand the knowledge. Therefore, in this course, Bloom's taxonomy is applied for our student understanding the meaning of learning selected knowledge and professional engineering tools (Figure 4.). By designing learning activities, such as problem-based or project-based learning cases, students are relatively easy to achieve the level of

apply, analyze and even create. Also, learning by operation, the student can easily understand the connecting between knowledge and real-world application.

CASE STUDY 1 (C):

The first case study was designed to build up the student's universal concept of innovation, which is a fundamental training even before the process of conceive. At the beginning of the class, the definition and difference between idea, novelty, creation, invention and innovation were explained as the key knowledge. After that, the case McDonald's entrepreneurial history has been select as a teamwork activity for the student to understand the definition of innovation. In the class, students were teamed up and working together to search the history of McDonald. After the preliminary understanding of the background, students were asked to analysis the reason for McDonald's success with the outcome of a 5-minute oral presentation. Peer review with other teams and the feedback from the instructor helped the students to gain the correct information.
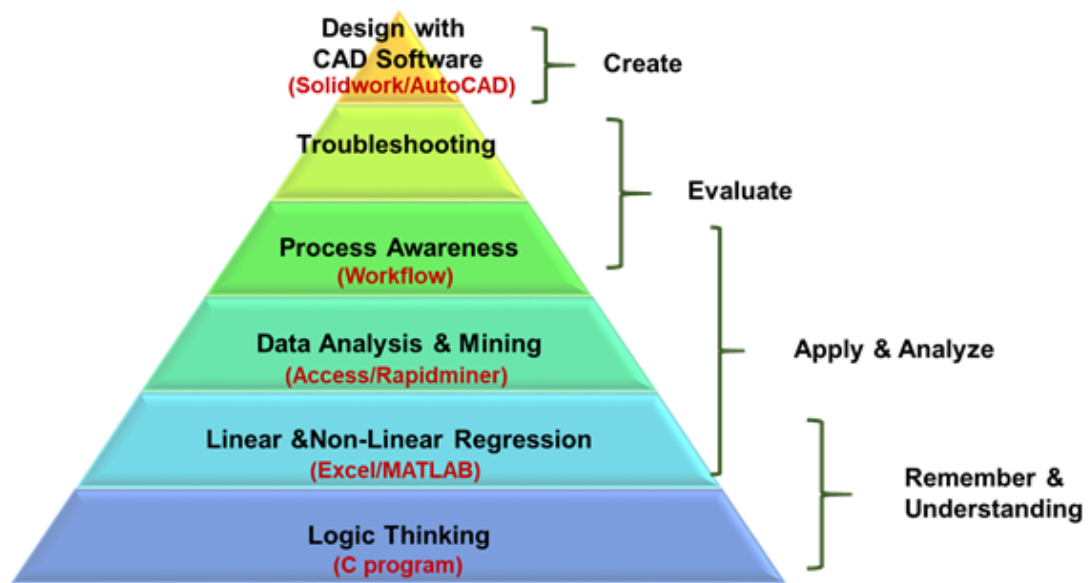
Figure 4. Alignment of learning tasks with Bloom's taxonomy using the CDIO approach

Figure 5. Case study 1 (innovation concept) – the founder, story of McDonald

CASE STUDY 2 (C, D):

To cultivate the ability of data analysis and accurate conceive process, a situational problem-based learning activity with a real-world dataset of accident statistics of firefighters was selected. Students tried to apply the skills of data analysis with multiple linear regression method to Figure out the key factors of causing death and present the analysis results with the ability of diagram drawing. After that, they are required to prepare a simple designed solution or suggestion as outcomes with the evidence of their data analysis/problem scoping results. During the activity, for solving a real-world problem with professional suggestion, students learned the application of engineering tools autonomously with strong motivation, which is good training of conceive stage with the ability of problem scoping and statement preparation. In the outcome, the student can provide reasonable suggestion by the analysis results and achieve evidence-based design. The description of the situational problem and parts of a student's analysis results are shown in Figure 6.
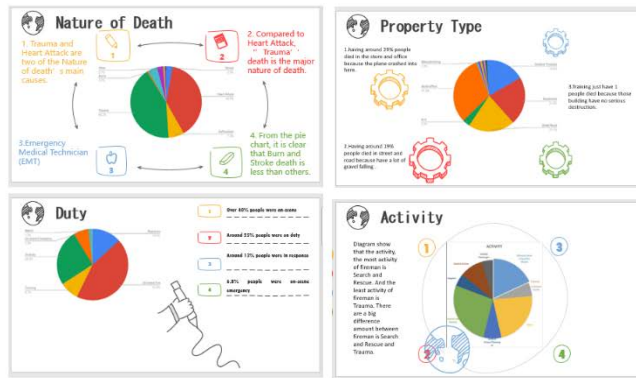
Figure 6. Topic of case study 2 (data analysis and problem scoping) and some outcomes from students

CASE STUDY 3 & 4 (C, D, I):

In the third stage, students were asked to review the ability of problem scoping and engineering tools application to understand the background of the challenge. Further, in these activities, students learned the ability of prototyping and modeling. Bridge and net zero energy building design were selected as a semi-open design projects. With expecting outcomes of several physical prototypes and digital modeling in a group, students are trained to learn by implement, testing, comparison and find out the way to improve their original design. During the case studies, to identify and list the key criteria of the user requirement is one of the core training to achieve evidence-based design and user-centered design. Some of the design results were shown in Figure 3.

CASE STUDY 5 (C, D, I, O):

At the final design project of the course, students will challenge an open-ended design with real-world topic- next generation classroom for CDIO learning environment. In this design project, students have to run the complete process of innovation (fig. 1) on their own. The first two weeks of this 4-weeks duration design project, students reviewed all the ability they learned before, to identify the criteria and constraints as the pain and limitation of all stakeholders; to run brainstorming with teammates for achieving maximum possibilities of solution ideas; to compare the pros and cons between solution ideas and narrow down to 3 reasonable and acceptable designs. In the latter two weeks, instructors introduce the meaning of "operation" in the CDIO concept. In here, students were trained to evaluate their top design with solution testing, comparison with the current solution, optimize the design detail and setting the standard manufacture process. As the outcome of their design, students had to prepare a 5 min advertisement video, a A0 size poster, and the prototype of their solution idea to join in a cross-class exhibition. In the exhibition, they have to descript their idea and solution in detail and also defend their design from the questions from both school faculties and other student teams, which is good training of professional communication on both giving and receiving sides. The photos of the exhibitions are shown in Figure 7.

Figure 7. Photos of the cross-class exhibition of the final open ended design project

ASSESSMENT METHODS

Based on the course design, several assessment methods were applied to different learning outcomes (Table 2.). The descriptions of each assessment methods are presented below:

Table 2. Assessment methods (with percentage)

Team activity	Assignment	Professional expectations report	Time limitation quizzes	Design project 1 (Poster)	Design project 2 (Poster)	Design challenge – (Oral & video)
10%	20%	15%	10%	10%	15%	20%

- Team activity:

Implement: Following from the method of the literature (Matthew W. O. (2012), the assessment method was divided to (a) monitoring form instructor (and teaching assistants), (b) peer evaluation, and (c) self-evaluation. To prevent potential internal disputes and keep students working on their own task is one of the most important issues in this section.

In part (a) instructors (and teaching assistants) guide and assist students to work as a team with 5 CATME teamwork models (contributing to the team's work; having relevant knowledge, skills, and abilities (KSAs); expecting quality; keeping the team on track; interacting with teammates), which have been transferred to students at the beginning of the semester.

In part (b) and (c), the comprehensive assessment of team member effectiveness-BARS version was selected for students to evaluate their teamwork behaviors with both peer and self- one. By doing this, students can review the concept of working as a team and reflect him/herself with standard rubrics. It is also a good private path for reflecting feelings and thoughts to the instructors.

Outcomes: In the past, around 80% of Taiwanese students confuse the idea between teamwork and division of labor, and 30~50% of the student team has had a dispute within the group. After introducing the new teaching strategy and methods, 80~90 % of our students understand the true meaning of teamwork, and also apply their personal value proposition in the team. On the other hand, less than 5~10 % of student groups have had disputes during the semester.

- Assignment:

Implement: Assignment is one of the most assessment methods through the semester. A weekly assignment is where our students implement their work and present their learning outcome in detailed after the lecture. The assignments were carefully designed in three individual sections, which are the summary of the lecture, learning goals/required abilities, and breakdown topics with answer sheets. By working on assignments, students can review what they learn from the class; finish their tasks step by step from simple to advanced one.

Outcomes: By grading weekly assignments, instructors can understand student's performance and track their learning effectiveness in detail, no meter individual or teamwork one. After applying the new designed assignments in the course, more than 80 % of our students can understand the learning goal and the process to build up their performance. When they found difficulties, 80% of our students exactly know where the problem is. It is much more direct for students to overcome the problems by themselves, or for instructors to help them.

- Professional expectations report:

Implement: Professional expectations report is applied at the end of case study 1 and 2. Students have to integrate what they learn from the 2~3 week works of the same project. It is a good chance for them to review what they did/learned before, to build up their integration ability and represent it in a formal/academic format for communication.

Outcomes: Compare with the students from other classes, our students can write original articles/reports with much more rich and relevant content, opinions or discussions in academic structure, but a listing report of their working process and simple result descriptions only.

- Time limitation quizzes:

Implement: Time limitation quiz is another assessment method different from assignments and professional expectation reports, with slightly more challenge. Two times of quizzes were implemented at the last part of case study 2 and 4, which a similar topic with 1 or 2 additional criteria/limitation were chosen, and working in a team as well. Furthermore, not like the original case study, students have been asked to finish the challenge in an hour. By introduce appropriate pressure, it is believed that students can improve their personal abilities, no matter the professional knowledge or soft skills. Agree to SDT, students will feel competence, relatedness and autonomy during the quizzes, try to know their own abilities, to accomplish goals, and to get stimulation.

Outcomes: As the expectation, most of our students try their best to demonstrate their learning effectiveness to finish the project with confidence. Student groups who complete the challenge, they do enjoy their competence; the groups who cannot succeed, usually will try to figure out where the problems are spontaneous. At this time period, it is important for instructors to listen to the way they achieve success, and to guide the one who failed. In our experience, only about 30~40% of our student groups can succeed in the first quiz, however, nearly 100% of them can succeed in the second one.

- Design project 1 & 2 (poster):

Implement: As the description of case study 3 & 4 above, not only problem scoping and design thinking, it is also important for instructors to understand the student ability of innovative solution creation. Based on the design of semi-open design project, students pay less attention to problem scoping but problem understanding, and more attention on solution design and implement. 4 rating criteria (1~5) were selected for student's poster presenting and presentation, including (1) problem understanding, (2) criteria and constraints analysis, (3) problem-solution fitting (4) communication skills.

Outcomes: Following from our course/project design, nearly 100% of the students know the structure of presentation/poster and the meaning of it; nearly 30% of them can reach 4 or 5 at all rating criteria; about 60% of them can reach the average between 3 and 4; less than 10% of them still struggling in 1 or 2 of criteria. By collecting their outcomes, it is very helpful for instructors to know where the difficulty is for our students, and have a chance to help them in the final project (case study 5).

- Design challenge:

Implement: The aim of the final challenge is to see the integration and application abilities of what our students learned during the whole semester. It is 5~6 weeks' project, which instructors and TAs helped students to review the skills and knowledge and try to apply them to challenge an advance/complete open-ended problem. The successful innovative solution/product/service should include 5 criteria with complete description: problem statement, current bottleneck, problem-solution fit, evidence-based innovative design, and solution quality, which match c.d.i.o. structure. They will present their results via 3 types of professional communication methods, such as oral presentation, video advertisement and (digital) prototype.

Outcomes: 80~90% of our student teams can finish the project with good quality solutions, also, students' progress between the final challenge and the previous one is significant. Rest

of them can figure out where their week point is and the way to improve it with professional feedback.

CONCLUSION

In decades, the education strategy of 12-year basic education in Taiwan only engaged with the traditional teacher-centered environment. As a result, college graduates faced big challenge and gaps when entering into society. To solve the problem, International school of technology and management, Feng Chia university design a new module "Innovation project – foundation" combing CDIO process with self-determination theory and bloom's taxonomy to improve the learning efficiency and also soft skills training. By completing the series of design projects in the module, the student is now able to apply the knowledge flexibly to challenge complicate real-world problems. It is also believed that the students who complete the training and once finish the credits of the graduation requirement, they can highly match the requirement and talent selection conditions of employers.

ACKNOWLEDGMENTS

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KNOWLEDGE GAINED BY WORKING IN UNIVERSITY–INDUSTRY COLLABORATION PROJECTS

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ABSTRACT

Many surveys from recent years emphasize the interdisciplinary skills of job candidates, such as communication, organization, teamwork and social skills. Companies tend to value practical work experience that provides evidence of the applicant's capabilities and potential. The CDIO initiative also adduces the importance of interpersonal skills. The CDIO Standard 7, Integrated Learning Experiences, sets the focus on fostering the learning of disciplinary knowledge simultaneously with personal and interpersonal skills as well as product, process, and system building skills. Accordingly, the CDIO Standard 8, Active Learning, engages students in analytical thinking and problem-solving activities, strengthening also the students' motivation and reflection on what they have learned. Students ought to gain both disciplinary and interdisciplinary knowledge in order to become future engineering professionals. Usually, courses in higher education provide fundamental knowledge and skills during the studies. In addition, students should work in authentic contexts and environments to deepen their competences and thus, become more ready for working life. This case study analyzes a set of soft skills students have attained by working in "theFIRMA", a project-based learning environment at Turku University of Applied Sciences (TUAS), Finland. The analyze is done based on the survey done for the alumni of the learning environment. The results of the survey indicate that theFIRMA or its previous forms have had a great impact on the work possibilities and the skills students have attained while working in the learning environment. In addition, the most valued interpersonal skills of the alumni are the same skills that the companies recruiting value the most. Thus, it seems that the integration of project-based learning and interpersonal skills works smoothly.

KEYWORDS

Soft skills, university-industry collaboration, project-based learning, ICT, R&D learning environment, Standards: 7 and 8.

INTRODUCTION

Soft skills allude to an extensive set of skills, competencies, behaviors, attitudes, and personal qualities that enable people to effectively navigate their environment, work well with others, perform well, and achieve their goals (Lippman, Ryberg, Carney, Moore, 2015). Many surveys from recent years emphasize the interdisciplinary skills of job candidates, such as

communication, organization, teamwork and social skills and critical thinking (Berger, 2016; Morning Consult, 2019). Morning Consult conducted an online survey in September 2018 for Cengage. The companies found out that according to 502 hiring managers and 150 HR decision-makers, the top skills they're hunting for among new hires are: 1) The ability to listen (74%); 2) Attention to detail and attentiveness (70%); 3) Effective communication (69%); 4) Critical thinking (67%); 5) Strong interpersonal abilities (65%); and 6) Being able to keep learning (65%) (Morning Consult, 2019).

Jobs requiring high levels of social interaction grew by almost 12 percentage points between 1980 and 2012 while math intensive but less social jobs shrank by 3.3 percentage points. However, in jobs that require high levels of both math skills and social skills, employment and wage growth was particularly strong. Skills in social situations have evolved over thousands of years and for example, reading the minds of others and reacting on them is an unconscious process. There is a growing demand for social skills and one reason for this is that computers are still poor at simulating human interaction (Deming, 2015; 2017).

Thus, engineering degree programs are challenged to create different ways for students to learn not only core and technical subjects but also this kind of interdisciplinary or soft skills (Martins & Ferreira, 2016). However, there is a tension between the two main objectives in engineering education: the need to educate students as specialists in a range of technologies – while at the same time teaching students how to evolve as generalists in personal and interpersonal skills (Crawley, Malmqvist, Östlund & Brodeur, 2007). Project-based education is at the core of the CDIO-inspired programs, meaning that students ought to be trained in contexts complex enough to be prepared for the complexity of industry projects (Einarson & Saplacan, 2017). The CDIO Standard 7, Integrated Learning Experiences, sets the focus on fostering the learning of disciplinary knowledge simultaneously with personal and interpersonal skills as well as product, process, and system building skills. Accordingly, the CDIO Standard 8, Active Learning, engages students in analytical thinking and problem-solving activities, strengthening also the students' motivation and reflection on what they have learned (Crawley et al., 2007).

In this paper, the focus is set on studying the impact of theFIRMA project-learning environment (and its previous forms) for its alumni who have attained skills in university-industry collaboration projects. The main research questions are: 1) What kind of soft skills did the students attain while working in the project office?; 2). What kind of impact did it have on getting employed?; 3) How did the learning experiences affect the career path decisions? In addition, the skills students attained while working in theFIRMA are compared to the skills companies' value the most. First, the operations in theFIRMA are introduced. Thereafter, the survey done for the alumni is being described and compared to the results from the companies. Finally, the past and current activities are being discussed, and future development thoughts are presented.

theFIRMA PROJECT OFFICE

The project office theFIRMA provides ICT-focused development projects to small and medium-sized companies (SMEs) and third-sector organizations. All the projects are conceived based on the needs of a customer and typical assignments include web development, small-scale game prototypes, graphic design and end-user training. In addition, theFIRMA participates in several externally funded R&D projects. Project office theFIRMA was established in 2015 when the previous learning environments of TUAS' ICT unit were merged. Previously there were four

different learning environments: "Education Support Centre Finland", "Network Support Centre Finland", "ICT-portti" and "Citizen's Helpdesk". The main objective of combining the learning environments of TUAS' ICT unit was to increase the performance of the learning environment, standardize processes and expand the operation (Säisä, Määttä and Roslöf, 2017).

TheFIRMA operates like a real company: A student CEO leads the office and student project managers are responsible for leading the customer projects. Teachers and other staff members mentor the students. Multicultural and multidisciplinary teams work together in challenging assignments to meet the goals of the projects and their customers. Students attain relevant disciplinary and interdisciplinary skills by participating in the projects in different roles. Teamwork is very important to the development of an engineer's work because many projects involve several professionals in a multidisciplinary approach and aspects such as leadership and communication are essential to achieve goals successfully (Martins & Ferreira, 2016). For more detailed information about theFIRMA, see https://thefirma.fi/?page_id=1181.

ALUMNI SURVEY

Based on the earlier feedback of the alumni, there are three ways that theFIRMA has had an impact on the students: 1) Technical skills; 2) Soft skills; and 3) Networking with other students and local companies. This new survey was solely focused on the soft skills that students have attained while working in the project office. The reason for this point of view is that the learning activities have been done in many different development projects. Thus, analysis of the different technical skills attained would have been very complex. For example, the project assignments have included repairing computers and installing cybersecurity software, applying Microsoft products and services to different customer needs, and troubleshooting computer networks etc. That is, the main goal of the survey was to study the impacts of project-based learning for the alumni who have attained skills in these university-industry collaboration projects. The main questions were: 1) What kind of soft skills did the students attain while working in the project office?; 2) What kind of impact did it have on getting employed?; 3) How did the learning experiences affect the career path decisions?

The survey included 10 questions. The first four questions dealt with background data: The learning environment version that the respondent worked in, gender, age, and the graduation year of the respondent. Question five examined the respondents' current position in working life. Question six presented a set of 15 different social skills and asked which of these skills the respondent learned while working in theFIRMA or its previous forms. Questions seven and eight examined on a scale 1–5 how much these soft skills had an impact on getting employed. Question nine examined how much effect the working in the learning environment had on getting employed. Question 10 examined how the learning experiences affected the career path decisions of the respondents.

The survey was sent to the alumni via LinkedIn, Facebook and e-mail (N=100).

RESULTS OF THE SURVEY

The total amount of respondents was 33 (18 of the respondents had worked in theFIRMA, nine of the respondents had worked in ESC Finland, five of the respondents had worked in ICT-portti and one of the respondents had worked in Citizen's Microdesk). Age and gender of the

respondents is presented in Figure 1. The graduation year varied between 2005 and "not yet graduated".
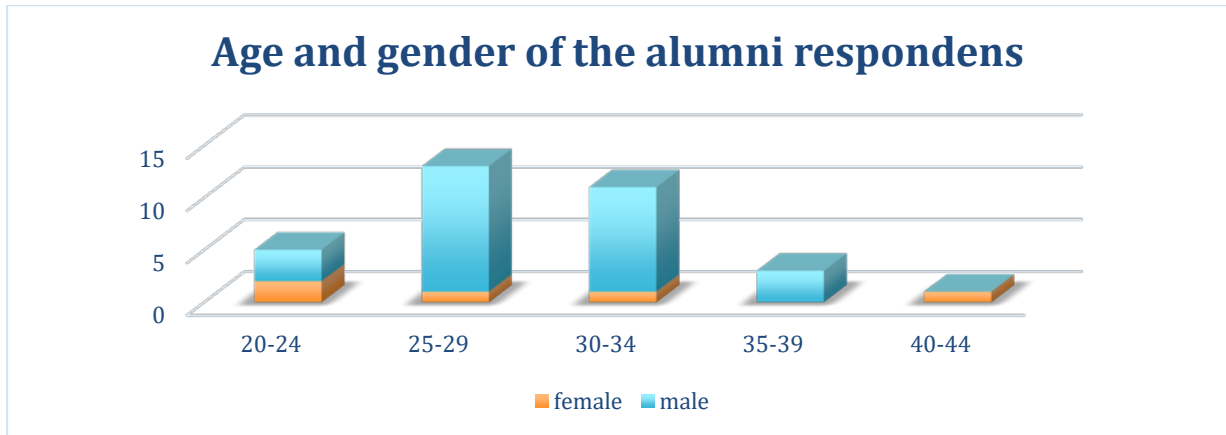
Age and gender of the alumni respondens

Figure 1: Age and gender of the alumni respondents

A bit less than one-tenth (9.4%) of the respondents work in an executive position in working life. 12.5% of the respondents work in middle management. The majority of the respondents (40.6%) work as senior-level specialists and a bit more than a third (34.4%) as junior-level specialists. One respondent (3.1%) works a clerk and one did not answer this question. The positions of the respondents are presented in Figure 2.

Position in working life
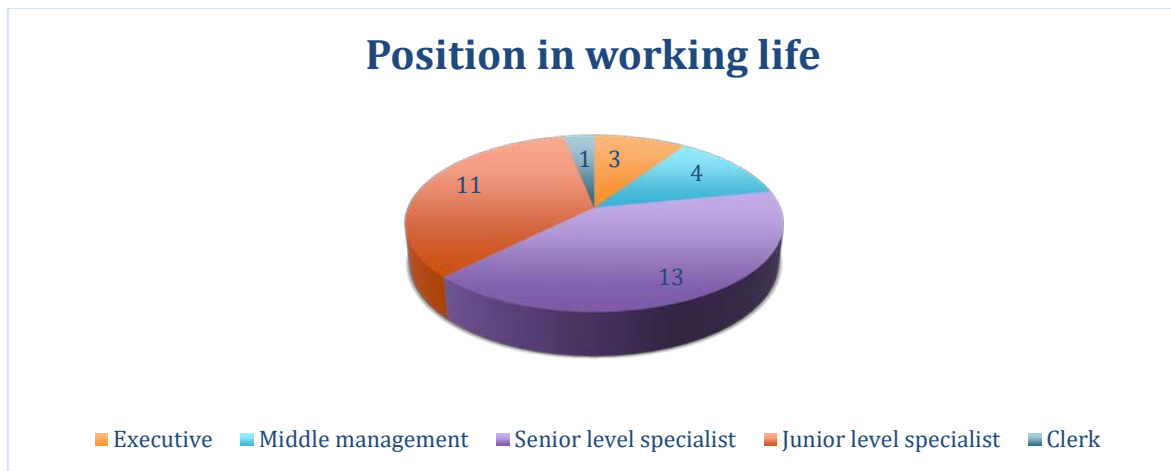
Figure 2: Position in working life of the alumni respondents

The first content question of the survey was to find out what kind of soft skills did the students attain while working in the project office. The soft skills that the respondents had experienced learning are presented in Figure 3. Communication, teamwork, problem-solving and leadership (n>20) were the skills that the respondents indicated the most. Time management, interpersonal skills, motivation and enthusiasm, organizational skills and presentation skills were also quite common answers (16<n<20). The soft skills that the respondents felt to have learned the least were flexibility, work ethics, creativity, negotiation, handling feedback and analytical skills (7<n<15).
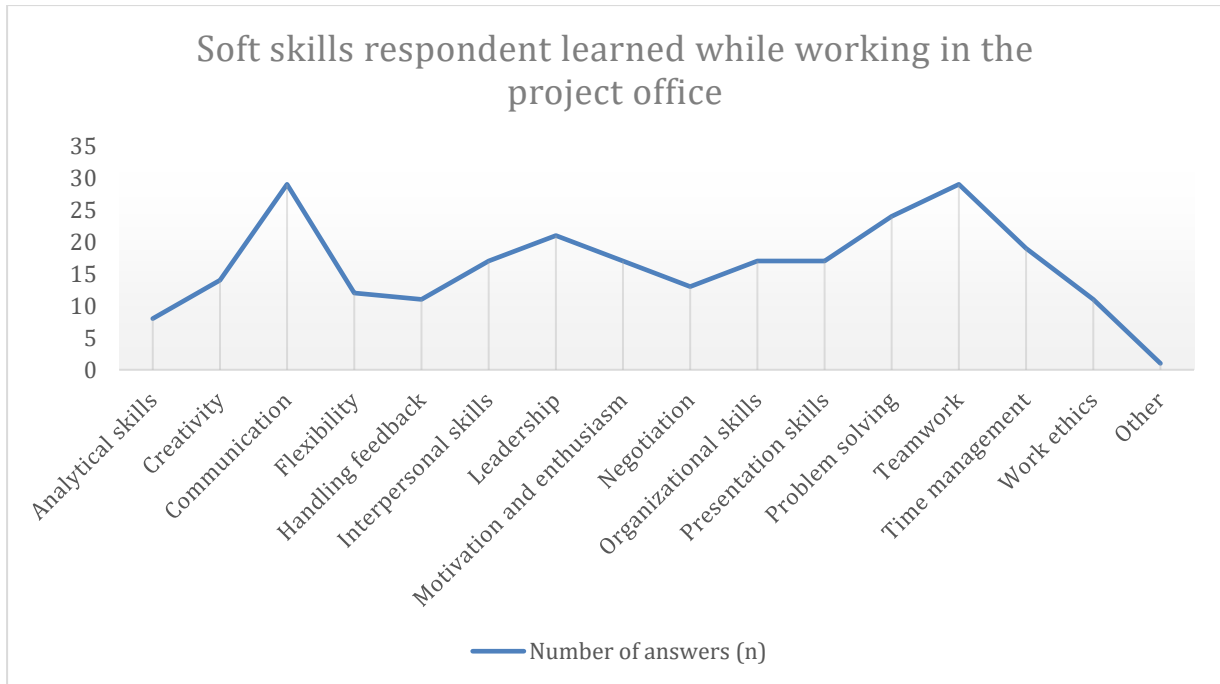
Figure 3: Soft skills learned while working in the learning environment

The second main question was to find out the impact of these skills and experiences had on employability. Communication, teamwork, problem solving, interpersonal skills, and motivation and enthusiasm were reported to have had the most impact on getting employed. For these, the percentage of replies between marks 4–5 was over 65%. Leadership, analytical, negotiation and time management skills had least impact. The impact scales of the different skills is presented in Figure 4.
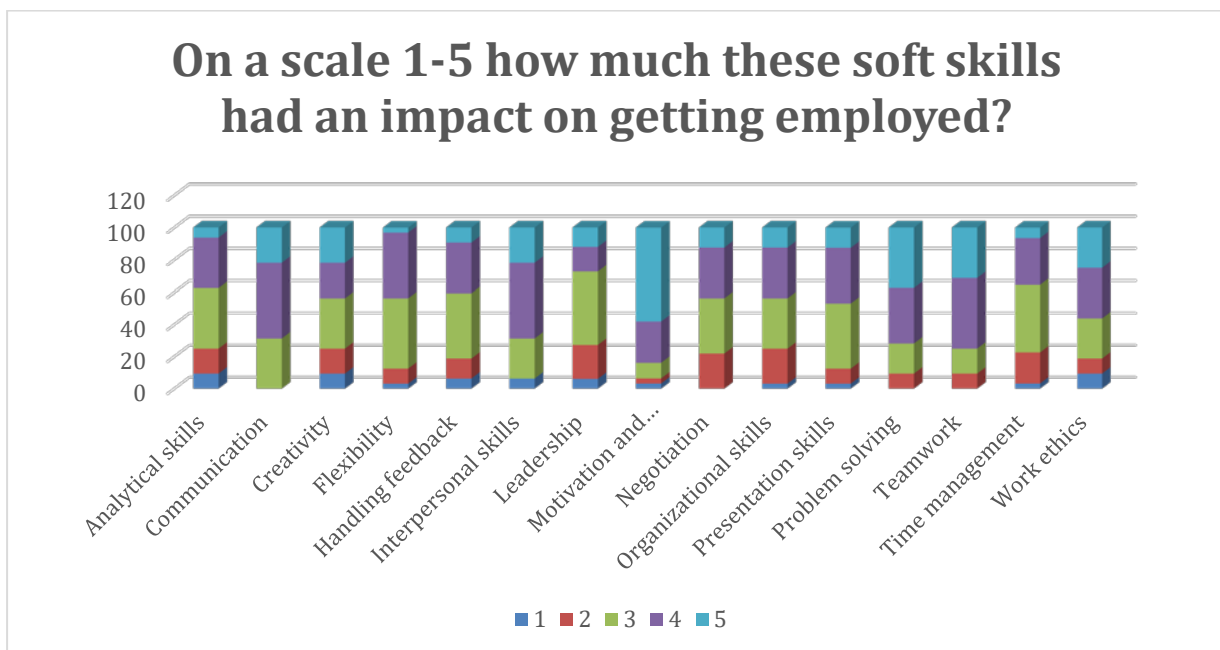
Figure 4: The impact scales of different skills (1 = lowest impact, 5 = highest impact)

When the respondents were asked to estimate on scale 1–10 how much their project-learning experiences affected getting employed, the answers varied mostly between 5–10 (average 7.8). The answers are presented in Figure 5. When comparing the answers between the learning environments, alumni from ESC Finland have had the biggest impact on getting employed with an average of 9. TheFIRMA learning environment had the second-best average 7.6. However, in theFIRMA, there was one answer with rating one and another answer with rating 4, which were the two lowest answers for the question. Also, the length of the professional career of the respondents may have an effect on this reflection. One of theFIRMA alumni respondents sent a message after completing the survey and told that this was a difficult question, since he has not yet found a job after graduation and, therefore, gave a really poor estimation. ICT-portti had an average of 6.8 and Citizen's Microdesk had an average of 5 with only one answer. In other words, it is not possible to find significant differences between the different development versions of the learning environments based on these results.

However, one of the differences between theFIRMA and ESC Finland is the amount of students that work in the learning environment. In the ESC, there were around 30–40 students working each year. Most of the students worked there for several months or even several years. In theFIRMA, some students study only a few credits whereas other students might study a major part of their degree there (Määttä, Roslöf & Säisä, 2017). Thus, it would have been a good idea to ask also, for how long the alumni worked in the environment. In this way, the correlation between the amounts of time the student worked in the environment and the impact on getting employed could have been analyzed.
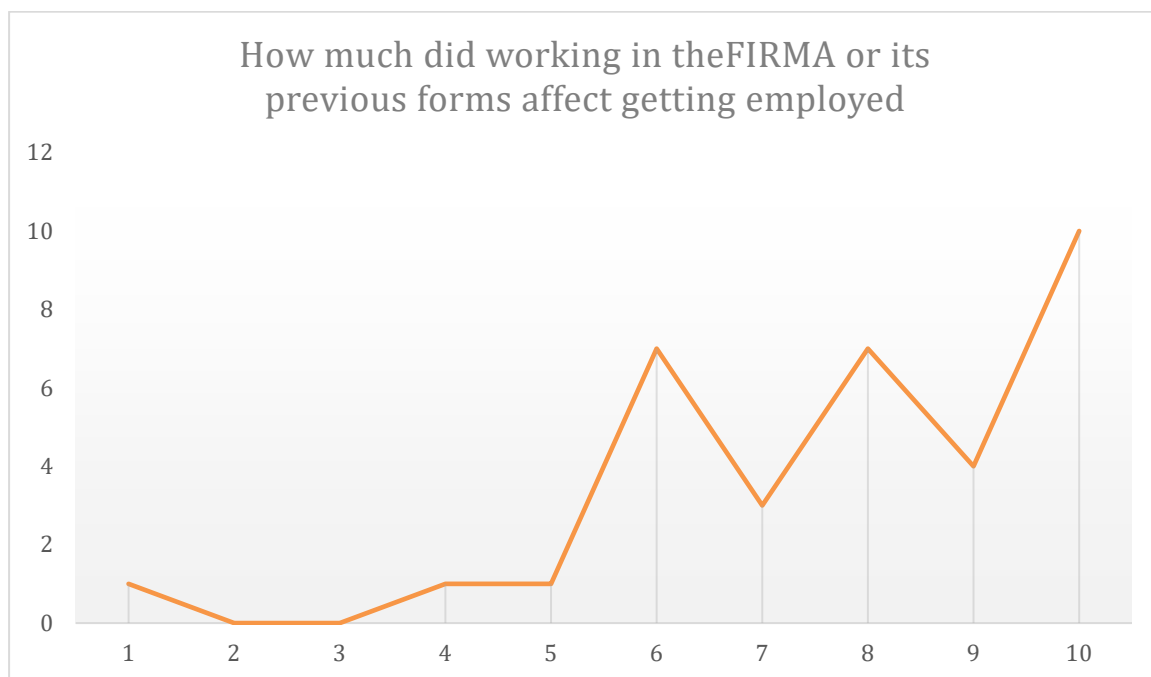

Figure 5: The impact on getting employed (1 = lowest impact, 10 = highest impact) (number of responses)

The last content question of the survey was to find out how the learning experiences affected career path decisions. The answers were given in free text form and 27 of the respondents

answered this question. Based on the answers, they can be categorized as follows: 1) Technical skills; 2) Soft skills; and 3) Networking – or a combination of these. Yet, one of the respondents felt that working in ESC did not affect getting employed in any way.

Most of the answers were related to technical skills. One of the main topics that arise from the answers was related to getting in touch with an interesting field of IT:

> "Working in ESC solidified the idea to work in a server environment and gave me valuable insight on what it might look like. Worked with anything Microsoft related from Windows Server and its basic features to OCS and Lync, SCCM, Virtualization and so on. Still work in the field doing the same stuff as a systems architect."

Quite often, the topics that students work within the project office are something that they get familiar with also after graduation:

> "The subjects in projects had topics on ERP software and invoicing software and a lot of web software development which brought experience on these topics. The job I got after theFirma used similar technologies and the business field was on a nearby domain with the projects. The experience in theFirma had a heavy effect on my career."

Quite many of the respondents felt like the work experience attained from the learning environment helped in soft skills as well:

> "In theFIRMA, I worked as a student CEO and student project manager in various projects. I learned a lot about working with different people and got the basic understanding on management tasks. Currently I work as a project manager in IT company, so all of the skills I learned in theFIRMA have been very useful. I doubt that I would be in my current position without the experience gained from theFIRMA. …"

The career path for many started already in the learning environment:

> "Worked in a manager role in ESC Finland. My responsibility was to share work tasks for teams and communicate with customers. And also did Windows servers administration on-premises and cloud. It had a huge benefit to my current position where I work nowadays. Keep up the good work!"

Networking is emphasized for the students. Moreover, when asked, many of the students say that the atmosphere and the people are the best things in the environment. It is not rare, that the students come across in working life after graduation. Thus, networking with other students is important already while studying. In addition, networking with alumni students and local companies is important for the future. One of the great networking stories were also presented in the answers:

> "I got my first IT summer job through the connections of ESC alumni and the manager later got me a job at a large IT company two years before graduating. This set me on a path where I spent 'a bit' of extra time to officially graduate but at that point, I already had a lot of real life experience from numerous projects and even an architect position under my belt. During my time in ESC, my colleagues and I actively participated in different events and hackathons and due to that I connected with some important people in the IT circles. I was mainly focused on web and mobile development and through a series of events; I ended up working as an IT consultant in another European

country eight months after graduating. There is no denying that working in ESC played an important role in my career path. I already had a long experience with programming but managed to meet the right people and built very important relationships throughout the years. To summarize, ESC gave me the confidence to aim higher than average, which resulted in seeking higher positions than what my actual work experience would suggest. The soft skills that I learned during that time gave me a head start and I've been building on top of those strong foundations ever since".

The skills students attained are comparable to the skills companies value the most. LinkedIn analyzed different soft skills of the job-hoppers that are members of their social media platform. Based on the analysis, the most important skills are communication, organization, teamwork, always punctual, critical thinking, social skills, creativity, interpersonal communication, adaptability and friendly personality. Based on the results of the alumni survey, communication, teamwork, problem-solving, interpersonal skills and motivation and enthusiasm have had the most impact on being employed. This goes hand in hand with the LinkedIn analysis.

CONCLUSIONS AND FUTURE WORK

Based on informal discussions with the alumni, the assumption was that theFIRMA or its previous forms have had a great impact on the work possibilities and the skills students have attained while working in the learning environment. The results of the survey indicate similar findings to the earlier assumptions. In addition, the most valued interpersonal skills of the alumni are the same skills that the companies recruiting value the most. Thus, it seems that the integration of project-based learning and interpersonal skills works smoothly.

From a statistical perspective, the survey was not ideal. For one, the exact number of alumni of all of the related learning environments is not known. Thus, the population of the survey included the alumni who we were able to reach. However, the main purpose of the survey was to find out the impacts of learning experiences for the alumni who have attained skills in university-industry collaboration projects. In that sense, the survey still fits its purpose.

In addition, this exercise made it clear that we ought to have better ways of communicating with our alumni. TUAS does systematical cooperation with its alumni in general, but this does not work very well for theFIRMAs purpose. We organize one or two mingling events each year for our current students and alumni, but the invitations reach only the active alumni that are part of theFIRMAs network. In the future, there should be a more standardized way to collect and maintain alumni contacts and communicate with them regularly. Currently, there is a mailing list and a Facebook group for the alumni. Since Facebook is not such a common social media among the young people anymore, the contacts were also made via LinkedIn. In the future, there will be a group for theFIRMA in LinkedIn, and when the students leave theFIRMA after a project or after graduation, they are advised to join the alumni group.

The benefit of project-based learning is dual-impact learning experiences: Students take on roles that simulate professional engineering practice and at the same time, responsibility for knowledge development transfers from the instructor to the learner. This methodology offers opportunities to use and develop higher-order learning and professional skills, such as critical thinking, teamwork and leadership (Meikleham, Hugo & Brennan, 2018). Dual learning is the key element of the project office at TUAS, too. Based on the survey results, the interpersonal and soft skills have been integrated well in the learning environment and they have an effect on getting employed and even for further future of the alumni.

There are other rather similar kinds of surveys done by the CDIO partner organizations, for example, the survey done for a BSc in Mechanical Engineering program in the Schulich School of Engineering. The survey measured twelve graduate attributes of which six were technical and six soft skills. The technical skills were: 1) A knowledge base for engineering; 2) Problem analysis & Professionalism; 3) Investigation; 4) Design; 5) Use of engineering tools; and 6) Economics & project management. The soft skills were: 7) Life-long learning; 8) Ethics and equity; 9) Communication skills; 10) Individual and teamwork; 11) Professionalism; and 12) Impact of engineering and society. The six-year study indicated that the top three self-efficacy attributes were design, life-long learning, and ethics and equity. The lowest three were knowledge base for engineering, problem analysis and use of engineering tools. (Brennan & Hugo, 2017)

The survey for theFIRMA alumni did not include technical skills, but when comparing the results of soft skills of the surveys, the respondents felt to have learned the least work ethics while, in the case of Schulich, the respondents estimated ethics and equity to be a top attribute. Then again, theFIRMA alumni respondents felt that they have learned communication, teamwork and problem solving the most while working in a project-based learning environment. In the future, work ethics is something that theFIRMA will focus more while also keeping the most learned soft skills on the top of the list.

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CDIO PROGRESS: MECHANICAL ENGINEERING OF THE BRAZILIAN MILITARY INSTITUTE

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ABSTRACT

The purpose of this article is presenting the CDIO approach development in the mechanical engineering of the Military Institute of Engineering (IME). In 2017, through the triennial academic evaluation carried out by the Brazilian Ministry of Education, the Brazilian Government considered the IME's Mechanical Engineering the best undergraduate course of the 291 Brazilian undergraduate courses evaluated in this area. The IME is a higher education institution of the Brazilian Army, located in Rio de Janeiro - Brazil. The CDIO approach implementation in the IME's mechanical engineering represents a change in the teaching and learning process, maintaining the recognized academic content and integrating the practices described in the CDIO Standards. In this way, there is a plan to improve the academical formation of mechanical engineer of the Institute, taking advantage to the excellent theoretical knowledge and adding the skills and competencies described in the Syllabus CDIO. The article describes the reasons for the change, the use of CDIO standards for implementation, and the experiences of the academic staff involved during their development and implementation. This article also presents the development of this academic structure model in the mechanical engineering since 2017, to become a parameter to be used in other undergraduate engineering departments of the Institute, so that they adapt to the CDIO principles and carry out the necessary reforms to improve their curricula. The implementation activities were carried out without a significant increase in the faculty workload, with the creation of new learning experiences. The successful implementation of some CDIO standards has been demonstrated as being effective at increasing student motivation, innovation and problem-solving in both practical, active learning sessions and conventional theoretical knowledge learning sessions.

KEYWORDS

Implementation, CDIO Syllabus, Standards : 1, 2, 4, 5, 10

INTRODUCTION

The Brazilian Army has a higher education college denominated Military Institute of Engineering (IME), located in Rio de Janeiro. The Institute has ten programs leading to the bachelor´s degree in engineering (Figure 1) with the main objective that graduated engineers will work in the Science and Technology System of Brazilian Army.
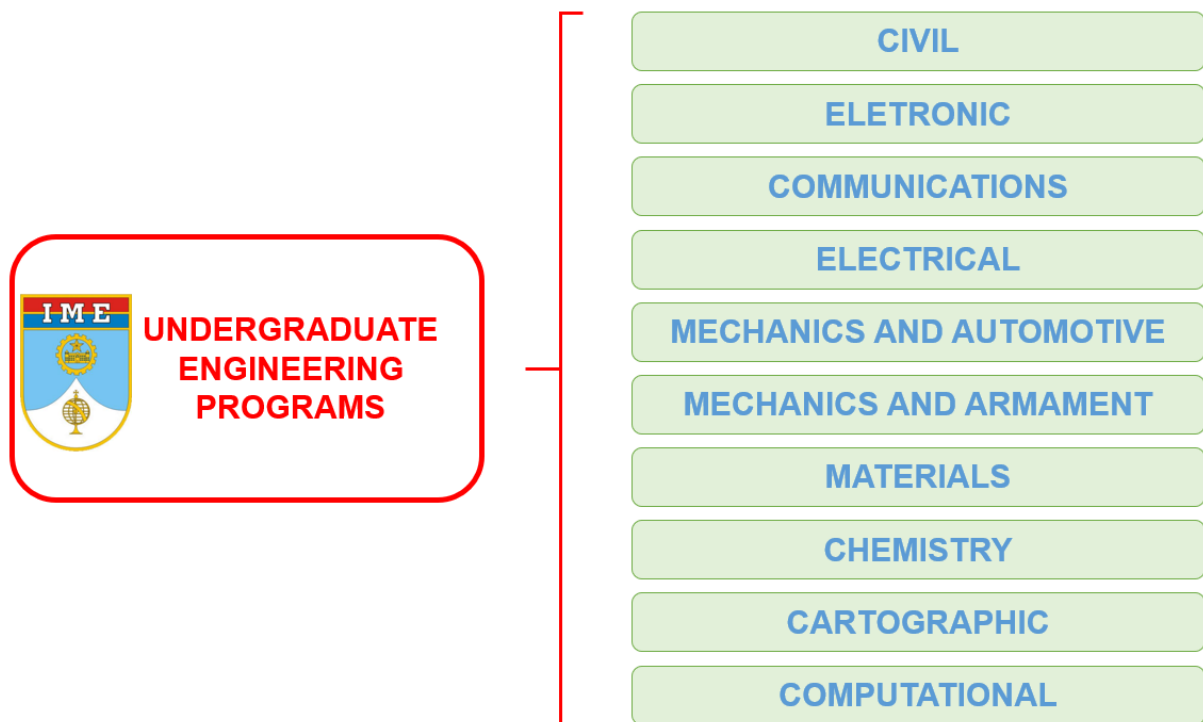
Figure 1. Undergraduate Engineering Courses of IME.

The IME is, at the same time, an engineering college and a military academy. As an engineering college, it must comply with, like all engineering bachelor´s degree programs in Brazil, the rules established by the Brazilian government. In a few words, all engineering undergraduate programs must have at least 3600 hours of academic activities and five years to be graduated (Brazilian Government, 2002) and (Brazilian Government, 2007).

IME's Mechanical Engineering has two specialties: Mechanics and Armament Engineering and Mechanics and Automotive Engineering. In both undergraduate courses are present the basic contents for mechanical engineering, such as Thermodynamics, Fluid Mechanics, Dynamics, Solid Mechanics and Machine Projects. For Armament Engineering there are disciplines involving ballistic phenomena and for Automotive Engineering there are disciplines involving the vehicular dynamics.

Around fifteen students are admitted to the IME's Mechanical Engineering every year. Most students are military (70%) and the others are civilian students. Military students will work in the engineering organizations of the Brazilian Army in the development of military weapons and vehicles. Civilians will join engineering companies.

The academic period for the student to become a mechanical engineer by the IME is five years, divided into ten semesters (or ten periods). The first four semesters, called the basic years, are the same for all ten IME's programs. Only after the fourth semester mechanical engineering students will have contact with the specific content. Each mechanical engineering program has 4,000 hours of activities in engineering education. Despite this number, most of the activities are theoretical activities, mainly a large number of lectures.

The quality of the mechanical engineering education in the IME, related to Brazil, is proven through ENADE. The ENADE is the Brazilian Performance National Examination Students (Brazilian Government, 2017b), and it has the objective to measure and monitor the learning process and the academic performance of students in relation to the knowledge, skills and competencies acquired during their studies. The examination is applied to students of the last period of undergraduate courses.

The application of ENADE for Mechanical Engineering began in 2005, being applied with a periodicity of three years. IME's mechanical engineering students always have exceptional results in ENADE. The results at ENADE have always made mechanical engineering of the IME recognized by the academic community in this area in Brazil.

Beyond the education in engineering, as a military academy, the military student has more than about 1700 hours of activities related to military education. These activities are scattered by the five years, even though more concentrated in the two first years, and they must comply with the Brazilian Army orientations. Figure 2 shows the curriculum´s structure of mechanical engineering.
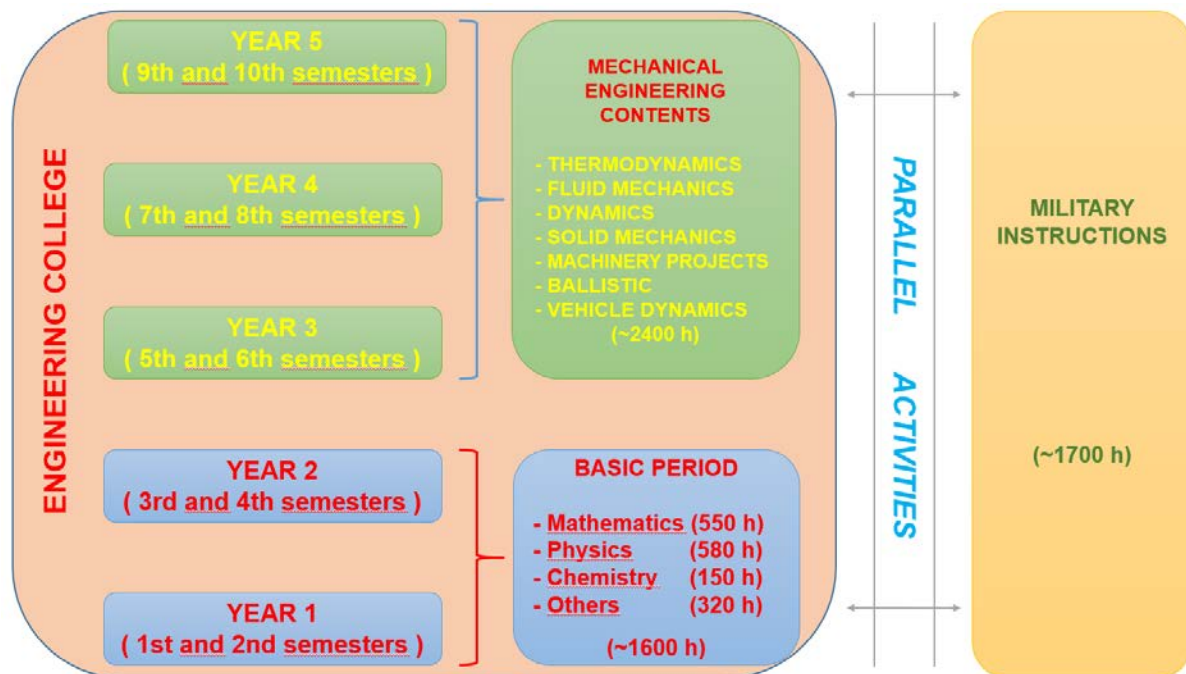
Figure 2. Curriculum structure mechanical engineering in IME.

Since 2012, a project to transform the Brazilian Army's Science and Technology System has been running, involving and introducing new aspects, such as the innovation and triple helix concept (Ranga & Etzkowitz, 2013). It created an opportunity for the mechanical engineering program to initiate a reflection about how to improve and adapt to the formation of the engineer to the new scientific and technological system.

At the same time, in recent years, there has been an increase in student dissatisfaction. This dissatisfaction is mainly related to the large number of theoretical activities in mechanical engineering classrooms. In fact, in the past, IME students had more practical activities. However, recently, education has been based mostly on scientific foundation with or without

practical activities, leading to superficial learning (Elmgren & Henriksson, 2014). This type of feedback was received, to a certain extent, by some engineering institutions of the Brazilian Army.

In 2010, a new activity was included in the mechanical engineering programs, which increased this demand. The students of the fourth year started to participate in international exchanges, created directly by IME or by Brazilian government educational programs, such as Science Without Border (Brazilian Government, 2017a). These exchanges allowed students from IME to attend six months of courses at some renowned engineering international institutions, such as West Point United State Academic, Texas Tech, Massachusetts Institute of Technology, Michigan Technological University, University of Cambridge and ParisTech. The feedback about the student performance, of all these universities, have been excellent. The students that return from the international exchange are very motivated but start to compare this with the IME's mechanical engineering structure. This comparison in relation to learning and teaching methodology, curriculum structure and teaching activities contribute to increasing the dissatisfaction among the students.

The students now have the perception that how the learning and teaching at the mechanical engineering program could change and could be.

In this way, the students forced mechanical engineering in IME to start a process of improvement in their learning process in engineering, despite its excellent results. Based on the demands of the students and the Brazilian Army, and after visiting some universities and analyzing some possibilities, the introduction of the CDIO approach in the IME's mechanical engineering was chosen, at the end of 2014, as the core of this improvement process. The CDIO structure is best suited to mechanical engineering requirements.

INTRODUCTION OF CDIO IN MECHANICAL ENGINEERING – CDIO STANDARD 1

Through presentations and meetings with mechanical engineering program faculty, the problems that generated the lack of motivation for the engineering learning and the current needs of the Brazilian Army and the companies were shown. The following subjects were discussed:

- Very theoretical courses. Lack of practice in disciplines;
- Demotivation for learning;
- Overload of non-academic activities for students;
- Need for integration between disciplines;
- There is no provision of improvement courses in teaching of higher education in engineering; and
- The current needs of the engineering professional – CDIO Syllabus (Crawley et al., 2014).

In this context, the CDIO approach (CDIO Standard 1) was introduced as a solution, providing to the future mechanical engineers the ability to perform their engineering skills with a more mature assessment of how a product meets the real needs of the Brazilian Army and society in general.

It was explained to the mechanical engineering program faculty that this choice was based on the alignment between the desired changes and the CDIO concepts, as shown in Table 1.

Table 1. Desired changes by mechanical engineering program and CDIO

DESIRED CHANGES	CDIO APPROACH
The concept that the engineer education should be based on fundamentals but with a context of Conceive-Designing-Implementing-Operating systems and products.	CDIO Vision and CDIO Standard 1
Creation of new opportunities for students to perform more engineering practice in the academic activities, as elaboration of engineering systems, well-designed work and design-build-test courses.	CDIO Standards 4, 5 and 8
Implementation of teacher training and improvement in new teaching methodologies, encouraging the use of more active learning activities.	CDIO Standards 8, 9 and 10
Inclusion of integrated learning, which means learning experience where the theoretical knowledge and professional skills are obtained simultaneously.	CDIO Standard 3
Implementation of the constructive alignment concept (Biggs, 1996) as a model for courses design, as also executing a revision of the intended learning outcomes and the curriculum of the programs	CDIO Syllabus, CDIO Standard 2, 3 and 12
Introduction the concepts of innovation and triple helix (Ranga & Etzkowitz, 2013) as part of the knowledge, skills and attitudes of the student	CDIO Syllabus

NEW CURRICULUM – SELECTION OF COMPETENCES AND ABILITIES

Starting in 2017, according to the CDIO implementation process diagram (CDIO Initiative, 2017), the selection of the knowledge, skills, and attitudes that engineering students must have when leaving university is the next step in the development of the integrated curriculum (CDIO Standard 2).

The mechanical engineering program began the curriculum design process through a careful study of the CDIO Syllabus 2.0, in order to compare it with the learning outcomes established by the Brazilian education laws, the Brazilian Army and the engineering companies.

For mechanical engineering higher education, the Brazilian law that determines the learning outcomes is called the National Curricular Guidelines for Engineering Undergraduate Programs (Brazilian Government, 2002). In order to exercise the mechanical engineer profession in engineering companies, the Federal Council of Engineering and Agronomy (CONFEA, 1973) establishes the activities, abilities and responsibilities of the engineer.

The knowledge, skills and attitudes, determined by the National Curricular Guidelines of Engineering Undergraduate Programs (Brazilian Government, 2002) and by the Federal Council of Engineering and Agronomy (CONFEA, 1973), present a strong similarity. In this way, Table 2 correlates the demands of National Guidelines and CONFEA with the skills and knowledge proposed by the Sections of the CDIO Syllabus 2.0.

Table 2. Correlation of competences between the Brazilian aspects and the CDIO Syllabus for mechanical engineering program.

Competencies established by the National Curricular Guidelines and by CONFEA		*CDIO Syllabus*
Apply mathematical, scientific, technological and instrumental knowledge to the engineering	➤	Disciplinary knowledge and reasoning
Design and conduct experiments and interpret results	➤	*Personal and professional skills and attributes*
Planning, supervise, elaborate and coordinate engineering projects and services		
Identify, formulate and solve engineering problems		
Develop and/or use new tools and techniques		
Understand and apply professional ethics and responsibility		
Assume the posture of permanent search for professional updating		
Communicating effectively in written, oral and graphic forms	➤	*Interpersonal skills: teamwork and communication*
Work in multidisciplinary teams		
Conceive, design and analyze systems, products and processes	➤	*Conceiving, designing, implementing and operating systems in the enterprise, societal and environmental context – the innovation process*
Supervise the operation and maintenance of systems		
Evaluate the impact of engineering activities in the social and environmental context		
Evaluate the economic feasibility of engineering projects		

There is another important aspect to be considered in the IME, which are the skills and attitudes that the future military engineer should have for the Brazilian Army. Since seventy

percent of the students are military, Table 3 shows the correlation between the skills and attitudes needed for the future Brazilian Army Officer and the CDIO Syllabus.

Table 3. Correlation of competences between the Brazilian Army and the CDIO Syllabus.

Competencies established by the Brazilian Army		CDIO Syllabus
Technical-professional	→	*Disciplinary knowledge and reasoning*
Self-improvement, moral courage, discipline, initiative, objectivity, integrity, dedication, responsibility	→	*Personal and professional skills and attributes*
Tact, camaraderie, emotional stability, communication, flexibility, leadership	→	*Interpersonal skills: teamwork and communication*
Creativity and project management	→	*Conceiving, designing, implementing and operating systems in the enterprise, societal and environmental context – the innovation process*

Both Tables 1 and 2 show that the CDIO Syllabus addresses all the needs of Brazilian education laws, the Brazilian Army and the exercise of engineering activity in companies (CONFEA requirements). Given that the CDIO Syllabus is a current document, covering the needs of the modern engineer, the mechanical engineering program decided to adopt the CDIO Syllabus completely and without any customization. In this way, the CDIO Syllabus 2.0 has been translated into Portuguese and is being submitted to the faculty for further development of the integrated curriculum. To this end, it is intended to use the tools called matrix ITUE Matrices and Black Box exercise (Crawley et. al., 2014).

CDIO IMPLEMENTATION – INITIAL ACTIVITIES

Introductory Engineering Course Implementation – CDIO Standard 4

In 2017, the engineering introduction course was designed to be carried out in two periods, that is, in the third and fourth periods of the second year, as explained in Figure 2.

In the first part of the course, held in the third period, the students learned the methodology of PMBOK project management (PMBOK, 2017), wrote technical reports and made professional presentations. In the second part of the course, held in the fourth period, the students were separated into teams and they received academic projects that had requirements and deadlines to be met.

In this way, the course took place in the year 2018, being considered a success of learning and motivation by students and teachers, according to preliminary qualitative survey.

Introduction of Disciplines for Design-Build Project Development - CDIO Standard 5

The mechanical engineering program decided to include two Design-Build disciplines. One in the sixth and seventh periods, called Initiation to Research, and another in the ninth and tenth periods, denominated Final Project of Course.

In both disciplines, students will use previously learned project methodologies and will perform activities to properly meet project requirements within the established deadlines. These disciplines already exist in the mechanical engineering curriculum of the IME, but they are not of the design-build type.

As an experimental design-build activity, in 2018, students were offered an academic competition for aero model design (Figure 3). The proposed design had simple requirements, such as maximum span length, maximum payload for in-flight transport, deadline for flight test, and written and oral presentation of the final report. With this different activity, it was possible to perceive the enthusiasm, the application of the theoretical concepts learned in the conception and construction of the prototype, the organization for teamwork and, most importantly, the consolidation of the mechanical engineering learning.

Figure 3. Experimental design-build activity

In progress, there are two academic spaces for the development of design-build projects by students. These spaces will be used in the courses of Introduction to Engineering, Initiation to Research and Final Project of Course (CDIO Standard 6).

These academic activities are expected to occur in this year 2019.

Improvement of the Pedagogical Update Stage and School Administration

In the IME there is a preparation for teachers called Pedagogical Update Stage and School Administration (ESTAPAE). This stage was only meant to present the administrative rules for the new teachers.

In order to implement the CDIO approach, ESTAPAE has been reformulated and now has as main objective to promote the updating and improvement of the pedagogical knowledge needed for teachers, instructors and monitors, in order to establish a debate on the feasibility of implementing improvements in the conditions of the process of teaching and learning, especially in the scope of graduation, including discussions on updating the curricular flow, active learning methodologies, evaluation, complementary activities, teaching of engineering in the 21st century, technological innovation, educational legislation and internal teaching standards.

In 2018, the new ESTAPAE was started with the faculty of the mechanical engineering program. Active teaching methodologies and new forms of assessment are priorities for improving the quality of teaching and learning (CDIO Standard 9 and 10).

CONCLUSION

This article showed the initial process of implementing the CDIO approach on Mechanical Engineering Program of the Military Institute of Engineering (IME). The main motivations for adopting CDIO were the transformation process of the Brazilian Army's Science and Technology System and the students' feedback on the need to make the courses more interesting and with academic activities of engineering practices.

From then on, the vision of the CDIO approach was spread among teachers and students. In addition, there was an in-depth study comparing the competencies desired by the Brazilian Government and the Brazilian Army, and the main conclusion was that the CDIO Syllabus can be perfectly used by the IME.

Some academic activities are already being used, aiming at the implementation of CDIO, with great success among students and teachers.

Finally, all this initial process of implementing the CDIO was considered adequate to the needs of the Mechanical Engineering Program. The CDIO approach is being accepted with great motivation. Implementation will continue to occur within the CDIO Standards guidelines.

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THE EXPLORATION AND APPLICATION OF "PSPC-CDIO" MODE FOR INNOVATIVE PRACTICE

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ABSTRACT

Innovative practice ability refers to the ability to raise, analyze and solve new problems. The innovation training project is a significant part of the quality project launched by the Chinese Ministry of Education, which provides an effective approach to cultivate innovative practice ability of college students. Focusing on the goal of promoting innovative practice ability, a "PSPC-CDIO" (project driven, student dominated, practice and training, and comprehensive assessment based on CDIO) mode for cultivating innovative practice ability is proposed. The application of innovative teaching and training demonstrates that the effectiveness of the "PSPC-CDIO" mode.

KEYWORDS

Learning target, Engineering practice place, Active learning, Student assessment, Programmatic evaluation, Standards: Design-Implement Experiences, Active Learning

INTRODUCTION

Innovative practice ability refers to the ability of college students to raise, analyze and solve new problems, and cultivating the ability has become an important task of education in colleges (Yang &Yan, 2017). During the period of the 12th Five-Year Plan (from 2011 to 2015), the Chinese Ministry of Education implements innovation and entrepreneurship training program for college students. It includes three categories: innovative training, entrepreneurship training and entrepreneurial practice project. Among them, the innovative training project aims at inspiring innovative thinking, cultivating the innovative spirit, improving innovative practice ability, and laying the foundation for training innovative engineering talents.

Different from the class teaching, the teaching of innovative training focuses on students' individual characteristics, and encourages students to carry out practice training based on their research interest and professional knowledge. It has many similarities and common points with "CDIO" (Conceive-Design-Implement-Operate) engineering education, such as educational objectives, training methods, practice contents, and so on. Both of them encourage students to practice collaboratively, emphasize "education and learning via practice project", and resolve the contradictions between theory and practice in engineering education effectively.

The CDIO engineering education provides a good reference for innovative practice training of engineering talents in Chinese colleges, and several research works have been proposed in the literature. Shantou University initiated the "EIP-CDIO" (Ethics, Integrity, and Professionalism-CDIO) engineering education and personnel training mode. (Gu, Shen, & Li, 2008) presented the concept, connotation and implementation plan of "EIP-CDIO". Tsinghua University utilized CDIO engineering education mode into practice courses, which regarded engineering education as a series of service engineering product manufacturing process, and organized learning activities of teachers and students with hierarchical structure (Gu, 2009). (Wang & Cheng, 2010) proposed the "three-in-one" training plan for knowledge, ability and quality of electronic information specialty based on CDIO. Li Tong (Li, Zhang, Wang, Liu, & Kang, 2014) proposed the "SE-CDIO" (Soft-Engineering-CDIO) engineering education mode for software engineering in terms of talent training syllabuses, curriculum systems, teaching methods and evaluation systems, and so on. (Xie, Jiang, Li, & Zheng, 2012) summarized the characteristics of teaching activities such as curriculum plans, teaching methods, practical experiences, and so on.

The development of engineering education and reform of innovative practice teaching raises two key problems to solve: one is how to combine innovative practice teaching with CDIO engineering education, and the other is how to construct a new practical teaching mode that contains CDIO educational philosophy and intrinsic characteristics. In view of the above problems, a new teaching mode of innovative practice called "PSPC-CDIO" is proposed, which is expatiated as "project driven, student-dominated, practice and training, and comprehensive assessment" based on CDIO. The main contributions of this work can be summarized as follows.

(1) The "PSPC-CDIO" mode is proposed for innovative practice training.
(2) A concept of "learning by doing" and "doing by learning" is introduced into the "PSPC-CDIO".
(3) The "PSPC-CDIO" mode has been applied to practice training and achieved many good results, such as prototypes, demo systems, technical report, academic papers and patents.

The rest of this paper is organized as follows. Section 2 expatiates the conceptual meaning of "PSPC-CDIO". Section 3 demonstrates the construction of the "PSPC-CDIO" mode. Section 4 demonstrates the application of "PSPC-CDIO". Finally, conclusions are given in Section 5.

CONCEPT OF "PSPC-CDIO"

CDIO is the abbreviation of the following four words: conceive, design, implement and operate. "Conceive" is to define user needs, consider all kinds of constraints, improve concepts, technologies and business plans, and form clear thoughts. "Design" is to propose the schemes and methods for products, processes and systems. "Implement" is the process of transforming design into a product, including manufacturing, integration, testing and verification. "Implement" is to show the value of the products, processes and systems that have been realized, including system maintenance and optimization, and so on (Kang, Lu, & Xiong, 2007).

The CDIO engineering education mode lets students learn engineering from practical courses covering the life cycle of product development and product operation. Its essence is "learning by doing", which emphasizes the practices, encourages students to take active learning, and pays much attention to the cultivation of teamwork consciousness. It is a unique mode that combines practice education with theoretical education, which accords with the training objectives of innovative practices.

In the process of learning, assimilation and application of CDIO, the authors proposed a "PSPC-CDIO" mode, which is expatiated as "project driven, student-dominated, practice and training, and comprehensive assessment" based on CDIO, as shown in Fig.1. "Project driven" means taking the project objectives as the "goal" throughout all the process of conception,

design, implementation and operation. "Student dominated" requires highlighting the dominant position of students, giving full play to students' subjective initiative and creativity, and encouraging students to complete innovation and practice projects collaboratively. "Practice and training" requires proposing problems and solve problems close to engineering practice, combining theoretical knowledge with engineering practice, and integrating technical solutions with product development effectively. "Comprehensive assessment" implements an all-wave, diverse and comprehensive examination and evaluation system, and takes the expert review as an important means of supervision and evaluation. "PSPC-CDIO" has constructed a comprehensive system of "engineering, teaching and practice" to integrate theoretical teaching and engineering practice so as to realize the coordinated development of knowledge, ability and quality.
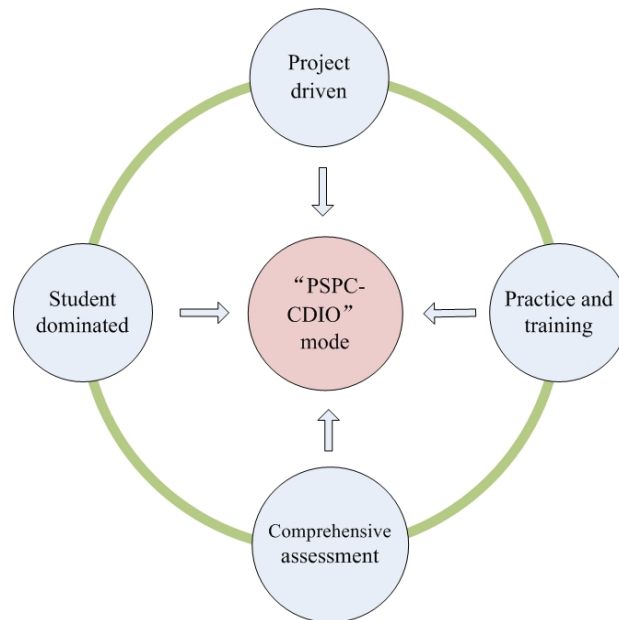
Figure 1. The concept of "PSPC-CDIO"

The "PSPC-CDIO" MODE

Project driven

According to the training objectives of different disciplines and the level of innovative practice ability of college students at different learning stages, a series of diversified, multi-level and open practice projects are rationally set up, and project-driven innovative practice is Launched (Wang & Hong, 2009).

(a)Taking task document of the practice project as "outline", which requires college students to implement projects abide by the plan and schedule strictly, to design, develop, integrate and test products strictly according to the technical requirements, to comply with the management requirements strictly.

(b)Taking research objectives of the practice project as "cable", this takes all stages of conception, design, implementation and operation, and covers all aspects of the cultivation of innovative practice ability. It integrates the basic knowledge, basic theories and basic methods, and combines innovative consciousness, innovative spirit, innovative thinking and innovative ability.

(c) Taking expected results of the practice project as "core", which means to evaluate intellectual labor of innovative practice quantitatively. The expected results mainly include

technical reports, academic papers, invention patents, prototype systems, products, and so on. Among them, the prototype systems and products are the concentrated expressions of practice project. The project achievement is the "realization" part after "conception and design". It is the specific object of "operation", and it is also an important basis for project evaluation.

Student dominated

"Student dominated" means "student-centered", which requires highlighting the dominant position of students, giving full play to students' subjective initiative and creativity, and encouraging students to complete innovation and practice projects collaboratively (Yang &Yan,2015). It is mainly embodied in the following three aspects.

(a) Topic self-selection. Students start from their hobbies, and choose the project based on their research interest, learning background and specialties. "Topic self-selection" fully respects students' interest and willingness to learn and creates a free and relaxed atmosphere for practice teaching.

(b) Practice collaboratively. It means "donging by ourselves", which requires working out project objectives, schedule and product plan, formulating research methods, test plans and technical routes, and complete product development, integration, testing, testing and verification via close teamwork (Jiang, etc., 2017).

(c) Self-management. College students usually form research teams and select a team leader and implementation of self-management under leader responsibility. "Self-management" requires college students to develop detailed research plans, optimize the task assignment, establish management regulations and form an efficient management mechanism, and arrange time and energy to deal with the relationship between innovative practice and curriculum learning.

Practice and training

Taking project as "traction", that is, to raise questions, analyze problems close to engineering practice. "Practice training" covers all stages of "conception, design, implementation and operation", and throughout the project implementation, node assessment and completion of the whole process. Practice training adheres to "student dominated", and lets students participate in the project widely and deeply.

Comprehensive assessments

The innovative practice projects implement a multi-dimensional and comprehensive evaluation system, including internal reporting system and expert evaluation system. The project team carries out regular reporting system and holds one or two project meetings once a week. The progress of the research is reported by the students, and the teachers follow up the progress of the project by listening to the presentation, checks the completion of research work, identify problems and provide solutions in time. The expert evaluation mainly focuses on the examination and acceptance check of the project. The experts carry out a comprehensive evaluation based on the technical summary report and research achievements obtained, and give one of the four different grades, i.e., excellent, good, qualified and unqualified comments. Expert evaluation plays an important role in improving the quality and effectiveness of innovative practice project.

Application of "PSPC-CDIO"

In the past three years, the author has guided five innovative training projects, as shown in table 1, among them, there are four national innovation training projects and one provincial innovation training project. Based on the research achievements of innovative training projects, five academic papers have been published and eight invention patents have been applied. Particularly, the "intelligent single-police system" has been reported by CCTV and "Science and Technology Daily" in China. Take the "intelligent single-police system" as an example to expound the teaching practice and experience of "PSPD-CDIO".

Table 1. Innovative practice Project

No.	Project title	Project hierarchy	Discipline/ Specialty	Grade	Total numbers of students	Semesters	Project achievements
1	Control system design and flight test for quadrotors	National level	Aeronautical and astronautical scientific and technical	Junior	3	1	Published 2 papers and applied for 2 patents
2	Design and implementation of intelligent control system for micro UAV	National level	Aeronautical and astronautical science and technology	Junior	2	1	Published 2 papers and applied for 1 patents
3	Design for a novel stratospheric airship	National level	Aeronautical and astronautical science and technology	Sophomore	5	2	applied for 2 patents
4	Space Spiderman -A new space debris acquisition device	National level	Aeronautical and astronautical science and technology	Sophomore	4	2	applied for 1 patents
5	Intelligent single-police system	Provincial level	Armament science and technology	Sophomore	5	2	Published 2 papers and applied for 1 patents

Project selection

The project should be innovative, applicable and feasible, and fully embody "user needs" and "student centered". In view of the current severe situation of anti-crime and the development of police equipment, the students start from their research interests and choose the project titled "intelligent single-police system". The "conceive" of the project is taking "intelligent single-police system" as the research object, considering the coupling relationship of man, equipment and environment, and designing a self-organizing network, modular and intelligent individual soldier system, which can enhance the capability of reconnaissance, communication and cooperation, and enable individual police to have stronger offensive capabilities, better synergy and faster variability. Students should write project applications, prepare application materials, and report the project idea by themselves to obtain approval through "project recommendation", "project pre-trial" and "expert review".

Project implementation

The whole process of project implementation adheres to "project traction" and "student dominated", and the practice work is carried out according to research schedule strictly. The research team was formed through the bilateral selection and free combination, including a team leader and three crew members, which implements self-management under the leader responsibility. There is a clear division of work and close collaboration among team members. The whole process of project implementation fully embodies "independent practice". The research team determined the technical route and test plan, designed the system solutions, tested and verified the designed system collaboratively.

The overall scheme of the project is designed as shown in Fig. 2. The system consists of computer subsystem, helmet subsystem, communication subsystem, energy subsystem, navigation subsystem and weapon subsystem, which has the functions of ad hoc network, video, audio, text communication, and so on. In order to test the feasibility and reliability of the system, a series of tests were carried out, and the design plan is constantly improved according to the test results.
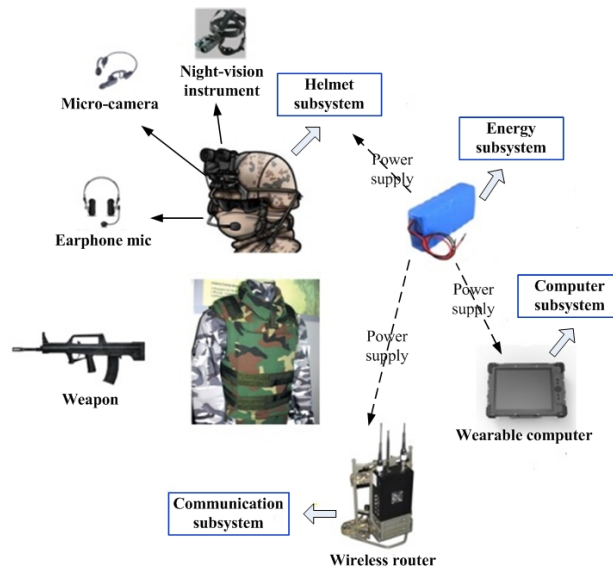
Fig.2 The sketch map of intelligent single-police system

Project evaluation

The research team developed a set of intelligent single-police system, published an academic paper entitled "Design and experimental research of a rescue assistance system based on a wireless network", and applied for two national invention patents.

The project is evaluated as excellent through communication review, results report, on-site demonstration, and so on. The "intelligent single-police system" was highly commended by experts and was reported by CCTV, "science and technology daily" and other media.

Project assessment also pays attention to the implementation process as well as the expected results. In addition, innovative practice projects are included in training programs and teaching plans, and quantitative evaluation is given from the aspects of practice hours and credit recognition.

CONCLUSIONS

This paper introduced CDIO engineering education into innovative practice teaching to promote teaching reform and prosed a practice teaching mode called "PSPC-CDIO", which is expatiated as "project driven, student-dominated, practice and training, and comprehensive assessment" based on CDIO, and it is applied to the innovative practice teaching. The teaching practice demonstrated that the "PSPC-CDIO" mode is effective for cultivating and improving students' innovative practice ability.

ACKNOWLEDGMENT

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TEACHING ENGINEERING STUDENTS: FROM PRINCIPLES TO PRACTICES

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ABSTRACT

The paper describes the idea, the process of implementation and the results of a teaching development course for engineering faculty, providing training for engineering students of Siberian Federal University in accordance with new challenges in higher education.

The paper covers the teaching development course that involves two levels: the first level – understanding and acceptance of CDIO ideas and Standards, basic pedagogical foundations and concepts, modern teaching methods and technologies by educational engineers. The second level implies designing advanced, personally significant course content. The developed course is implemented with the use of interactive technologies, involves the formation of professional and personal competencies by means of solving integrated problem tasks, teamwork, active learning. The results of the teaching development course for engineering faculty are demonstrated by a new educational product or technology that a particular educational engineer has developed, and are subjected to expert evaluation. The process of implementing the described teaching development course for engineering faculty is carried out by means of volunteering participation in problem-analytical workshops and roundtables, reciprocal visiting of classes and the idea of mentoring and cooperation implemented in the university environment. The experience of Siberian Federal University in the teaching development course for engineering faculty is provided with the experts' and students' feedbacks and course evaluation.

KEYWORDS

Teaching development course, engineering educators, active learning, problem-analytical workshop, redesign, Standards: 8, 10.

INTRODUCTION

In the process of implementing the educational program "Metallurgy" at the Siberian Federal University in the CDIO ideology, a system for enhancing faculty teaching competence has been developed and introduced for four years of the program implementation. The paper describes the idea and the results of a teaching development course for engineering faculty in accordance with new challenges in higher education. One of the factors of successful teaching engineering students in accordance with modern requirements is providing the educational process with the concerned teaching staff. The huge work on creating teachers' training program and making the staff concerned with new challenging effective teaching methods was started with the analysis of the ideas and approaches of Engineering Pedagogy and still goes on. The experience of engineering schools and technical universities (M.J. Terrón-López et al., 2015) and (W.B. Gaskins et al., 2015), ways of redesigning engineering education (B. Lucas and J. Hanson, 2016), strategies for developing interdisciplinary lessons (A. Gero, 2016) and

many other works have been reviewed before and on launching the described program. The paper opens with a quick vision of the problems engineering educators encountered with teaching engineering students and followed by a presentation of the principles and the results of the teachers' training course; a description of the developed modules and organizational form of the teachers' training process. After the authors' insight of two-level teaching development course elaborated with the examples of the redesigned educational product and achieved faculty progress, the conclusions are presented.

THE TEACHING PROBLEMS ENGINEERING EDUCATORS IDENTIFY

To specify the personally-significant goals of improving pedagogical competences, the engineering educators of the educational program "Metallurgy" of Siberian Federal University have presented a self-assessment of the level of formation of their pedagogical competencies. According to the results, 60% - 80% of them have stated the following professional gaps in:
−   organization and management of students' project activities (70-80%);
−   understanding and perceiving the features and basic requirements for the implementation of the educational process within the CDIO ideology (75-80%);
−   determination the substantive and methodological links at the interdisciplinary level and at the level of interdisciplinary integration (60-75%);
−   competence formation methods and competence level assessment (80-85%).

Engineering educators who have passed the teachers' training program have rated these competencies by 20–30% higher than the initial ones.

The problems of motivating students for project activities have been brought into focus. Some university teachers have set the problem of organizing engineering classes, planning and achieving educational results in a holistic pedagogical process.

Analysing the results of self-assessment and further discussions have revealed such problem as the inability of engineering educators to reflect on their pedagogical activity, which has been shown in the difficulties of separating problems from causes and consequences, the lack of clarity in formulating the problems, the inability to build a hierarchy of problems and their interrelation.

DESCRIPTION OF THE WORK DONE

The idea of the teaching development course is based on several principles and is focused on the innovating personally significant content and redesigning educational courses and discipline programs in integration with other disciplines. The developers of the teaching development course have distinguished the following principles of implementing the course which is aimed to enhance faculty teaching competencies in redesigning and integration aspect:
−   continuity of the process of teachers' training throughout the period of implementation of the educational program, that allows considering the process of training future engineer of the certain year of study holistically, systematically, reflexively;
−   the synchronicity of the problems considered in the teachers' competence development program to the problems of the implemented curriculum of the educational program "Metallurgy" that increases the motivation of the teachers and provokes personal significance of the improvement of the educational process;
−   practicing "learning by doing" that determines the need for the teachers to present products of their activities for the team expertise;

−   focusing of the educational process of teachers' training on the formation of teachers' competencies in the integration of the educational areas and the development of integrated tasks (Standard 3, 7), support student' project work (Standard 4, 5), effective use of active teaching methods: problem-thinking, case-studies, STEM technology, role-plays, etc. (Standard 8).

At Siberian Federal University the design and process of the teaching development course have been implemented in the logic of reverse design, which allows building a clear strategy for mastering program material in the following sequence: learning outcomes – testing – tuning content and pedagogical technologies that ensure confidence in learning outcomes by validated procedure measuring. Designing of the content of the teachers' training program is focused on Standard 10, which defines the necessary content to ensure the ideology of CDIO initiative:
- integrated learning experiences (Standard 7);
- active learning (Standard 8);
- learning assessment (Standard 11).
In addition, the focus on the organization and implementation of students' project work requires the teacher's ability to perform this activity (including educational process design), as well as in project management.

The short description of the challenges that engineering educators had to overcome and the results of the work done are described below (figure 1).

Teachers' training program							
	level 1					level 2	
challenges	redesign the course through content integration of related disciplines and learning outcomes	enrich the course with active learning practices and elicit the formation of the personal and interpersonal competences		develop and implement new monitoring, evaluation and reflexive procedures		reduce the individual professional gaps in pedagogy	
	Module 1	Module 2	72 academic hours	Module 3	72 academic hours	Module 4	72 academic hours
progress	56,75% of engineering educators covered the module	63,04% of engineering educators covered the module		54,3% of engineering educators covered the module		32,6% of engineering educators is currently covering the module	
	45,6% of program courses were redesigned	64,8% of program courses were enriched with active learning practices		62,1% of program courses uses more than two evaluation methods		40,5% of program courses is currently being redesigned	

The results of the development of pedagogical competencies of engineering educators in the framework of the teaching development course have been supposed to be the following:
−   the ability to organize interactive cognitive-reflexive activities based on the active teaching methods, through the use of round-table discussions, debates, visualization, revealing the understanding of the content of the discipline being studied.
−   the ability to develop integrated tasks based on the analysis of discipline learning outcomes, educational and engineering activities in accordance with the specific requirements of the CDIO concept.

−   the ability to implement quasi-engineering activities in the educational process based on the topical practical experience of the particular industrial sector.

−   the ability to research into industrial topics and to project management for the specific tasks of the employer and learning outcomes in accordance with the competence model of the future engineering undergraduate.

−   the ability to develop assessment methods and activities for each type of educational activity (discipline, project activity, modules).

Control and progress of the process of improving the pedagogical competencies of engineering educators have been carried out through the achieved progress and development of the students' competencies within the framework of requirements for learning outcomes using SMART technology: S (Specific, the most specific and clearly defined result); M (Measurable); A (achievable); R (Relevant); T (Time-bounded). Substantially each of the requirements of SMART-technology is as follows:

−   specific – to create new technological processes and products in the relevant industrial area;

−   measurable – to make calculations and design products for various technical applications;

−   achievable – to create products and technologies according to international standards;

−   relevant – to develop new technologies considering the conditions and limitations;

−   time-bounded – to meet deadlines in the process of training or performing quasi-professional activities.

The Teaching Development Course (level 1)

The work on the innovative educational program, built in the ideology of the CDIO Initiative, involves, first of all, teachers' awareness of the main principles and requirements of this approach. Therefore, the first, initial module of teaching development course is the module devoted to the critical consideration of all CDIO Standards, which is carried out in an active joint thinking activity of all program engineers and teachers at problem-analytical workshops. The awareness of the requirements of CDIO Standards at this stage contributes to the engineering educators' reflection about their own model of teaching and further self-development as a teacher. It has been noted that a personally meaningful intention to improve pedagogical competencies as well as teaching methods appears.

The above-mentioned requirements for the teaching competences of engineering educators are projected into the appropriate modules of the teachers' training program and determine its invariant component:

Module 1. Disciplinary curriculum. Educational process design in reverse design logic. Interdisciplinary links. The methodology of knowledge.

Module 2. Competence approach in education. The shift from the process characteristics of the educational process to competence-based results. Meta competencies. Integrative learning in the development of personal, interpersonal competencies of the students.

Module 3. Monitoring and evaluation of the educational process and learning outcomes in the implementation of the CDIO ideas. The functions of the evaluation procedure (diagnostic, organizational, educational, controlling). The principles of evaluation activity. The subject matter and technology of formative assessment. The structure and methodology of creating assessment materials and activities.

The organization of the process of improving the pedagogical competencies of engineering educators is aimed at bridging the gap between the requirements for the implementation of innovative activities and the existing pedagogical competencies of the teaching staff. The procedure for entering the process of improving the pedagogical competencies of engineering

educators, who start the implementation of the educational process in CDIO ideology, begins with a workshop that defines the goals and results of this process. Professional development of engineering educators has a continuous prolonged nature with the discussion of problems that simultaneously appear in the educational process. The organizational form of teachers' training program has become a problem-analytical workshop, which has several advantages:

1.	allows to organize a dialogue of each teacher with everyone and collaborate within the program, to consider the problem from different sides, to expand the knowledge and experience, to acquire new ways of activity;

2.	stimulates brainstorming of engineering and pedagogical ideas of engineering educators, developing communicative and presentation skills, including the skills of public speaking;

3.	creates the conditions for teachers' teamwork.

In the course of the problem-analytical workshop, a pedagogical problem is presented for discussion, the solution of which is either absent or ambiguous, there are no specific methods for its solution. The formulation and interpretation of problem-solving tasks are assumed. Such problems as "Crisis of engineering education, causes and solutions", "Ways to increase students' motivation to learn", "Modern student as a representative of the digital generation", "Styles and models of pedagogical training", "Organization of effective interaction of participants of the educational process" have been discussed.

Problem-analytical workshop creates an environment where engineering educators get experience in identifying and understanding the nature and specifics of the problem, finding ways to solve it through the formulation of a sequence of tasks. The acquired skill is transferred to the organization of problem-based learning with students.

The most part of the participants of Teachers' training program who have covered all three modules developed the initial redesigned courses but still, there are quite many problems with content integration considering the formats of the lessons, evaluation methods and etc. Figure 2 shows the number of educators of a particular module who completed the programme. As it can be seen the Module "Natural Sciences" which includes here Chemistry, Physics, Mathematics, Material Science and Thermal Physics has the best results in covering the Teachers' training course. For the educators of Metallurgical Module, the program has appeared to be quite difficult to cover especially considering the course redesigning. They had to solve the problem with integration and implementation of active methods of teaching.
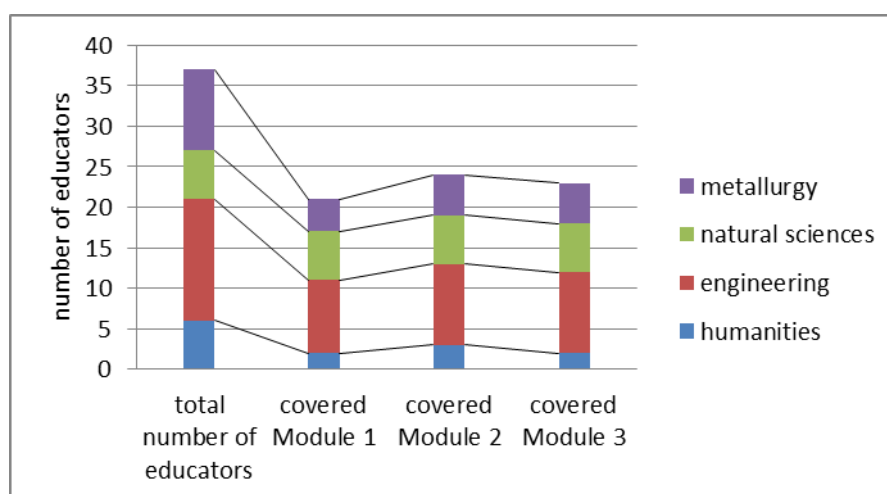
The number of courses (disciplines) which have been redesigned after covering the Modules of Teachers' training program is demonstrated in figure 3.
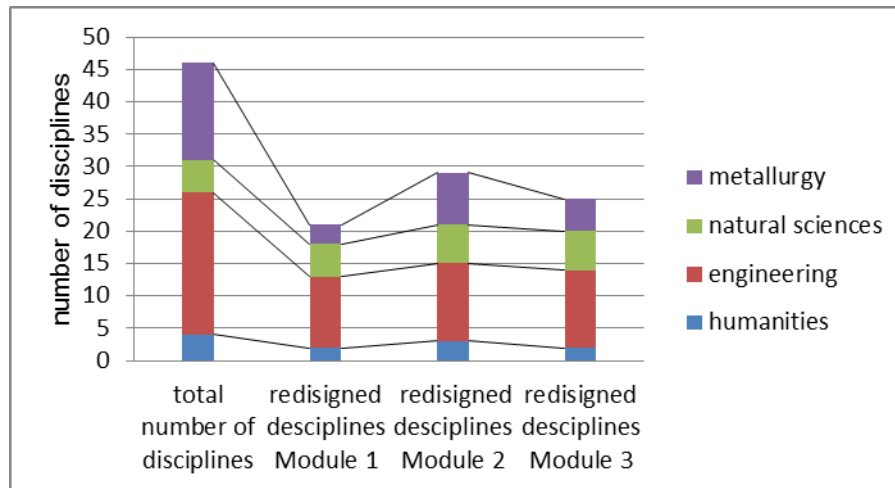
The substantive content of the modules of the teaching development course (level 1) meets the requirements of CDIO Standards, but is not sufficient for implementing systemically complex changes in the educational process, especially considering a large number of engineering educators with technical and technological degrees who are not familiar with psychology and pedagogy. Thus, the teachers' training program of the first level comprises such encouraging extra-program activities as:

−   learning at pedagogical courses and seminars at different universities and schools;

−   organizing and participating in communities of practice;

−   reciprocal visiting of classes (classroom observation) and expert consultations as a means to promote reflection and peer exchange;

−   participating in pedagogical conferences, meetings and making research in education.

The results of the passing teaching development course (level 1) can be noted as *the achieved faculty progress* which is demonstrated in:

−   creating teams of teachers concerned in the development of a particular CDIO Standard within the educational program;

−   working out and implementing an assessment method for the integrated course/discipline (for instance: one integrated examination on 3 different disciplines);

−   implementing e-learning in the course by means of using MOOCs, digital tools and platforms, webinars and videos in collaboration with the employer;

−   publishing findings in pedagogical journals;

−   preparation and presentation of the final teaching projects on the following topics: "Development of a cluster of professional competencies of future engineers during the implementation of the integrated interdisciplinary project in the CDIO ideology", "Assessment of the formation of design and implementation competences of the students based on the components of the product life cycle", "Digital educational environment for the development of project activities", "Curriculum model as an organizational and content dominant of ensuring the quality of engineering education".

The Teaching Development Course (level 2)

The second level of the teaching development course implies applying an individually-differentiated approach to improve pedagogical competences of engineering educators. It has been implemented by individual mentoring work depending on the current level of the development of personal pedagogical competencies, the awareness of personal professional gaps in implementing pedagogical activities, the period and experience of teaching. The work has been organized by regularly conducted individual consultations with the program leaders, project managers and experienced colleagues. The round-table discussions of the teaching

problems of a certain engineering educator were carried out by means of solving specific pedagogical cases, which has allowed to reveal the problem in the course/discipline design and to learn how to apply definite teaching methods by means of learning by doing. Working on pedagogical cases in the context of improving pedagogical competencies has let the engineering educators form a methodological culture both in the aspect of developing case assignments as the assessment tools and in the aspect of organizing and managing students' project activities. This training has been facilitated by mastering the algorithm of case solving:

− the study of the presented pedagogical situation;
− problem analysis;
− the development of criteria for solving problems;
− making hypotheses for problem solving and mechanisms for its implementation;
− the analysis of possible risks;
− the development of a problem-solving program (plan) through solving a sequence of research tasks.

As a result, some basic disciplines and courses have been changed completely adjusted to the project tasks, industrial demands and a metallurgical component of the educational program. One of the examples is Chemistry which has been redesigned in integration with Physical Chemistry, Material Science, Foundry Technologies, Project work and English for the Specific Purposes. The content and the teaching methods of the discipline have to be changed due to the new challenges such as the need to work on the 2-year industrial interdisciplinary project the results of which have to be presented and described in English.

Another example of redesigning engineering course is connected with Standard 4 – Introduction to Engineering, which is an introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills. The first idea of the course was provided by 2 disciples: Theory of Inventive Problem Solving and Engineering Thinking, which were conducted in a conventional manner. The stated learning outcomes haven't been reached and the lack of real engineering practice and thinking as well as weak teamwork has been recognized by the experts and educational engineers. The active role of the teaching staff in participating in different kinds of pedagogical courses and teachers' training program implemented in Siberian Federal University and also the collaboration of two technical universities has resulted in creating new interactive course consisting of such modules as: Engineering Start, Engineering Cluster, Engineering Laboratory which is implemented in STEM technology and supported by the developed redesigned disciples: Project Management, Information Technologies, Technical Case-Studies, etc. The students' feedback to the newly redesigned course of Introduction to Engineering proves the success in reaching learning outcomes as well as the emotional reactions to the educational process. In the freshman year of engineering, it is important for students to participate in an active learning environment to foster a positive experience as the first year experience is linked to success and retention. Research has shown the more positive and dynamic the first year experience for engineering freshman, the more positive students' attitudes, expectations, and skill level (A. Rugarcia et al., 2000).

The experts evaluate the redesigned course as useful engineering practice however there is still some lack of metallurgical integrated tasks in the course. Some students' feedbacks proposed here to underline the importance of gaining new practical experience while doing the course.

"That is a rather challenging approach to learning with lots of practice and self-work."
"That was a real test for my personal abilities. What can I do in solving engineering task?"
"During the course which lasted for 4 weeks I've received more knowledge and practical experience than during all physics lessons at school."

Many students imply the development of their personal, interpersonal, communicative skills at working on the problem engineering tasks in a team which appeared to be a quite new practice for them as before they solved the tasks individually.

"That was my first experience in creating engineering products in a team of just first-year students."
"That was real teamwork when you are united by solving a problem in a very short time period with intensive engineering practice."

Also, the students distinguish the role of a teacher.
"Teacher's role is great, he is a motivator and assistant in the specific field where I have lack of knowledge."
"What I like the most is creating the product together with an engineering practitioner."

The results of the passing teaching development course (level 2) can be noted as *the achieved personal teaching progress* which is demonstrated in:

−   collaborative work in the teams of teachers of different disciplines focused on getting the particular learning outcomes (engineering skills and interpersonal competences);

−   working out and implementing different assessment methods according to the learning outcomes of the discipline/disciplines;
The Humanities which consists of four disciplines and five competences are assessed by 12 different assessment methods including expert evaluation, role-playing, cases, and others.
The Science which is presented by five disciplines and develop five competences are assessed by 14 assessment methods including peer and self-assessment.
Engineering and industrial disciplines which are presented by the most number of disciplines and competences in the curriculum are assessed by 11 different methods.

−   redesigning the course by means of using digital tools and platforms engaging the industrial engineers;

−   reducing personal pedagogical gaps by mastering active teaching methods (each member of the educational program has completed more than 2 pedagogical courses).

CONCLUSIONS

A survey of engineering educators has shown that the most part (80%) of them determines the integrated goals of improving pedagogical competencies through mastering knowledge of modern ways of solving professional tasks, taking into account advanced international practices, gaining experience in learning the active, STEM, project-based teaching technologies. Engineering educators recognize that comfortable psychological climate in the process of teaching development course, high interactivity of problem-analytical workshops as the main form of the educational process has contributed to the formation of personal and significant goals of their own professional upgrading. The comparison of personally-significant goals and expectations from the teaching development course and their achievements has been shown through the implementation of the results of teachers' training program into the educational process by means of increasing the use of active, integrative technologies, different types of integrative tasks, including case assignments, project management, developed assessment methods. Therefore, the teaching development course has provided the progress in implementing such CDIO Standards within the educational program "Metallurgy" as Standards 1, 7, 8, 11.

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IMPROVING WRITTEN COMMUNICATION – IMPLEMENTATION AT INDUSTRIAL DESIGN ENGINEERING

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ABSTRACT

The purpose of the paper is to present how we have improved the quality of technical writing for students in Industrial Design Engineering at Luleå University of Technology. To achieve this, we have identified a number of courses focusing on verbal and written communication, one course – Product and production design focus on documenting and reporting a technical development work to a client. During the last seven years, the course has continuously been improved, and this paper contains an in-depth review of the course performed during spring 2018. The review was done by discussions in the teaching team, interviews, workshops, analysis of course documentation (course-reviews, course-pm, assessment-scheme etc.). The evolution of the course and how different support systems have been implemented such as peer-reviews, templates, formative feedback and self-assessment has been developed is described in detail. The current course is designed as a stage gate process with four design reviews, in which the student present and receive critique. At each design review, each team produces a short process memo (PM) that is peer-reviewed. Each student conducted three individual peer reviews, as well as group review. With 56 students in the class (spring 2018) over 180 completed peer reviews are performed by the students themselves before they receive formative feedback from the teachers. Self-assessment is also used, first by the team on their own final documentation. Finally, all student perform a personal self-assessment with feedback from their team members. The final assessment of the student is performed by the teachers and the result is similar to the students' self-assessment.

KEYWORDS

Technical writing, design-implement experiences, peer-review, assessment, continuous improvement, Standards: 1, 2, 3, 5, 7, 8, 11.

BACKGROUND

This paper describes an implementation of CDIO at Industrial Design Engineering (IDE) at Luleå University of Technology, Sweden. The focus is on improving written communication. In Sweden the Higher Education Ordinance (Appendix 2, Chapter 4.) describes the learning objectives for each higher education degree and written communication is described in the learning outcome 5 *"…the student must demonstrate the ability, in both national and*

international contexts, to explain and discuss in a written and written manner in dialogue with different groups their conclusions and the knowledge and arguments that underlie them."

The learning objectives are both general (are applied to all engineering master programs) and quite formal and described in a way that they are difficult to interpret and implement in teaching. To simplify the assessment of learning objectives of IDE students, a specific competence profile has been developed (Wikberg Nilsson & Törlind, 2016) that will support the students' understanding of overall goals and what they aim for. The competence profile is inspired, among other things, by the Vitae Research Development Framework (Bray & Boon, 2011) and other similar frameworks. The competence profile is designed to support the students' individual development and supports that students themselves can map their knowledge, skills, experiences and qualities. The competence profile should at the same time provide support for teacher feedback and assessment. In the course, the competence profile is used for goal formulations and also by the students for self-evaluation.

Course placement in the program

The course Product and production design was created in 2012 in connection with an audit of the education program in technical design, when there was a need for an integration course between product design and production technology (the two specialisations in the program. The course is today the third design-implement experiences (Crawley et al. 2007), see Figure 1) located in spring term the third year. A more detailed overview of the program is described in Wikström-Nilsson et al. (2017).

Figure 1 Course placement (D3) in the IDE programme. Shaded areas are design courses.

Students have already been introduced to design-implement experiences in the introduction course D1 (first course year one), and D2 (first course second year) these courses contain a mix of theory, methodology and more practical design-implement experiences.
The Product and Production design course is the first Design-Implement Experiences where no new theory is presented, and the aim is to integrate knowledge and skills acquired previously in the program and also focus on improving their teamwork and interpersonal skills in a product design project. The course was inspired primarily by courses at Stanford University such as d.school (Brown 2008) and ME310 course (Carleton, & Leifer 2009), that teaches a way of working based on design thinking that combines creative and analytical methods and

requires collaboration across disciplines. A more advanced design-implement experience (D5) is also performed in the fifth year.

Course aims:
- Acquire theoretical and practical knowledge of the interaction between product and production design.
- Under real-life forms, gain an understanding of how design and choice of materials affect production.
- Apply theory, knowledge and methods from previous courses.

In the course students work in small teams, each team consist of 4 students, that go through a traditional design process with five phases (see Figure 2). Students know when and what they should deliver at each stage gate, then it's up to the students to decide which methods are suitable for performing the design.
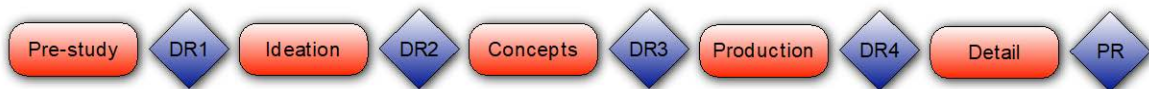
Figure 2 Phases in the course (red), design reviews and the final presentation (blue).

After each phase, students present their progress and receive critique at four design reviews (DR), they also produce a 4-page written Process Memo (PM). The course ends with a presentation and documentation of the final concept.
The written communication implemented in the program IDE follows a progression path over the years, where the students learn to create different types of written communication in different courses. For an overview see Table 1.

Table 1 Progression in written communication in IDE.

YEAR	Design	ID	ECTS	NAME	TYPE OF WRITING
1	**D1**	D0030A	15	Design: process and method	Presentation-Poster-Posters-Presentation (group) Workbook v,1, v.2 (individual)
1		A0014A	7,5	Ergonomics 1	Theory presentation (individual), Project report (group)
1		A0011A	7,5	Industrial production environment	Investigation report (group)
2	**D2**	D0037A	15	Design: theory and practice	Workbook x 2 (individual)
3	**D3**	**A0013A**	**7,5**	**Product and production design**	**PM x 4 (individual) + technical documentation (group)**
4	**D4**	D7007A	7,5	Form giving	Workbook (individual)
3-4		D7011A	7,5	Product visualization	Process poster (individual) Workbook (individual)
4		D7015A	7,5	Interaction design	Workbook (individual)
4*		A7004A	7,5	Research project	Academic paper in English
5*		D7017A	7,5	Advanced prototyping	Storybook (group)
5	**D5**	D7006A	15	Advanced product design	Project plan, presentation x 4 (group) Workbook v.1, v.2 (individual)
5		D7018A	7,5	Design science	Academic report in English
5		D7014A	30	Master thesis	Thesis in English
* Elective course					

METHOD

The course product and production have continuously been improved since the course started, through review by the teaching team, course evaluations (one more informal performed after 5 weeks into the course and a formal at the end of the course each year). The latest improvement cycle was performed in the spring of 2018 where a more systematic analysis, evaluation and improvement was performed. The analysis was performed in nine steps, see Figure 3 for an overview and the details below.
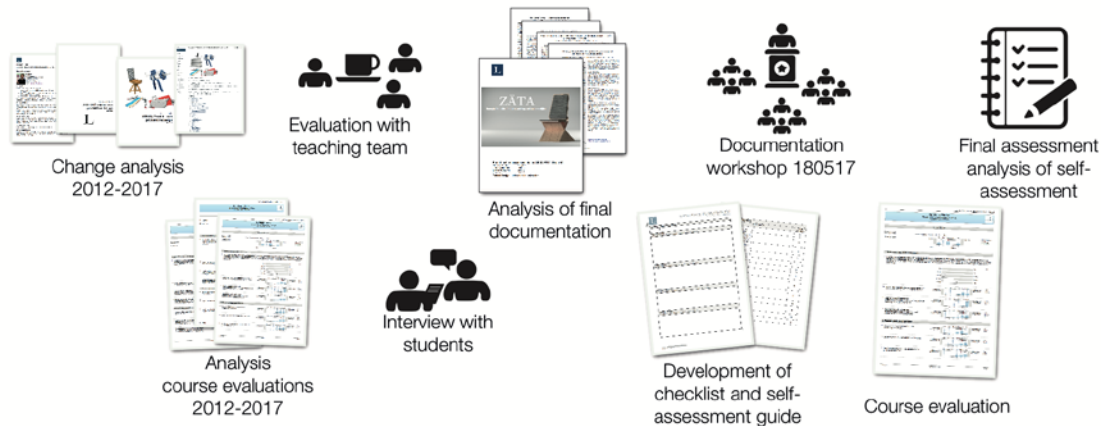

Figure 3 The systematic analysis and improvement performed during spring 2018.

1. *Change analysis* first, a review was performed of the changes that have been implemented since 2012-2017 by going through the course memo and introduction lecture material.
2. *Analysis of course evaluations 2012-2017*, mainly focusing on issues regarding the written report and peer-review. Open comments were compiled in an Excel document and coded according to 'final documentation', 'PM', 'peer-review', 'DR'.
3. *Evaluation with the teacher team*, written documentation has been evaluated with some of the teachers who have been involved in recent years and weak areas identified.
4. *Interviews with students*, short informal interviews have been conducted with three students who attended the course in 2016. The focus was on what was good with the written moments and how they could be improved.
5. *Analysis of submissions* has been reviewed by selecting final documentation from the years 2012-2017. Documentation from 2016-2017 was mainly used because all teachers' comments are still available in Canvas, the Learning Management System (LMS) used at LTU. It was not possible to see the previous comments from 2012-2015 (because they were made in Fronter, an older LMS system).
6. *Development of checklist and a self-assessment,* to support the final phase, developed a checklist and template for self-assessment. This was done by searching for 'checklist' and 'self-assessment / self-evaluation' on Google Scholar.
7. *Development of the documentation workshop*, in order to support the students' writing of the final documentation, an interactive documentation workshop was performed where 98% of the students participated. During the workshop, Mentimeter (mentimeter.com) was used to receive feedback.
8. *Course evaluation*, since we wanted to get the self-evaluation and their experiences of the report writing, the course evaluation was done after they submitted the report and self-evaluation (usually this is done after the final presentation), unfortunately using this approach we only got 16 answers (28% response rate).

9. *Analysis of the final documentation*, when the final documentation was submitted, the results of the self-evaluation and self-assessment was compared with the final assessment of the teachers. Figure 4 shows an example of the compilation of the self-evaluation and the report for all students. We also see an example (right sheet) of the students' self-assessment of the final documentation and the teacher's assessment.

Figure 4 Part of the evaluation sheets used.

RESULTS – THE EVOLUTION OF THE COURSE

One of the crucial parts of CDIO is the evaluation of the programme and individual courses to enable continuous improvement. Since the start of the course, it has constantly changed and improved based on the students' feedback. Each introductory lecture has gone through important feedback from the previous year and the changes that have been implemented.

Below, the main changes are briefly presented, see also the summarised in Table 2.
- HT2012, the course is implemented for the first time
- HT2013, removed a submission on production technology after feedback from students. Scheduled coaching meetings were introduced (previously, the students had to book coaching meetings with the teachers, but many did not use this). Clearer expectations for the various DRs and PMs with assessment templates. Document templates were introduced for both PM and final documentation.
- HT2014, clarified study guide, introduced feedback templates for written PM (used only by teachers).
- Spring2015, the course moved to the spring term and a facilitated peer review was introduced for each PM (4 times) and a lecture and coach session was performed before the final presentation.
- VT2016, introduced Canvas LMS system and then moved the course Memo to Canvas (instead of a pdf document) to get a more uniform structure and to make it easier to find and hyperlink to different types of information. Self-evaluation with student feedback with the help of competence profile was introduced (Wikberg Nilsson & Törlind, 2016).
- VT2017 introduced an agile template and SCRUM methods to facilitate the planning of the project. Facilitated peer review was performed two times, then the peer-review was done by a team, and the last peer-review was done individually by each student.

Table 2 Summary of improvements in the course

	Course memo [nr words]	Number of students	Course evaluation (1-6)	Templates						Assessment, ECTS Points					
				PM	Assessment	Feedback on PM (lärare)	Peer review	Self assessment competence profile	Self-assessment of final documentation Slutdokumentation	PM	Final presentation	Final documentation	Process	Self-assessment	Other
HT2012	2551	48	4,6							2	1	3			1,5
HT2013	4513	56	4,3	x	x					4	1,5	2			
HT2014	4599	50	4,9	x	x	x				4	1,5	2			
VT2015	4535	15*	5,1	x	x	x	x				1,5	2,25	2,25		1,5
VT2016	canvas	68	4,9	x	x	x	x	x			1	3		3,5	
VT2017	canvas	61	5,0	x	x	x	x	x			1	3		3,5	
VT2018	canvas	56	?	x	x	x	x	x	x		1	3		3,5	
*Only bachelor students															

From 2015 (after the CDIO implementation started at LTU) the assessment change quite a bit. In 2012-2014, PM1-4 were also assessed. From 2015, PM1-4 was used only to provide formative feedback, and the examination was done only on the final documentation. From 2016, a self-assessment was also used where students assess their contribution in the course towards the course objectives.

CURRENT IMPLEMENTATION

McHugh, Engström and Tinto (1997) showed that students are more likely to continue and develop their skills in a learning environment that provides frequent feedback on their abilities. Formative feedback also offers students an opportunity to improve their performance and supports better students' motivation and their willingness to work more constructively towards specific goals (Biggs and Tang, 2011). To implement this type of continuous feedback an iterative approach is used with four design reviews where students presented current status results and receive critique. At each occasion, the students also write a short 4-page PM and at the end of the course, they submit a project report, see Figure 5.
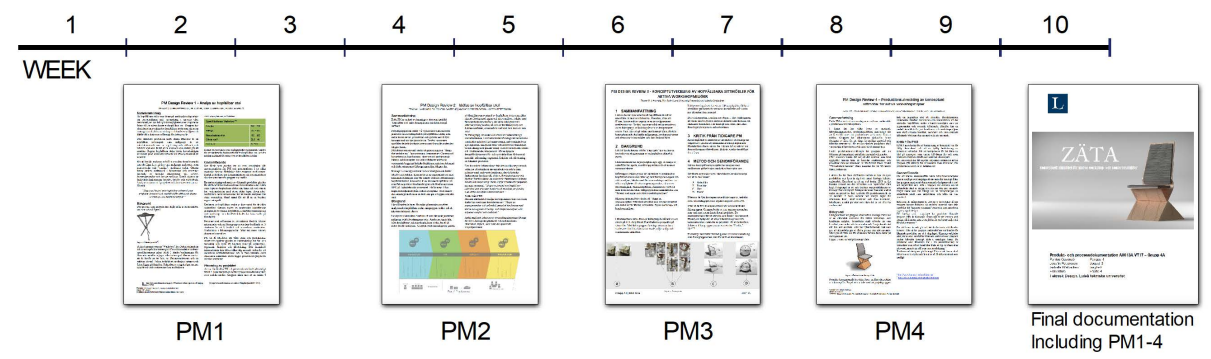

Figure 5 Submissions of four PM and a final report.

Peer review

After each submission, students receive feedback through a peer review process, as well as formative feedback from the teacher, see Figure 6.
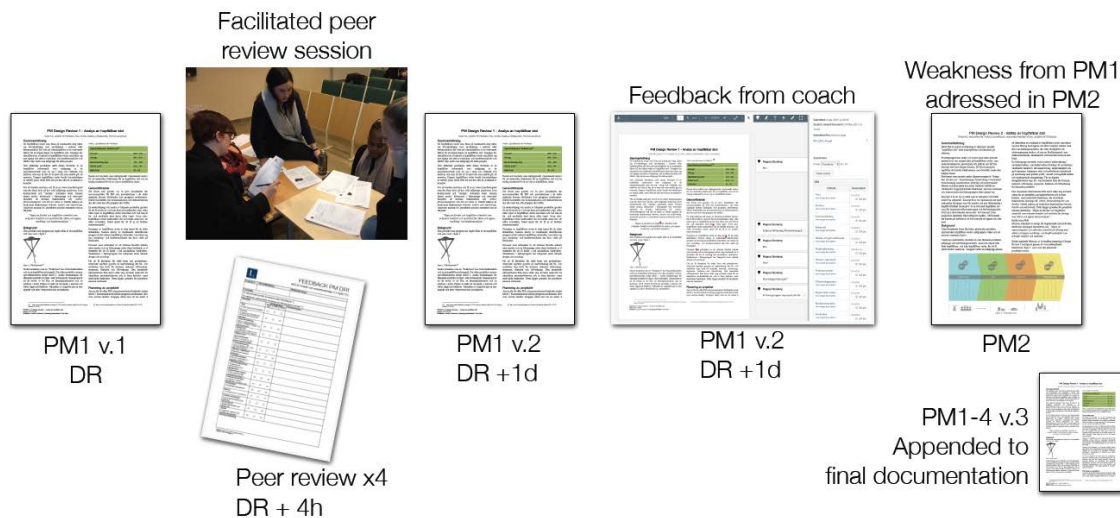

Figure 6 Feedback via peer review and formative feedback from the teacher team.

In order for students to learn to give feedback, feedback templates are used and in the first two peer reviews, the teacher facilitates the feedback process (what the students should think about, how to give critique, etc). The students also have the opportunity to discuss their feedback and how they individually have assessed the PM in smaller groups. Using this peer review the students receive feedback from four different people on three occasions and one group feedback, they also receive formative feedback four times from teachers. They also have to update and improve each PM two times.

Overall, in the course 2018, each student conducted three individual peer reviews, as well as a peer review group, with 56 students this represents over 180 completed peer reviews where the teachers are not involved. This means that the students will be well acquainted with what is expected, and they become accustomed giving feedback and that they actually spend time reading and assessing others' work, learning how to judge what is good and bad (Gibbs 1999) this type of active learning and time on task are two principles for learning (Chickering and Gamson, 1987). The peer-review is supplemented with the teachers' written formative feedback four times per team. The final assessment is seen as quality control (Gibbs 1999) and is only done on the final documentation.

From the course evaluations, we can see that most students appreciate the peer review sessions, and they believe that it has improved the quality of the written documentation. Also, students think that by reading others documentation they have improved their documentation. The formative feedback given throughout the course is supplemented by a self-evaluation that the students perform at the end of the course.

Final documentation

When performing the analysis of the final documentation from 2012-17 it was obvious that the final documentation more or less was a compilation of the four PM, and from the student feedback, they thought it was unnecessary work to rewrite the four PM into a new document, and that they did not really improve the documentation. From 2018 the final documentation is

similar to a compilation thesis and consists of the main part that presents the overall process and the final product, the four previous PMs are attached as appendices to provide the understanding of the process of the early stages and argumentations for the design rationale. From 2018 also a checklist /self-assessment was also appended, see Figure 7.
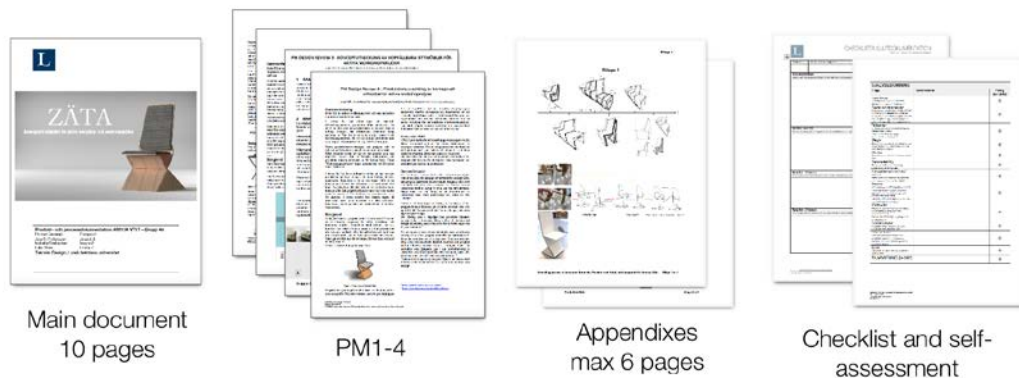

Main document
10 pages

PM1-4

Appendixes
max 6 pages

Checklist and self-assessment

Figure 7 Final documentation.

From the interviews, it was clear that the student felt that they did not understand the difference between the final documentation and the four PM that they had delivered during the course, and they also explained that they did not know what was important to present in the final documentation. So to improve this for the 2018 course, a documentation workshop was introduced. In the workshop, all teams prepare by reading through the template for the final documentation and bring their four PMs. The goal of the workshop is to understand why documentation is vital in design projects and why we make technical documentation.

During the workshop all teams discuss specific questions regarding the documentation e.g.:
- *Why is this part of the report important?*
- *How can you describe customer needs?*
- *How do you describe your final product and its features?*
- *What are the most essential features, and why?*
- *Can a reader understand your design rational?*
- *Does the product fulfil all needs and requirements? Also, how to visualise this?*

After the team discussion, teams present their views in an open discussion in the classroom. To receive direct feedback Mentimeter was used (a web-based service where students can answer questions with the help of their mobile phones). Almost all student appreciated the workshop and liked the interactive discussions, after the workshop they felt much more confident on what should be in their final report.

To remove small errors and force the team to read and evaluate their documentation a checklist was also introduced. The checklist is inspired by Hörte (1999; 2010) and Hartley (2008). Since the focus of the final documentation in this course is not an academic report but technical documentation, also literature focusing on technical documentation was used (IBM, 1983), (Hargis ,2004).

Self-evaluation of documentation

The team also had to provide a self-assessment of their own documentation, using the same assessment rubric that was later on used by the teachers. In this assessment, they had to argue why they fulfil the criteria for the documentation. When comparing the self-assessment

with the final assessment of the teachers, students assessed their work a slightly better than the teachers (Maximum points 30, Student average assessment 25,9 points; Teachers average assessment 23,6 points).

Self-assessment of competences

At the end of the course, students perform a self-assessment of (Wikberg Nilsson & Törlind, 2016), see an example in Table 3.

Table 3 Self-assessment of written communication

Written communications				
NOVICE	ADVANCED BEGINNER	COMPETENT	SKILLED	EXPERT
Understand use and format a basic template	Apply a variety of reporting methods (lab reports, project reports, workbook, pm etc.)	Evaluate, assemble and convincingly formulate work, results and arguments in a credible manner	Select and develop the structure, content and format of written communication for different audiences	Communicate in writing in English

1. The student assesses their own competences and abilities and must describe how they meet the learning objectives (with examples from the course).
2. The student's self-assessment is then reviewed by their team members that give feedback on the student's individual assessments.
3. Teachers review the assessment and have the possibility to adjust the assessment.
4. The teacher also assesses the quality of the feedback given to their team members.

In the feedback team members often highlights personal competencies that students themselves may not be aware of, and also performs a 'sanity -filter' so the students cannot take credit for something they did not perform. By performing this assessment, students are given the opportunity to assess their abilities and compare them to the requirements and also the formal assessment by the teachers. This type of self-assessment is in agreement with Rendon (1994), which points to the importance of formative feedback on student competence. The difference between the self-assessment and teachers' final assessment was about 5%.

CONCLUSION

This paper shows the importance of continuous improvement and that an examiner can learn quite a lot from reviving the improvements that have been performed in a course. By comparing the feedback from course evaluation, quality of the written documentation and the amount of feedback given to the students the current implementation of the course is much better than when it was introduced 2012. The basic ideas and the structure are still the same, but by introducing formative feedback, peer-reviews, workshops, and self-assessment the quality of the written communication has improved. However, the most important part is that the student learns to give feedback, assess their capabilities and reflect over their performance. We can also see that the students' self-assessment is a little higher than the teachers (about 10% on the final documentation and 5% on the individual assessment) but the students have a quite accurate assessment of their own work. Also, the changes in the course are mostly based on active learning activities where students are activated instead of being passive. By introducing several peer reviews, and self-assessments most of the improvement does not need any extra work from the teachers.

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MOODLE QUIZ: A METHOD FOR MEASURING STUDENTS' ENGAGEMENT

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ABSTRACT

Students' engagement is an important factor in students' success. It refers to the degree of which students are attentive, curious and passionate about their studied subject. Therefore, academics have a responsibility for creating platforms that ensure and measure students' participation and engagement during the delivery of different modules. Moodle is a great platform where tools such as Quiz can be easily deployed for improving and measuring students' engagement. This paper discusses the design and implementation of Moodle Quizzes and provides a reflection on their advantages in aiding students' participation in the classroom. In this study, the process of designing and creating quizzes that are used effectively to engage students before, during and after the classroom have been covered. Our study shows that Moodle Quiz could be used for measuring student engagement level which can be placed on Student's Moodle front page to create a sense of completion and belonging. The study has been primarily carried out on the degree apprentices (Applied Engineering Program: AEP) at Warwick Manufacturing Group (WMG), Warwick University.

KEYWORDS

Moodle, Quiz, Engagement, Engineering, Active Learning, Digital Learning, Blended Learning, Standard: 8.

INTRODUCTION

Some teaching theories widely accept that teaching is one-way of knowledge transfer, where the teacher is the transmitter and the student is the receiver. The focus of these theories is on either who the student is or what teachers do (Biggs & Tang, 2011). Carl Rogers (Rogers, 1957) argues that teachers cannot teach directly but they can only facilitate learning. Therefore, students activities before, during and after the classroom is what matter to measure learning compared to what teachers do.

The responsibility of conveying the subject knowledge according to these theories rely on the student's ability to learn and the teaching skills the teacher has. The depth of understanding during the classroom is not practically measured. While it is vitally important that the intended learning outcomes, learning activities and assessment are constructively aligned (Biggs and Tang, 2011), it is even more important to ensure that effectiveness of these learning activities is measured.

Bearing in mind that students have different learning styles, background, motivations and subject-knowledge experience, our proposed approach at WMG follow a student-centred

approach where the purpose of teaching is to aid learning (Biggs & Tang, 2011). Student-centred teaching strategy does not necessarily reduce teacher preparation load rather it is a more complex business. In our approach, considerable attention has been paid on what students do and how well the intended learning outcomes are achieved. This is carried out using a variety of Moodle tools amongst which is the Quiz.

Moodle is an open source virtual learning management system used by a large number of education providers (Nash & Moore, 2014). It has rich learning tools that allow for engaging and user-friendly experience. As a secure and robust system, educators can create personalised or cohort-level learning plans (Moodle, 2019).

Moodle Quiz activity is a great tool that allows academics to design varieties of online questions, including multiple choice, matching, short answer and numerical as shown in Figure 1. Moodle Quiz provides design flexibility and creativity by incorporating text, images and videos (Coy & Edstrom, 2013). Based on its purpose, the Quiz can be configured to run for a set time limit and for multiple or unlimited numbers of attempts. It can be also ordered systematically or randomly. The use of quiz in our teaching methodology prior, during and after the classrooms is a practice that helps reflective teaching and deep learning (Knutson Wedel, 2011). This enhances students' experience and optimises the achievement of the intended learning outcomes and development of students which in turn uplift the performance and reputation of the institution (Trowler, 2010). Therefore, we accept that students' engagement is a responsibility of both students and their academic institution.
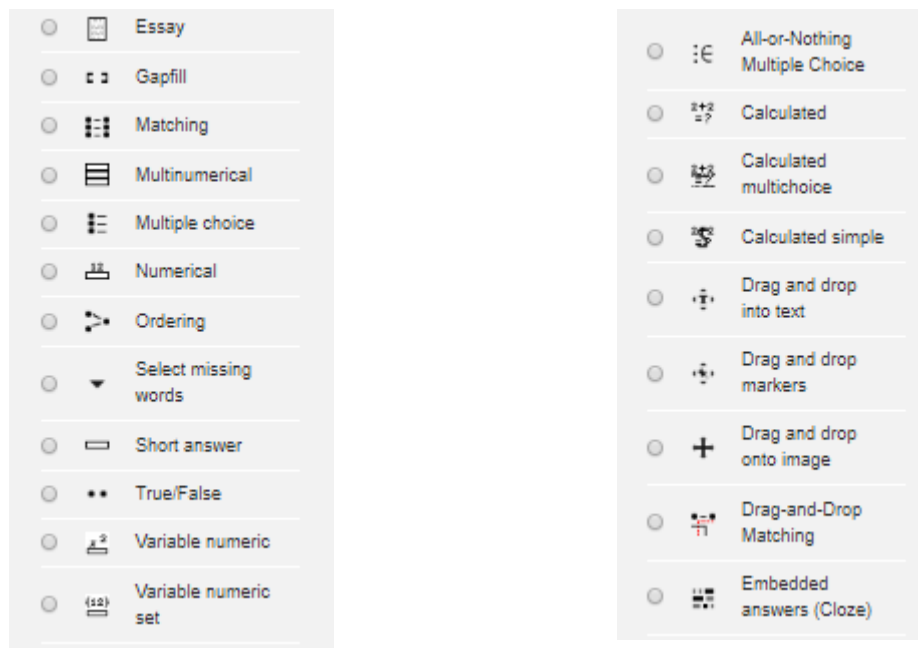
Figure 1. Example of Quiz types offered by Moodle platform.

A portfolio can be regarded as the purposeful collection of a learner's work that can be structured to exhibit the learner's efforts and achievements over time (Kim, Ng & Lim, 2010). Portfolios are increasingly seen to be a valuable tool for the assessment of competencies and are used in many professions (McColgan & Blackwood, 2009). In accreditation environments, digital portfolios can provide a space where learners' evidence of their competencies and achievements can be stored and systematically evaluated (Fiedler, Mullen & Finnegan, 2009).

The paper contributes to the CDIO initiative educational framework by investigating the idea of building up a learning portfolio via Moodle Quizzes. Each awarded mark acknowledges a successful completion of an individual activity, assessment or even a whole module. The awarded mark also increases personal satisfaction and functions as an indicator to demonstrate to their teachers and peers what they have learned, rather than what was taught.

PROPOSED METHODOLOGY

We have designed and used Moodle Quiz for pre-class, in-class and post-class activities. These activities have been tested for different modules in the AEP program. The AEP offers a flexible teaching pace tailored around the industry need. The programme welcomes students from different industry backgrounds and ages. Currently, for year 1 and 2 students, modules are split into 6 blocks with one week long each and 5 weeks between each two consecutive blocks. Students are expected to be working full time outside these blocks with some given time at work to revise.

In line with the university education strategy and in recognition of its commitment to communicate teaching excellence, life-shaped learning is ensured through the design of teaching sessions and seminars. These sessions ensure that students are well engaged with the subject knowledge during 5 weeks of full-time work. The students may study an average of 6 subjects a week which makes session engagement an essential part of its design. Each of the facet used for increasing student engagement in AEP program is explained as follows:

Pre-class: Flipped Learning

Quiz tool comes in handy to be especially useful in its support of flipped learning. In order to cover easy-learnt subjects, students are encouraged to watch a short subject-related clip of recorded lecture or YouTube video and answer several relevant questions before the class.
To reward achievement and ensure learning, students may not have access to particular resources unless they pass a quiz. Nevertheless, students are allowed to attempt the quiz an an unlimited number of times until they pass. An example of this set up is shown in Figure 2.
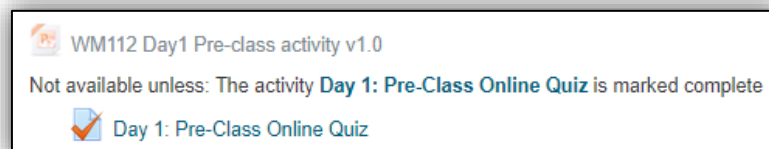

Figure 2. Example of restricted resources to ensure and reward achievement.

In-class: Class interaction and existential involvement

Active learners learn by doing, reflective learners learn by thinking back. This is often missed by traditional teaching as students are unable to do or reflect during the lecture or briefing itself. To encourage both, the student should actively take part throughout the virtual learning environment then also be given something to take away and think about (Kvam, 2000). Group-based activities during the lecture make students active learners and measure the understanding of the content introduced during the class. Educators can also observe which questions spark students' attention, which leads to a deeper discussion.

The classroom that we currently use for delivering AEP lectures has a theatre set-up with a capacity of 60 students, which is not the best structure to support group activities and does not easily allow the lecturer to interact with the students. Until we have a classroom with a flat structure, in class activities, have to be delivered differently. Quiz helps lecturers create in-class quiz that should not take more than 5 to 10 minutes to complete. This quiz breaks the lecturer rhythm and recharge students' attention. Students can discuss the quiz questions with peers sitting on both sides. This type of quiz can be considered as an informal formative assessment that helps both educators and students to measure understanding and identify gaps in the design of the subject knowledge taught during the classroom. Students or in fact anyone like to get his effort rewarded and hence the score that students received at the end can fulfil this desire. This learning activity is likely to motivate and help students achieve the learning outcomes intended.

Post-Class: Learner commitment, consolidation & assessment

A quiz related to paperless seminars or home revision activities is a great method to measure students understanding and interaction with the module contents. It quantifies the amount of time and efforts students invest in their revision and other extracurricular activities.
A quiz is also helpful in running online assessments, a method that majority of the professional bodies use to assess and hence award professional qualifications.
To involve students in our self-reflexive process (Lea, 2015) and to ensure students engagement with the course design, students-faculty partnership (Cook-Sather, Bovill & Felten, 2014) was formed via a survey to solicit feedback on this type of assessment. This ensures that the quality system is well equipped with the right method that fosters active students' participation (QAA, 2012).

RESULTS & DISCUSSION

We have conducted our proposed study on different degree apprenticeship modules offered in WMG. For example, the pre-class activities have been assessed for the Y1 Electrical and Electronic Principles (EEP) module offered to the BSc in Engineering apprenticeship, in-class activities have been evaluated in the Y3/Y4 AEP module: Sustainable Energy Systems (SES) module while Quiz has been used as an assessment tool and post-class activity for the AEP Y1 module: EEP.

Pre-class activities

Successful delivery of intended learning outcomes is bounded by the relevant learning activities that support it. These activities not only have to be used but also they should come with a measurable outcome to ensure their effectiveness. In order to assess students' involvement in learning, educators can simply identify whether students have viewed the lecture notes and completed the designated activity via the quiz result section. In order to create a sense of competition and belonging, the top 10 results may be configured to be visible to all students on the main page. This is done via utilising the "Activity Results" block feature as seen in Figure 3.

Additionally, to have a holistic view of all students activities including what resources students are ignoring, a "*Progress Bar*" feature can be employed as seen in Figure 4. Educators will be able to track students' engagement via the "progress Bar tool and hence identify students who are disengaged or struggling.

Figure 3. List of the top ten students

Figure 4. Students interaction with a set of activities on Moodle

In-class activities

We introduced in-class Quiz for the SES module, which is an elective module selected by about 30 of Y3/Y4 students. The Quiz, as illustrated in Figure 5, covers the content of the lecture titled "Wind Energy". Figure 6 provides proof of measuring the level of students' attention during the classroom and hence a method of measuring students' learning.

After completing the activity during the lecture, the lecturer observed that the students' engagement level was increased. Giving the students a set of questions to answer before proceeding the lecture stimulates their thinking process and encourages a wider engagement.
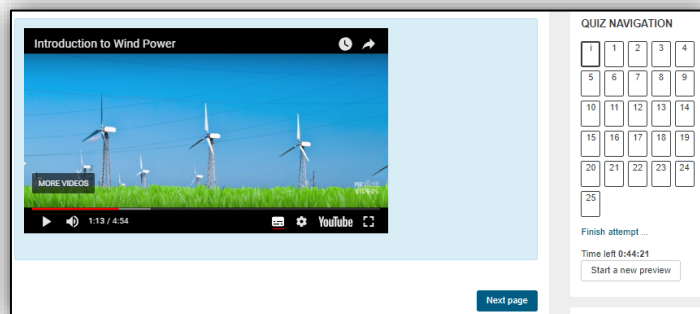

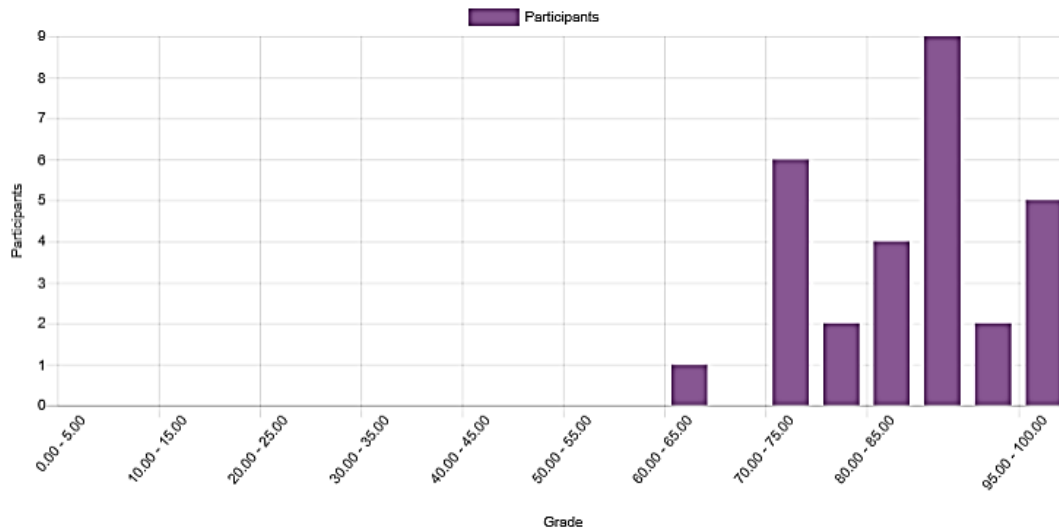Figure 5. SES Moodle quiz showing 24 in-class questions

Figure 6. Students scores of the in-class questions

Post class activities

Modules like EEP, which are content-intensive, require face-to-face teaching, seminars, simulation and lab experiments.

Based on the EEP Module Information Descriptor or MA1 form, students have to submit two Lab reports forming 30% of the overall mark. A suggestion of replacing one of the reports with a new assessment in the form of an online quiz was welcomed and approved by the Teaching and Learning Committee.

Students were supplied with a mock test that emulates the test question behaviour and complexity level and it can be retaken as often as they wish. Self-evaluation is an important process in teaching reflection, however, it should be undertaken in active consultation with students (McNiff, 2001). Therefore, the students were asked to express their views on the online test, a sample of which is shown in Figure 7.

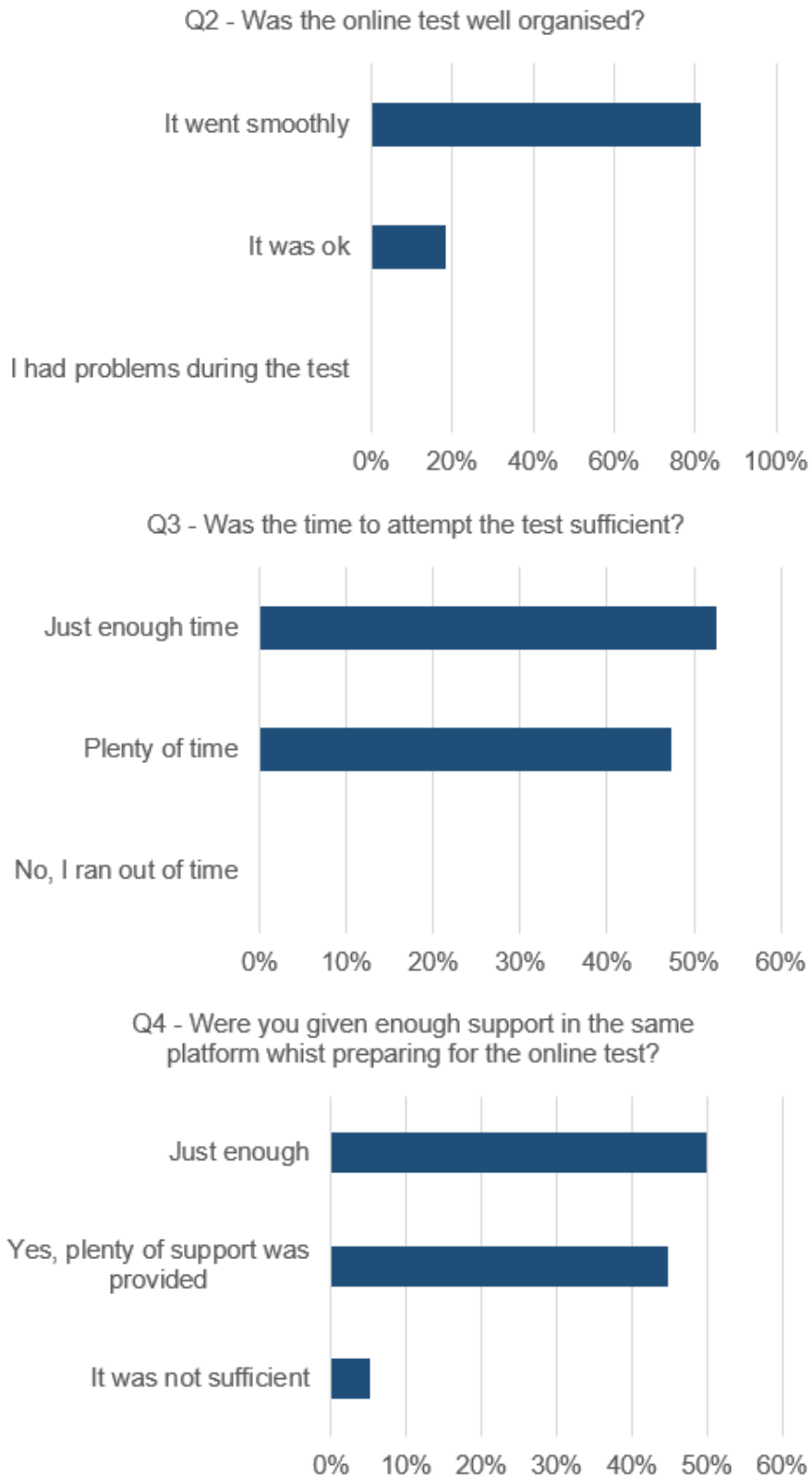Q1 - Would you like to have more online tests used in the future as an assessment method?
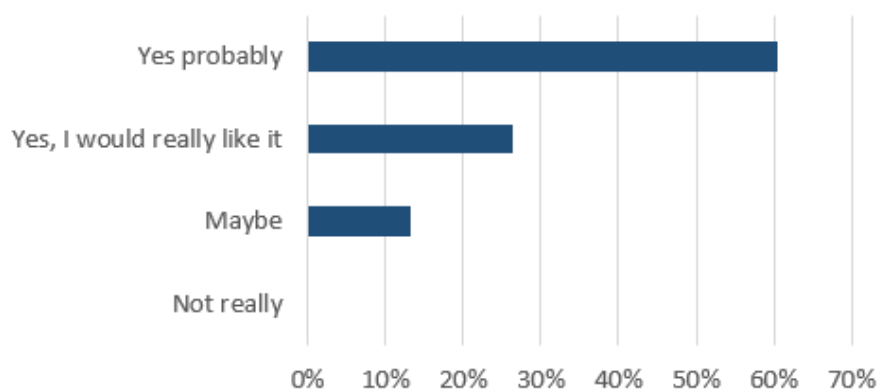
Figure 7. Students' feedback on the proposed new online-based assessment

Feedback of the newly implemented assessment method was collated and proved positive. Example of the qualitative feedback is presented in the Box below wherewith students expressed their acceptance of the online Quiz style and provided some feedback. The feedback was collected anonymously after the Quiz marks were published to students. Therefore, the students had the freedom to express their opinion which eliminated the tutors' influence on the feedback result.

I think the test went well. It allowed just enough time and the mock exam was adequate preparation before it. There was an issue with members of the class doing the exam on IE instead of Chrome which resulted in issues.
Great mix up from 3 hour examinations
I thoroughly enjoyed this test and the practice tests really helped me learn and understand concepts much better and learn from my mistakes.
Really liked the idea. I had the ability to concentrate more as a person who dislikes exams. As a suggestion, I think holding the exam on a Monday would be better.
More variety in mock quick s would be helpful to get a greater feel for the test, as with the mock test once completed you would remember some of the answers making it difficult to then try to test your self to see if you have improved in terms of revision for the actual online test. On a while I was very pleased with this type of test, one recommendation for modules that cover a lot of content such as materials and manufacturing processes, this type of test would help to spread out testing of the content rather than say having to revise continent for 3 blocks worth of content having a test on two blocks worth of continent and a quiz test in this format for one blocks worth of content (similar to what was done with this electrics module test that was done.
A couple more variations on the online test format would be good, i.e. Mock Test A, Mock Test B etc.
Having an online mock test on the same platform really helped as it left no room for nasty surprises when sitting the actual test. Not having to write out long wordy answers was also a welcome change.
Check the quiz is compatible with the internet software prior to the test, and that all images needed are shown.
If this was to become a platform used for assessments in the future I'd like to see more practice resources. I feel like one practice online test is not enough to use before the real exam.
More mock tests
Advise not to use google chrome as image of circuits etc appears to small on screen and can not be enlarged. Works ok in internet explorer.
Would have benefited from having solved solutions to the mock test. Also feedback on which questions were correct and incorrect on the test would be helpful.
Would be good to have multiple mocks to aid revision/different results. Steps taken to get correct answer could be given in mock for incorrect solutions
No marks for working on tricky questions. Had no access to the lab the day before test but were told to check accounts worked in lab :/.

The feedback shows a positive reaction towards the new assessment/online test. The test was able to give the students the chance to demonstrate their understanding of multiple learning outcomes without going through 3-hours exam time and without necessarily writing long answers. However, challenges always exist with technology; one of which is checking the compatibility of the web browsers with quizzes different elements (text and image). A common request from students was to be provided with more mock exams/extra practice questions. Creating questions in Moodle Quiz might take longer time than typing it for a traditional exam, however, once the question is created then it can be saved in a question bank and reused again when necessary. Generating a test from question bank is a simple and straightforward procedure in Moodle. You can choose which questions will go to the test and save it.

CONCLUSIONS

Measuring whether learning has taken place during a lecture helps educators to define the areas of focus where students struggle or need extra support. Regardless of the number or type of the teaching techniques used in the class, if the learning does not take place then the contribution of used techniques is null. Technology enhanced teaching empowers educators to develop various opportunities for students' engagement and interaction and evaluate their understanding.

Moodle provides practical solutions for overcoming common barriers to students' engagement before, during and after the classroom. Amongst several tools, Quiz feature has been proven to be a powerful tool to engage students with subject content on different pace and scenarios. They allow educators to experiment with different approaches to encourage class participation and evaluate the level of engagement. The quiz tool has been well received by the students, colleagues and learning development advisors. The quiz results provide educators with gaps demonstrated by students and hence help in setting up a more suitable teaching strategy. Furthermore, students' interaction with activities and resources can be traced using "**Activity Results**" and "**Progress Bar**" features. Therefore, educators can create a competitive environment for strong students and identifies those who are struggling.

FUTURE WORK

Research articles related to engineering education illustrate that industry demands play a very large role in determining how engineering curricula should be structured and delivered (Arlett et al., 2010). Given the highly technical aspects of the degree, which also requires the active application of knowledge within the field, it is no surprise that graduates are expected to not only effectively apply the theories they are taught but to do so almost instantly as and when required in real-world settings. Given that we are teaching apprentices at WMG, who are working full time in Industry, it becomes hard for apprentices to commute to the University for accessing resources, (such as software), performing experiments and getting guidance from tutors. In this situation, our main goal at WMG is to provide a majority of the educational support online. We are aiming in future to use virtual learning environments (such as Moodle, Blackboard) to create an effective portal for students that is not only engaging but also useful for developing practical knowledge. We are exploring the features such as remote labs to find the possibilities of delivering authentic learning using online platforms.

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PROJECT-BASED LEARNING AND SERVICE LEARNING: TOWARDS HELPFUL MEDICAL DEVICES

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ABSTRACT

This study presents an innovative teaching-learning experience, aimed at connecting project-based learning with service learning in the biomedical engineering field. This experience is planned and implemented, coordinately, in two courses devoted to the biomedical engineering field: "Bioengineering Design" and "MedTECH". These courses are respectively included in the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management respectively, both at the ETSI Industriales from Universidad Politécnica de Madrid (ETSII-UPM). These courses follow the framework established by the Industriales INGENIA Initiative, which is completely aligned with the spirit of the International CDIO Initiative. Students from both courses collaborate in teams and live through the complete development life cycle of innovative medical devices. In the current academic year, the projects from the different groups of students stand out for their extra degree of complexity and for their intimate connection with real medical needs. This has led to a higher degree of realism, motivation and social impact, as a way for continuously improving these courses. The needs and ideas for the different projects on medical devices, which can be considered services for the community, are obtained by systematic interaction with medical professionals from public hospitals, patients and social services operating in the Madrid region. Along with the medical device development projects, students from different backgrounds and with varied skills interact, not only with the group of professors but also with the entities, for which they are providing the services and designs. Besides, students are placed in contact with international initiatives, such as UBORA, a global community operating through an accessible online infrastructure and pursuing the reinvention of the biomedical industry, by promoting collaborative and open-source approaches in the design and development of medical technology. In this context several groups of our students proactively participate in the 2019 UBORA Design Competition, designing medical devices for global health emergencies, in a challenging environment and in connection with the promotion of their understanding of the relevance of engineers for achieving the Global Goals. Main benefits, lessons learned and future challenges, linked to the continuous improvement of these CDIO-inspired courses and to the strategy for connecting project-based learning and service learning, are analyzed.

KEYWORDS

INTRODUCTION

Problem-based learning, project-based learning, experiential learning, game-based learning, learning in collaborative project and environments, among others, are just different versions of highly formative and integrative learning experiences that place students in the center of the teaching-learning process, in accordance with a desire for a more holistic training for the 21st Century, especially in engineering education (Larmer, 2014). In all these project-related teaching-learning methodologies, student teams face a real life (engineering) problem, more or less simplified, and perform the specification, design, prototyping and testing of a product, a process, an event or, generally speaking, an engineering system. In some cases, prototyping and testing are achieved just virtually, but there is always a critical analysis of results and a public exposition and subsequent debate for increased learning throughout the groups of students taking part in the course or courses. Besides, creativity, decision making and critical thinking are fostered and professional resources for engineering practice (i.e. design and simulation software, prototyping tools…) are applied, so as to prepare students, as globally as possible for their professional and personal lives. Knowledge acquisition is necessary for these experiences, but the development of specific professional skills and transversal abilities, for more adequately applying the acquired knowledge to solve real challenges, is also fundamental in modern education (Shuman, 2005). These varied experiences mainly differ in the level of depth, to which the project, product, process or engineering system is specified, designed, implemented and managed or operated, and in the proposed context and desired level of realism, which depends also on the time and resources available for students living through the formative experience (De Graaf, 2003, Larmer, 2015, Díaz Lantada, 2013).

The "conceive-design-implement-operate" CDIO approach to project-based learning, in a way, encompasses all the aforementioned types of active learning experiences (Crawley, 2007). In fact, the complete CDIO cycle involves the whole life-cycle of any engineering project or system, from specification and planning, through the design, engineering and construction, towards full operation, maintenance and end of life. In addition, the CDIO model goes beyond traditional project-based learning, as the CDIO educational model involves also actuations, within the institutions and the professionals committed to "reinventing engineering education", aimed at continuous quality improvements in all engineering education-related processes. To this end, the support of a set of CDIO standards (see: http://www.cdio.org), together with the sharing of good practices in the CDIO events, is fundamental.

Among the characteristics of CDIO educational experiences, is the permanent search for educational contexts with an increased level of realism (when compared to a more classic project- and problem-based learning experiences) and, therefore, with a higher potential social impact. In many cases, the CDIO projects are linked to real research and innovation projects or to industrial, entrepreneurial and social activities, in which highly transformative objectives are settled down and relevant human needs are addressed (Kontio, 2010, Cea, 2014, Norman, 2014, 2017).

All this links with service learning, defined by Jacobi as "a form of experiential education, in which students engage in activities that address human and community needs together with structured opportunities for reflection designed to achieve desired learning outcomes" (Jacoby, 1996). Ideally, the solutions developed in these learning experiences reach society and transform it. This project-based service learning model adds to the previously listed types of active and integrative learning experiences and is clearly within the scope of CDIO. This hybridization between service learning and project-based learning can have additional impact if open-source and collaborative approaches to engineering and its education are also involved and promoted, as recent international "express CDIO" learning experiences have put forward (Ahluwalia, 2018).

Our team, conscious of the potential of these interconnections between types of CDIO training actions, decided to improve previous experiences within "INGENIA" courses, a set of subjects following the CDIO model (Lumbreras, 2014, Díaz Lantada, 2014). To this end, we searched for an additional degree of connection with real medical needs, with patients and healthcare professionals and with actual professional practice in biomedical engineering, in courses focused on the development of medical devices and technologies, hence hybridizing service learning and project-based learning. The courses involved, the overall strategy for promoting social impact and preliminary results are presented in this study.

"BIOENGINEERING DESIGN" AND "MEDTECH" COURSES AT ETSII-UPM

The faculty of Industrial Engineering at Universidad Politécnica de Madrid (ETSII-UPM) includes a set of courses, called INGENIA" for the systematic promotion of the CDIO approach to engineering education. These INGENIA subjects are compulsory for all students enrolled in the first year of the Master's Degree programmes in Industrial Engineering and in Engineering Management at ETSII-UPM (two-year programmes with 120 ECTS and 90 ECTS respectively, offered after a four-year Grade in Industrial Technologies or related topics with 240 ECTS). These subjects (with a similar CDIO orientation but offering different topics and projects) are 12 ECTS equivalent, which correspond to a student workload between 300 to 360 hours, distributed along two semesters with the following structure: 120 hours of supervised work plus between 180 to 240 hours of personal student work, organised usually in teams. Professor supervised part of the subjects is divided into 30 hours dedicated to adapt basic theoretical knowledge derived from other subjects to those directly related with the project, and a second set of 60 hours is devoted to practical work in the lab, with professor supervised sessions. Students also receive two seminars of 15 hours; one oriented to transversal outcomes, in particular, workshops on professional ethics, teamwork, communication skills and creativity techniques, and the other one about social responsibility issues such as environmental impact, social, political, security, health, etc. These lectures, practical sessions, seminars and workshops, are distributed along the 28 weeks of the two semesters of the first year, resulting in 5 hours per week of lectures or practical sessions in the regular schedule of students. Placing the INGENIA subjects in the first year of these formative programmesis indeed interesting, as additional 12 ECTS are devoted to the final thesis during the second year. Therefore, at least 20-25% of these programmes is devoted to project-based learning aimed at the complete development of engineering products and systems, as presented and explained in detail elsewhere (Lumbreras, 2014, Díaz Lantada, 2014).

In academic year 2017-2018 our team introduced a radical innovation to the INGENIA model, by means of the coordinated design and implementation of two courses, namely: "Bioengineering Design", in the Master's Degree in Industrial Engineering, and "MedTECH", in the Master's Degree in Engineering Management, working upon previous experiences (Díaz Lantada, 2015, 2016). This resulted in the first successful example of coordinated and complete CDIO-based experiences working across programmes, within the Industriales INGENIA Initiative, and one of the very first examples of project-based learning in the biomedical field with such a holistic approach. In fact, the positive aspects of collaboration across programmes, with students from different backgrounds, working together for the development of complex projects, and with a devoted team of multidisciplinary professors, capable of better guiding the progress of student teams, has been rewarding. In addition, it opens new possibilities and offers solutions for expanding the INGENIA model to other programmes of our university, by means of "educational joint-ventures", in connection with trends focused on collaborative project development and with the understanding that the future of engineering is collaborative and requires from interdisciplinary collaboration for solving social challenges.

Going into details, "Bioengineering Design" and "MedTECH", share some fundamental lessons and common topics along the two semesters, while some specific lessons also help to differentiate according to the different backgrounds and motivations of the students. Those from "Bioengineering Design" take part in the Master's Degree in Industrial Engineering and prefer to deepen in aspects linked to design, simulation and manufacturing technologies, while those from "MedTECH" belong to the Master's Degree in Engineering Management and are more interested in strategic and business aspects, together with topics related to the organization of production and to the supply chain management. In short, both courses advance in parallel and share several general lessons, while 30-40% of the lessons are devoted to the more specific aspects with the students from different Master's degrees separated. Each team counts with students from both Master's degrees and all students work together and are responsible for the successful conception, design, implementation and operation of an innovative medical device, although the different skills and backgrounds make them share and distribute tasks according to their experiences and expectations. Globally speaking, conceive and design stages are covered during the first semester and implementation and operation stages are covered during the second one, as previously analyzed and presented (Díaz Lantada, 2018).

INNOVATIONS FOR ENHANCED CONNECTION TO SOCIAL NEEDS

After the first coordinated implementation of "Bioengineering Design" & "MedTECH", an emphasis on developing medical technology for solving real needs is placed for academic year 2018-2019: In spite of still letting students decide upon the needs to address and the related medical devices to develop in this coordinated CDIO experience, the relevance of collaborating with patients and healthcare professionals in any medical technology project is highlighted and additional efforts are given for providing students with a more realistic context. To this end, during the needs identification phase, so as to select the topics for the medical technology projects to be developed by student teams, contact with different patients associations and clinical areas has been fostered. Besides, connection to open-innovation approaches to medical technology has been supported by proposing students to join the UBORA community, to use the UBORA e-infrastructure asan open-source tool for guided medical technology development and to participate in the UBORA design competitions (Ahluwalia, 2018). Furthermore, the involvement of a team of doctors focused on organ transplants and of a couple of associations focused on physical, psychical and sensorial disabilities has been achieved thanks to the proactivity of our students. Besides, a seminar with participants from hospital innovation units, with surgeons as users of advanced medical tools, with medical technology entrepreneurs, and with experts from notified bodies, has made students more aware of the complex context of the medical industry.

All this has led to a more careful selection of medical needs and to the consequent proposal of very relevant and innovative medical technologies, to be developed during these courses. The potential impact of these technologies is increased, not only because they address more realistic needs, but also because the patients and professionals associations involved can constitute fundamental links of the chain towards eventual technology transfer, which may take place beyond the temporal framework of these courses, hence providing students also a path for professional development. In order to promote impacts and sustainability beyond the courses, students are sharing their developments through the UBORA e-infrastructure, a sort of "Wikipedia" for open-source and collaboratively developed medical devices, which also supports designers in their decision-making process towards safer and EU regulation compliant medical devices. Finally, some teams are considering spin-off creation and all students participate in the Actúa-UPM ideas challenge for technological enterprises and in the 2019 UBORA Design Competition focused on health emergencies.

IMPACTS OF THE INNOVATIONS AND PRELIMINARY RESULTS

Continuously evolving project-based learning experiences keeps them alive and is directly connected to quality improvement cycles. In the case of the educational joint-venture between "Bioengineering Design" and "MedTECH" courses, the modifications introduced in the academic year 2018-2019 for an increased connection to reality have derived, first of all, in a more global context and training. This is schematically highlighted in Figure 1, which shows the already presented structure and content of these courses (Díaz Lantada, 2018), but now surrounded by several relevant actors, especially in the needs identification phase (connection to patients and professionals associations, seminars by experts...) and as regards technology transfer (connection to international communities, local and multinational competitions...). These main innovations previously detailed, have interesting impacts in course structure, content and context, but also in the complexity and quality of the learning process and on the achieved results. The experience is resulting more multidisciplinary, with additional medical sectors involved, as also schematically highlighted in Figure 1, which the team of professors considers positive and which is proving motivating for students themselves, according to the increased attendance to lessons and in-class participation in debates and through questions, which were already high in previous editions.

Figure 1. Collaborative scheme among "Bioengineering Design" and "MedTECH" and connections to key stakeholders for improved needs identification and social impact. The topics to the left represent the "MedTECH" track and the topics to the right the "Bioengineering Design" track, while the central topics are common. The fundamentals and conceive and design stages are *grosso modo* covered during the first semester, while implementation and operate stages correspond to the second semester.

A total of around 55 students (40 from "Bioengineering Design" and 15 from "MedTECH") are collaborating divided in 7 teams for developing medical devices including: a pump and fluidic circuit for improved liver transplantation, a stand-up chair for children with mobility problems, a device for eyelid cleansing, an intelligent insole for detecting problems related to diabetic foot, an smart system for varicose vein massaging, a visual display for vein detection and a thumb prosthesis for children. The conceptual designs of some selected examples are presented in Figure 2. Support from UPM for hybridizing project-based learning and service learning and constructing the prototypes of the different devices has been achieved and final presentations with patients associations and healthcare professionals have been scheduled. Detailed results of the implementation and operation phases are to be presented in the CDIO 2019 Conference of Aarhus.
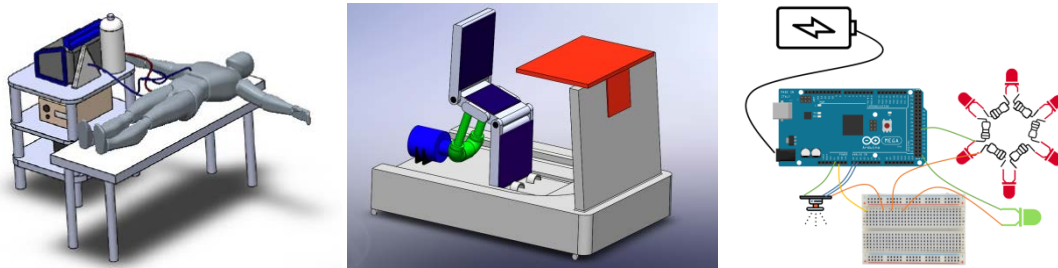

Figure 2. Selected conceptual design examples from the different projects: a) Pump and fluidic circuit from improved liver transplantation. b) Stand-up chair for children with mobility problems. c) Circuit for display for vein detection connected to a smartphone. "Bioengineering Design" and "MedTECH", 2018-2019 academic year.

CONCLUSIONS

This study has presented an innovative teaching-learning experience, aimed at connecting project-based learning with service learning in the biomedical engineering field. This experience has been planned and implemented coordinately in two courses devoted to the biomedical engineering field: "Bioengineering Design" and "MedTECH", included in the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management respectively, both at the ETSI Industriales from Universidad Politécnica de Madrid. These courses follow the framework established by the Industriales INGENIA Initiative, which is completely aligned with the spirit of the International CDIO Initiative. In them, students from both courses collaborate in teams and live through the complete development life cycle of innovative medical devices and healthcare technologies.

Main innovations presented in this paper, which shows an evolution of these two courses working upon previous experiences, deal with: 1) the designed strategy for increased connection of student projects with real medical needs, and 2) with the promotion of social impacts, by means of more straightforward connections to entrepreneurship and other sustainability-oriented options. All this derives into more socially relevant development projects with a remarkable potential for having a real impact in the medical field, thanks to the involvement of patients and professionals associations, not just in the needs identification phase, but also in the monitoring, evaluation and search for sustainability of the proposed solutions. The results obtained motivate us to continue with this coordinated and truly holistic approach, based on hybridizing project-based learning and service learning, which will let us hopefully reach medical professionals and patients for improved social impacts in the near future.Continuous improvement is promoted by a growing community of collaborators and cases of success, which are used as teaching-learning examples.

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INDIVIDUAL ASSESSMENT OF STUDENTS WORKING IN PROJECT TEAMS

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ABSTRACT

Many engineering courses include assignments where students work together in projects. The approach promotes students, among other things, to be educated and skilled in project management and managing system thinking within complex engineering environments. However, a problem with project-based learning is to accomplish a fair and valid assessment of individuals in a team setting. For example, in many project-based courses, students are only graded pass or fail, or graded collectively as a group. This paper presents results from a new course design based on CDIO-principles, with the aim to increase our understanding of individual assessment and grading in a project-based course. A preliminary conclusion is that it is possible to introduce individual assessment in a project team, assessing the learning outcomes and obtain a high level of student satisfaction. The course development process described in this study has implied a lot of struggling for the teachers involved. Hence, some general aspects of introducing CDIO-principles in a project-based course are also discussed.

KEYWORDS

Project-based learning, individual assessment, in depth learning, Standards: 6, 7, 8

INTRODUCTION

In industry, many problems are multidisciplinary, open-ended in nature and have economic constraints (Savage et al., 2007). Hence, engineers are expected to master not only technical competencies concerning problem-solving but also interdisciplinary skills of cooperation, communication, project management and life-long learning abilities in diverse social, cultural and globalized settings (Lehmann et al., 2008; Edström, 2017). As a response to the situation described, many engineering courses atthe university level are designed around assignments where students work together in projects. The aim is to make the students educated and skilled in project management, teamwork, and managing system thinking within complex engineering environments. This is also reflected in CDIO Standards 6 (Engineering workspace), 7 (Integrated learning experiences) and 8 (Active learning), see e.g. Crawley et al. (2014). These standards have a lot in common with many elements of the concept Project-based Learning (PBL), derived from principles of inquiry-based learning (Pedaste, 2015). According to Thomas (2000), a PBL-approach implies that students are investigating solutions to a problem, building

knowledge by active learning and interacting with the environment, and working independently or collaborating in teams. Students are not only learning from each other but also learn to share knowledge and organize a process of collaborative learning. This is also in line with the reasoning by Senge (2006), claiming that the team, not individuals, are the fundamental learning unit [in corporations]. The concepts PBL and CDIO emphasize student development of skills and personal development, i.e. the process of becoming a professional.

Applying CDIO- and PBL-principles in courses can bring several advantages. For example, students get the opportunity to improve their teamwork and collaboration skills when solving problems together (Frank et al., 2003 and Cooper et al., 2008) and learn to see designs from a systems perspective (Savage et al., 2007). According to Hallström et al. (2007), many students increase their motivation to study and take higher responsibility for their learning when encouraged to manage challenges themselves. Hence, applying principles of CDIO and PBL promotes a deep and integrated understanding of content and process (Frank et al., 2003) and (Savage et al., 2007) and may shift focus from teaching to learning (Hallström et al., 2007). According to Edström & Kolmos (2014), the concepts of CDIO and PBL share underlying values and goals, and their practitioners might be able to learn from each other.

Problem Discussion

Two fundamental principles of teaching are to promote individual learning and to provide summative feedback in the form of individual assessment. As described by Gibbs (1999) assessment plays an important role for learning. Hence, it is essential to align learning outcomes, course activities and assessment, i.e. applying constructive alignment (Biggs & Tang, 2011). According to Edström et al., (2005) assessment is a powerful tool to guide and support student learning, and that it is the assessment system rather than the learning objectives that constitute the real learning mechanism for students.

Misaligned summative feedback may distort the constructive alignment of courses and programs. One aspect of this is problematic design of examination based on student team performance rather than on individual student performance. Tensions may occur when students with different levels of ambition work together in teams (Conway et al., 1993; Webb et al., 1998). Another, perhaps more weighty issue is that division of labor between team members may get in focus rather than learning, i.e. misleading students to prioritize efficiency before effectiveness (Buckenmyer, 2000). When allowed, students often choose to maintain their teams and work together with the same peers over and over again in many team-based courses, basing their collaboration on specialization which they master better and better for each course. Such teamwork could lead to students only achieving parts of their learning objectives. This behavior is of course facilitated if students are allowed to form teams themselves, instead of having the teacher allocate students to groups randomly or forming groups according to personal characteristics (see also Huxham & Land, 2000; Edström et al., 2011).

Strategies such as peer-assessment (Goldfinch & Raeside, 1990) and the use of group interaction profiles as predictors (Webb, 1993) have been suggested. Nonetheless, individual assessment has been thought difficult to uphold when students work together in teams. According to Savage et al. (2007) and Hallström et al. (2007), it is often difficult to accomplish a fair and valid assessment of individuals in a group setting. Hence, in many project-oriented courses, students are only graded pass or fail, or even graded collectively as a group. The aim of this paper is to contribute to an increased understanding concerning individual assessment

and grading in team-based settings and to share experiences of introducing principles of CDIO and PBL in a project-based course.

THEORETICAL FRAME OF REFERENCE

The assessment process

As described above, individual assessment might be difficult to achieve in project-based courses where students work together in teams. Such courses have a number of unique elements that add to the complexity of assessing student learning outcomes (Gray, 2013), and according to Kolmos & Holgaard (2007), PBL has become more widespread at a global scale, implying that the variation in assessment practices has increased.

The examination that focuses on student teams differs from an examination that focuses on individual students. In general, a student team is responsible for the performance and defense of the project as a whole, while the individual student has to demonstrate mastery of the desired competencies of the project as a whole (Powell, 2004). Powell claims that the essence of project examination is to test whether the student team and its individual students have mastered the learning objectives of the project and the project-supporting courses to a satisfactory level. Among other things, Powell (2004) recommends having a team of examiners examine each project, since the problem usually is complex and open-ended, to reduce the subjectivity of individual examiners.

Kolmos & Holgaard (2007) give an example of a standardized way of working concerning team-based examination with individual grading. The approach includes elements of oral presentation, feedback, discussions, specific questions to individuals, and grading. They also describe assessment focusing on examination of individuals. From a study of courses at Chalmers, Sweden, Gray (2013) identifies the need for more clearly and explicitly defined assessment criteria. He suggests rubrics based on the VALUE concept, i.e. Valid Assessment of Learning in Undergraduate Education developed by the Association of American Colleges and Universities (AAC&U). Each rubric includes a definition of the particular learning outcomes area, framing to provide the context for assessment, a glossary explaining the assessment criteria, and the generic rubric form. The rubrics provide, among other things, a point of reference for the review of assessment methods.

From practicing CDIO-principles Edström et al. (2005) found that students' perception of the assessment process depended less on how it was designed, and more on how it was presented to the students. A conclusion was that it is important that students are aware of the teachers' will and efforts to promote student learning. Hallström et al. (2007) describe a way of creating a fair assessment. This includes inviting students in the process of designing the assessment system and encouraging students and teachers to discuss aspects such as relative versus absolute grading and quality versus quantity. In this way the assessment process became more transparent to the students. It also became evident to the students that the teachers handled the examination process with great awareness and concern (Hallström et al., 2007).

Some Advantages, drivers and obstacles

When implementing principles of CDIO and PBL various drivers and obstacles have to be managed. Changing course design with regard to the examination might lead to opposition in

the form of student objections and professional anxiety among teachers (Fullan, 2001). It usually takes a while before students understand, accept and adapt to new course designs based on principles of CDIO and PBL (Hallström et al., 2007). Transiting towards higher degrees of self-directed learning can be frustrating for many students (Savage et al., 2007). According to Hallström et al. (2007), the introduction of a new course design has to be based on good general management principles, for example, making students involved, providing adequate resources and while carefully supporting and nurturing the transition process. However, both Savage et al. (2007) and Hallström et al. (2007) claim that managing a fair assessment process in a PBL-course can be very time and resource consuming.

Students may have insufficient skills and knowledge regarding project management and teamwork, which could become a source of tensions when working in project teams. Thus, students should be trained in project management and teachers need to be able to mentor teams in a proper way (Frank et al., 2003). According to Savage et al. (2007) students need to see the relevance of the project presented to them and it can be a challenge to come up with motivating projects. Another issue is when students experience problems in their projects. Many times they may feel that the teachers should have saved them from these inconveniences, i.e. that the troublesome aspects are equal to teacher failings. This reaction is not surprising as the teacher role is an obvious change in comparison to traditional course structures (Edström et al., 2005). They mean that many students and teachers gravitate back into their traditional roles, i.e. where the teacher has the "right" answers and students guess or determine through logical questioning, the correct answers.

METHODOLOGY

As the aim of the study is descriptive, a qualitative research approach might be suitable (Denzin & Lincoln, 2011). Our unit of analysis was a project-based course in customer-oriented product development, given during 2017a and 2017b (spring semester and autumn semester) and 2018. During this time period, the course underwent major development. Principles based on CDIO and PBL were introduced, including individual assessment. A reason to the embedded case study design was that the phenomenon of interest deals with interrelated issues in a real-life context, see also Merriam (1988). The case study approach implies limitations concerning generalization of the results, but might arguably be a powerful tool for in-depth analysis of a complex change process (see for example Eisenhardt, 1989). Limitations aside, as our aim is to contribute to an increased understanding concerning individual assessment and grading in team-based settings, and to share experiences of introducing principles of CDIO and PBL in a project-based course, the approach is intended to meet rationale criteria for case study methodology.

Course evaluations (measured via Likert scale and open questions), e-mails, written class council feedback and meetings with the student program council constitute our main sources of data. In addition, written student reflections based on portfolios have been a valuable source of information. Our way to collect data and perform analysis has been inspired by the approach of directed content analysis (Hsieh & Shannon, 2005) aiming for qualitative rigor (Gioia et al., 2013). The analysis was made mainly through comparisons of findings with themes in the theoretical framework, and comparisons between course evaluations.

THE CASE

Luleå University of Technology (LTU) became a CDIO Collaborator in 2015 (Gedda et al., 2016). In 2016 the Examiner and the Course responsible participated in a course named "Program-driven course development" with a focus on faculty teaching competence, with a main focus on CDIO-principles and constructive alignment.

One assignment was to develop an undergraduate course, where the choice fell on a course named "Customer-oriented product development". The course was designed as a product development project, i.e. improving a conceptual design of an existing product, where groups of four to five students collaborate in teams. The course (7,5 ECTS on advanced level) has around 80 students per semester and is mandatory within the Master Programme in Industrial and Management Engineering at LTU. The course was of administrative reasons given two times in 2017. Design changes were first introduced in the course in the spring 2017 (a). Additional adjustments were made in the fall around 2017(b) and 2018. Below, characteristics of the changes made and the change process in itself during the years 2016 to 2018 are described.

The Course Before Design Changes Was Implemented

Main course activities (not including lectures and seminars) for the students were to collect data via a survey, focus group interviews and complementary in-depth interviews. The data were structured and analyzed through thematic analyses, quality function deployment techniques and conjoint analysis. At the end of the course, the project results were presented in a final report and presented orally. Before the course changes were implemented, project teams were formed by the student themselves, which together decided what kind of product or service they wanted to develop. In addition to giving lectures, the teachers involved in the course also took roles as supervisors. If needed, the students could discuss with any of the teachers (for example due to a teacher's specific area of expertise). Before the change summative feedback was based on the project reports (i.e. all students in a team got the same grade), and individual quizzes. The grading scale was Fail, 3, 4 and 5 (highest grade). Grades from the project report and quizzes were then averaged and rounded upwards.

Motivation for new course design

The need for changing the course was not primarily based on students' course evaluation results as the last five years evaluations hovered between 4.5 and 5.0 on a six-grade scale. Several issues had been identified based on student comments in course evaluations. For example, the examination was described by many of to be unjust, complex and opaque. The summative assessment was considered unfair by many students, especially related to the individual quizzes: "It is unreasonable that 50 percent of the grade is quizzes (does not correspond to half of the course work)" and "You judge what we have read, not what we understand" (expressed by students 2016). In addition, the course was experienced too resource demanding by the teachers, in terms of time on supervision and feedback. However, the Examiner and the Course responsible felt that the most urgent issue was that the relation between course learning objectives, learning activities and student learning outcomes was unclear (i.e. unconstructive misalignment). To create better conditions for each student to obtain the intended learning outcomes of the course, a new design was introduced enabling individual assessment of students working together in project teams.

Project Context and Student Team Design

Randomized project teams were introduced 2017 (a) with the aim to make students take on new roles (compared with working in the same group constellation several times) and increase their abilities in teamwork and formal/informal leadership. After the compilation of the feasibility studies, the Course responsible picked the members to the project teams randomly. The team then met for the first time during a mandatory seminar, to discuss the direction and management of their development project, based on the team's inherent feasibility studies (which the students reviewed a day in advance). During the seminar, each student argued for his/her feasibility study. Based on the following discussions, the team came up with a mutual decision on what product to develop, and an overall direction for the project.

Managing their project according to project management principles was highly promoted during the course's introduction lecture. Project management had been a subject field for the students in previous courses, hence no additional lectures were given in that subject.

Introduction of an Individual Feasibility Study

An individual feasibility study where introduced in the course with the aim for students to increase their ability to plan development projects. Before, students decided together in the team what product to develop and how to plan the project directly. In the feasibility study, each student had to individually create a proposal on what product to develop, and how to do it (planning).

Introduction of Individual Portfolios

Inspired from the course including CDIO- and PBL-principles the concept of portfolio was introduced in the course. The aim was to promote students to take responsibility for their learning process. The individually written portfolios allowed the students to describe, explain and reflect on their activities to reach the learning objectives of the course. The first time (2017a) the students were allowed to compile their portfolio in a maximum of 500 words. The second time (2017b) the concept of portfolio extend into two parts: portfolio A (500 words) and portfolio B (500 words). The aim with portfolio A was to make reflection based on learning outcomes concerning the customer-focused product development process, while in portfolio B make reflections on project management skills and group dynamics. To better promote students to analyze the project management and teamwork, the guidelines have continuously been adjusted. For example, in the course 2017b students had to write constructive feedback to the other members of the team, to improve analysis and reflections of group dynamics in portfolio B.

Introduction of Individual Student Peer-review

To increase student ability to make evaluations and assessment, peer-review was introduced as a course activity. The approach also implied a shift from teacher to student feedback. The activity trained students to give constructive feedback and recommendations. In practice, it meant that each student individually gave constructive feedback on another team's report. Peer-review occurred two times during the course. Hence, each time, a team got four to five written peer-reviews on their report draft. The peer-review guidelines were repeatedly adjusted as an attempt to promote constructive feedback,

THE ASSESSMENT PROCESS

The feasibility study, portfolio A and B, peer-review, and oral exam were graded according to: Fail (F), 3, 4, and 5. Hence, the assessment becomes work-intensive and resource demanding the first time practising the new course design. Formal templates or guidelines to support the grading were lacking and had to be invented during the grading process.

Assessing feasibility study, peer-review and portfolios

During the course 2018, guidelines to support the grading process was available, but mainly concerning the feasibility study, the portfolio B and the peer-review. The teachers find a way to support the grading during the oral exam was difficult. However, most felt they could make the grading based on their experiences of grading in other courses. The grading of the feasibility study and the portfolio B was simplified, using only Fail/Pass. If failed, the student had to redo the task to obtain the grade 3. If the feasibility study or the portfolio B was very bad or very good, the teacher made a note, which influenced the total grading. In addition, to make the examination process more efficient, portfolio A became mainly a quality assurance function for the students, i.e. not a basis for grading.

The oral exam

The oral exam was the most comprehensive and decisive assessment activity. The aim with this form of assessment was to promote students to develop their ability to argue for their case, the project results, their efforts, and to show a deeper understanding of methods used.

The oral exam was based on the teams' final report. In the course 2017(a) four teachers divided the reports among themselves (to review and assess). The teacher reviewing one report had later on the main responsible to perform the oral exam with the students responsible for the report. To make the exam process more efficient, it was decided by the Examiner and the Course responsible to only let students qualified for grades 4 to 5 (based on the other individual tasks) to do the oral exam. I.e. to be able to reach the highest grade (5) in the course. However, after the first course occasion all teachers appreciated the great learning environment the oral exam implied (for both students and teachers), and the oral exam became further on mandatory for all students.

As the approach for the examination was more or less new for most of the teachers and experience was gained over time, the way of doing the exam has changed repeatedly. The exam 2017(a) included two teachers and one student during each occasion (15 minutes). When oral exam became mandatory the constellation was changed to one teacher (which was accepted by the teachers due to better knowledge and skills how to perform that kind of assessment). To make the process even more efficient, the teacher held the exam with two or three students at the same time (and from the same group), 30 - 45 minutes. However, the teacher experienced it too difficult having three students at the same time, i.e. to be able to assess each student's individual achievements. Therefore, from 2018 one teacher met two students (sometimes one student if five in one group) at time. An advantage with two students (compared to only one) was an improved learning environment, as students could listen to and reflect upon each other's answers during the occasion.

During the oral exams, the discussions departed based on the teacher giving the same question to each student (the students were aware of the question in advanced): "What do you consider being the strengths and weaknesses with the report?". The student had to argue for his/her standpoints, while the teacher listening and came up with suitable follow-up questions. The teacher decided which student who should answer a question, and when to direct a

question to the other students when suitable. The oral exams were also recorded, making it possible for other teachers to evaluate the discussion if some kind of issue turned up (from a teacher or a student perspective). If the report was assessed a grade 3 (information not shared with the students), it was mainly possible for a student to argue for a grade 4. Hence, the oral exam mainly gave students an opportunity to deviate one level higher/lower grade than the assessment of the report.

Total Assessment and Final Grading

The teachers only reviewed portfolio A if they have had difficulty to assess and decide upon a grade during the oral exam. The different parts were in the end weighted to come up with a final grade for each student. The weighting varied between course occasions, but overall the oral exam has had the highest priority, followed by peer-review, portfolio B and the feasibility study.

In a way to standardize the grading process, the teachers made notes to describe and explain the grades given for each student. In the end of the course, the teacher team together evaluated and discussed the students' preliminary grades, with the aim to obtain a common agreement for the total grade.

FINDINGS AND ANALYSIS

Putting the new course design into operation was not without a lot of struggling, generating many "lessons learned". In this section, some student quotes from the course evaluations are described to illustrate overall findings, including comparisons with the theoretical frame of references.

When introduced 2017(a) the students did not appreciate the assessment process, which became a source for anxiety and stress, mainly concerning how they should be graded: "The assessment criteria are unclear" and "…the high focus on the way of achieving feedback [within the team], portfolios and oral exam, on the final grade, takes away the focus on the report and the project". Especially the introduction of portfolios, and grading of the same, was a major change and concern for many students, and the reactions became very strongly in 2017(a): "The portfolio add nothing", "Get rid of the portfolios! Do NOT bring anything to MY learning", and "The portfolio is a joke". These reactions are in line with the reasoning by Fullan (2001), i.e. changing a course design with regard to the examination might lead to opposition among students. In accordance with increased students' satisfaction during the evaluation 2017(b), comments about worries, frustrations and complaints were highly reduced. Several students also expressed a positive attitude to the new assessment process: "It is very good that you do not grade the group [as one unit]" and "This is a good way of doing the examination". These findings correspond to the view of Hallström et al. (2007), i.e. that it usually takes a while before students understand, accept and adapt to a new course design based on principles of CDIO and PBL.

Concerning the final grades 2017a, many students contacted the Examiner and the Course responsibly (mainly via e-mail), concerning their final grades. Students were dissatisfied or experienced diffuse motivations of the given grades, for example: "Why, and how do you motivate that I only got grade 4 – and why didn't I got grade 5?" and "Is all the work I put into this course only worth grade 3?" Some students also remained critical about oral examination during the course 2017b: "I believe that the oral examination do not show the efforts made in

the course." and "…is unfair since I have not participating in all parts [methods] of the course". The quotes indicate that students experienced an unclear examination process. A more standardized and visualized way of working, inspired by for example Kolmos & Holgaard (2007) and Gray (2013), should probably make the process more transparent for the students (and the teachers). Also, inviting students in the assessment process, i.e. discussing different aspect together with the teachers, would probably contribute to a more positive reaction among the students, as described by Hallström et al. (2007).

One of the quotes indicates that students were not fully aware of their obligation to fulfill the course's learning objectives. I.e. that it is ok to lack knowledge in some areas, similar to written exams where the approved level can be 60% of the total points. In accordance with the reasoning by Powell (2004), it is important to test whether the individual student masters the learning objectives to a satisfactory level. In that perspective, the new design of the examination process seems to improve preconditions testing if students obtained the learning outcomes.

Oral examination

Only a few comments concerned the oral examination in the course evaluation 2017(a), as it was performed before the examination. However, many general questions came up during the course, i.e. how the examination would be structured and performed. To facilitate for students, the procedure was described to the students during a lecture and in written information via the course's IT platform. However, after the oral examination, many students expressed strong reactions, mainly via e-mails to the Examiner and the Course responsible: "Get rid of oral examination and introduce quizzes again. Oral examination to get grade five is the sickest thing I've heard of! What if I am nervous and doing a bad argumentation…. Am I not worth grade five then?" Another student claimed: "I hate being assessed on [my ability to] reflect and not [on my] achievement". Also, some students remarked on the assessment in itself: "I think the assessment you made was very wrong...". The students' reactions and experiences of the oral examination can to some part be explained by aspects previously described by Fullan (2001) and Hallström et al. (2007). However, making students confident in grading based on oral examination seems difficult, and is discussed only briefly in the previous studies. The use of rubrics (Gray, 2013) could probably facilitate creating legitimacy and transparency among students.

Teacher Supervision and Support

Overall, most feedback from the students has been about supervision and support. The new approach, relying more on peer-reviews and less formal supervision by teachers, made many students frustrated (students 2017a): "Help the students. Answer the questions. Teach!", and "I have had no idea what to do, why I should do it, when to do it". The course evaluation 2017b pointed out similar dissatisfaction: "The teachers have to spend more time with the students" and "I feel I've not get any feedback on my work efforts…" and "…more feedback from teachers, not only peer-reviews". However, many students during the occasion 2017b apprehended the peer-review procedure, among other things, as a way to promote individual achievements: "Peer-reviews have been good and rewarding" and "It is good that individual achievements can be visible via peer-reviews and oral examination".

Some of the quotes above indicate too little guidelines and supervision during the course, especially during the first and second course occasions. In the same time, the new course design requires students to be more self-directed in their learning and to take "ownership" of

their learning process (Savage et al., 2007). It seems that some students had difficulties to adjust to that new kind of responsibility. Students also seem to put some blame on the teachers for the inconveniences in the course. Such reactions are common (Edström et al., 2005), as the new role of the teachers having a less prominent role is a major 'game changer', in comparison to traditional course structures.

CONCLUSIONS AND DISCUSSION

When introduced in spring 2017 the new course design was heavily criticized by the students, including an all-time low course evaluation (3,2). Interestingly, already in the 2017b, the course evaluation became 4,5, i.e. quite on par with the 2016 evaluation (4,7) before the changes had been introduced. An interpretation is that the new course design promotes better conditions for students to obtain intended learning outcomes.

In this paper obstacles and driving forces when introducing principles of CDIO and PBL in a project-based course have been described, especially concerning the management of individual assessment and grading. When the new course design was introduced, student anxiety regarding the examination process put a shadow over most course activities. This was manifested in the all-time low student evaluation. Another reason for this could be that students in previous courses had been able to receive top grade even if they did not fully meet intended learning outcomes. With the new course design, this opening was reduced, based on new methods of examination, mainly through portfolios, peer-review reports, and an oral examination based on the project teams' final reports. The portfolio B provided a good basis for evaluating learning outcomes concerning teamwork and leadership, based on the students' reflections. From the peer-review reports, it was rather easy to assess if a student comprehends the content of another team's final report, and could make relevant evaluation and recommendations. During the oral exam, teachers were able to assess the argumentation and reflections made by the student concerning weaknesses and strengths in the team's final report, providing valuable insights in whether the student had obtained the learning outcomes.

Apparently, students had to face new challenges that they were not prepared for, creating frustration. In the same time, the Examiner and the Course responsible failed to explain and describe the new course design to the students. Having a transparent assessment process that makes it clear if the students have obtained all the intended learning outcomes in a course is clearly important. A way of handling the issue concerning fair grades and obtaining the learning outcomes is to let students be more involved in the design of the assessment process, as recommended by Hallström et al. (2007) and Edström et al. (2005).

The initial student reactions bear witness of frustration with the change of course design. This may to some part be explained by general change management theory, i.e. that change many times creates anxiety. According to Edström et al. (2005), student perception of the assessment process may depend less on how it is designed and more on how it is presented. From the student feedback received, it is clear that in our case the teachers initially failed to communicate and explain the new course design.

Limitations, lessons learned and future development

The authors have been active parts of the case and context that has been studied. Therefore, there is an obvious risk of bias in our data collection and analysis. In order to reduce this problem, we have tried to describe the course development process carefully, giving examples

based on student comments. Our study aims to explain a rather complex reality using a very limited set of parameters. Hence, the risk of oversimplification is apparent and our results and conclusions should, therefore, be treated with caution.

The improvement of the course design is a continuous journey towards perfection, with lessons learned continually coming up during the way. Guidelines and instructions are being developed and revised to promote student understanding of the course design and to facilitate the examination process, increasing transparency and strengthening quality assurance. Another initiative is to prepare for handling conflicts in student teams. It is important that the teacher can be proactive to avoid and manage such conflicts, quickly helping the team to put the focus on and work towards the learning outcomes in the course.

According to Savage et al. (2007) and Hallström et al. (2007), achieving fair assessment in a project-based course can be very resource consuming. So far, the course described in this study requires the same total amount of man-hours also after being redesigned. Attaining increased student learning can be viewed as reaching higher effectiveness, i.e. doing the right things. In that perspective, the new course design is more effective than the previous one. However, we also need to consider efficiency, i.e. to complete the course with limited resources. Further studies will examine the course development from such a perspective of efficiency.

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DESIGN-IMPLEMENT COURSES TO SUPPORT CHANGE IN ENGINEERING EDUCATION

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ABSTRACT

This article describes the results of well-succeeded design-implement courses developed at the Military Institute of Engineering (Rio de Janeiro, Brazil). The implementation of these courses is part of the ongoing transformation process in engineering education and considers simultaneously aspects from different CDIO standards, embedding active-learning methods and creating additional opportunities for integrated-learning experiences within the Institute. The article also describes important aspects of planning and execution, pedagogical results obtained and provides a benchmark for other teachers interested in implementing similar activities.

KEYWORDS

Change process, design-implement courses, PBL, project management, Standards: 5, 7, 8.

INTRODUCTION

The Military Institute of Engineering (IME) is a very distinct Brazilian engineering school that decided to follow the CDIO guidelines to enhance engineering education. In 2015, new strategic planning was initiated (Passos et al, 2017) and in 2016 the engineering education started to change. However, the implementation of these good practices suggested by the CDIO is very tough and requires some years of continuous effort. For this reason, we chose the creation of new design-implement courses as the first initiative to change engineering education. This article describes the conception and features of these courses, regarding the change process currently underway at the IME, besides providing some artifacts and a guideline to help other groups to initiate the same kind of course.

Regarding the experience brought from the Linköping University (LiU) and the Royal Institute of Technology (KTH) by two IME's teachers, it was decided to remove some courses from the existing curriculum to create the new design-implement courses (henceforth Introduction to Engineering Project I and II, with the acronym IEP I & II) in the 3rd and 4th semesters. The Scientific Theme (ST), previously taught in the 4th semester, was the main substitution. This course was science-focused, with its main learning outcomes linked to research skills, instead of planning, management and execution of projects. Historically, ST mostly provided poor learning results and generated demotivation of students and teachers. Clear evidence of this former statement was the difficulty to recruit themes to allocate all students during this semester. It should be emphasized that during the first 4 semesters, all the students belong to

the Department of Basic Sciences and are not designated to any Engineering Department. So, this demotivation had a heavy impact on all departments.

The expected gains of IEP (the acronym for both courses) include the opportunity to develop skills and integrate multidisciplinary knowledge at the same set of activities, according to the CDIO motivations (Crawley et al., 2014) and industry requirements (McMasters, 2006). This is also aligned to the worldwide maker movement (Dougherty, 2012) with several implications and contributions to education (Halverson and Sheridan, 2014) that is especially valuable for the young engineer students, that are increasingly interested in practical activities and conscious about the importance of developing skills like oral and written communication and team working.

Beyond the Swedish benchmark mentioned above, we should also compare our work to other valuable experiences from other universities, that also used design-implement experiences to develop skills and integrate knowledge. The mature design-implement courses from Kanazawa Institute of Technology (KIT) and Vietnam-Japan Institute of Technology (VJIT) serves as the main pillar in the engineering curriculum integrating contents from other knowledge-based courses (Nguyen-Xuan et al., 2018). However, their main focus is the relationship between problem-solving and other disciplines. Similarly to IPE, teachers from the University of Piúra also selected *project management* as the core discipline to develop their design-implement experience and develop the skills mentioned above (Guerrero, Palma & Rosa, 2013). Some design-implement experiences benefit from the relationship with the industry to provide real projects for the students. That is an important feature of the FIRMA environment created by teachers from Turku University of Applied Sciences (Määttä, Roslöf & Säisä, 2017). In fact, the IPE framework provides to the students all the intended learning outcomes and opportunities described in the tutorial chapter about design-implement experiences in Crawley et al. (2014). Additionally, it is also interesting that we also face the same challenges described in this chapter. However, we still have several improvement opportunities for the courses.

This paper was divided into five parts, where the first part reviews relevant background involving the new courses, change management and CDIO implementation. The second part explains how changes have been implemented applying the 8-step model (Kotter, 1995). The third part describes IPE I and II and explains how they allow the development of desired skills. After, the fourth part shows the evaluation of the courses, that support the conclusions presented at the end.

IMPLEMENTING EDUCATIONAL CHANGES AT IME

Amongst several courses of action to start the transformation in engineering education (teacher training, improvement of engineering workspaces etc.) it was decided to adapt the curriculum of the Department of Basic Sciences to create new design-implement courses. These courses are part of the transformation process, that has been managed using John Kotter's 8-step model (Kotter, 1995).

Applying the 8-step model to this case

The 8-step model was used as a guideline and not as rigid process itself. Regarding this idea and considering the *implementation of the good practices in engineering education* as the change to be implemented, we present how this model has been used to support this change.

Step 1 - Create a sense of urgency

The necessity to improve engineer education is already clear within IME, despite the excellent results that our students and Institute obtain in national and international evaluations. This

motivation for change originated from different sources, but mainly: a) students that returned from international internships proposing several improvements and b) teachers reporting student indifference within the classroom.

Step 2 - Building a guiding coalition

Regarding the problems mentioned above, the provost/commander selected some motivated teachers to discuss and address solutions for these problems.

Step 3 - Form a strategic vision and initiatives

The CDIO approach was selected as a reference to improve engineering education and two teachers were sent to Linköping University (Sweden) to live and learn about this set of good practices. After their return to IME, it was started a strategic planning to implement changes and some courses of action were prioritized, namely, a) the *Entrepreneurship Course* along Getúlio Vargas Foundation (Passos et al, 2018), b) the diffusion of active learning methods amongst faculty (ongoing activity) and c) the implementation of *new design-implement courses* in the Department of Basic Sciences.

Step 4 - Communicate the vision

The commander/provost used all the *resources available* to communicate this vision and motivate the faculty and students, but mainly lectures and videos produced by the *communication department*. The coalition group, selected in step 2, is very important to this step because they are local leaders that carry credibility to the change process.

Step 5 - Enable action by removing barriers

Focusing only on IEP *I & II*, it was necessary to *build a teaching group* to conceive the courses and after that discuss its implementation with IME's teaching advisory board. Regarding the course features some previous courses were excluded or merged into the current curriculum to avoid content repetition. At the same time, the new course benefits were widely discussed and several valuable contributions were provided by the teaching advisory board.

Step 6 - Generate short-term wins

The new courses generated great motivation among the students since the beginning. The using of active-learning methods to present the content represented a paradigm shift for the students. The discussion about skill development was emphasized, and it was possible to perceive the student's reaction taking care about their performance on presentations, reports and team working. Additionally, the competition of popsicle-stick bridges gave them the opportunity to put the knowledge in practice. All this energy and motivation was registered by the *communication department* in a very successful video, that reached more than 1 million views in the social networks (in YouTube, https://youtu.be/K1yNYUxOaak). This article itself represents a short-term win. The publication of these results in an international-reputed engineering education conference validates the courses.

Step 7 - Sustain acceleration

The second version of the courses was already planned. The difficulties and improvement opportunities were registered and the teaching team is working to enhance the course. The association of former students (Alumni IME) also provided financial support for the next project-based learning experiment: catapult commanded by Arduino. The successful use of active-

learning methods, good project executions and, mainly, the student motivation empower the implementation of other engineering education good practices.

Step 8 - Consolidate change

The change consolidation will occur with teacher training on these engineering education fundamentals. The training contributes to disseminate good practices and prepare future teacher teams to continue and enhance these design-implement courses.

COURSES DESCRIPTION

IEP I & II were implemented in 2018. The core of both courses is the theory and practice of Project Management (PM). During these two semesters, the practices become increasingly complex, always considering the student's level and knowledge, as described below. Detailed information may be obtained in the website: www.iep.ime.eb.br.

Introduction to Engineering Project I (3rd semester)

Beyond the teaching of PM knowledge, IEP I also aims the improvement of oral and written abilities. The PM classes are taught using problem-based learning (PBL) method and, in 2018, oral presentation and written techniques were discussed with traditional lectures. Figure 1 provides an overview of IEP I & II.

In 2018, the practical activity of IEP I was the competition of popsicle-stick bridges, following the specifications provided by the teaching team. The student groups had to build their bridges in a limited period and soon after its construction, all the bridges were submitted to a destructive test to determine the maximum load supported by each bridge. The students practice PM knowledge carrying out the initial planning and executing the construction according to the specifications and the predetermined time. The teaching team of IEP I is multidisciplinary, composed of engineers from different specialties, administrators (both with PM knowledge) and language specialists.
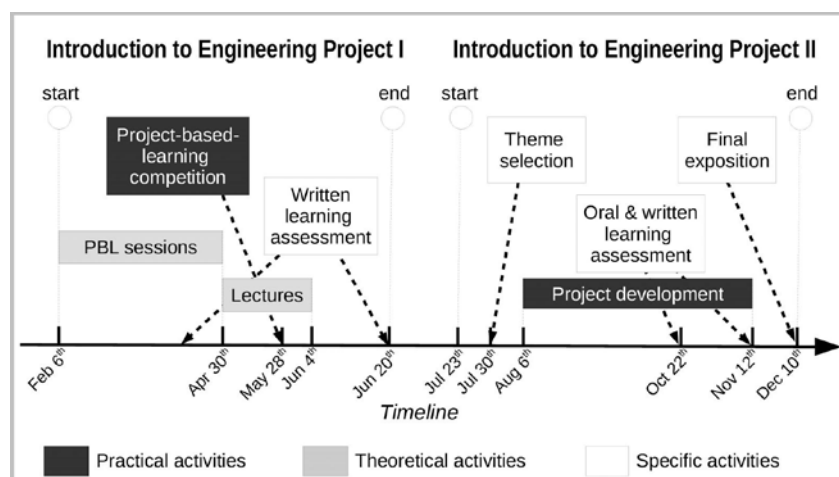

Figure 1- IEP Timeline

Introduction to Engineering Project II (4th semester)

In this course, the major focus was the practical application of the knowledge acquired in IEP I in a real engineering project.

The projects in IEP II were advised by 28 teachers from the Engineering Departments from IME. Despite most of the themes were proposed by teachers, some of them were proposed by students. These themes ranged from the implementation of mobile and web applications to the development of rocket models. Naturally, the complexity of the projects should be was adequate for the available time (14 weeks) and the students' knowledge. Considering the PM knowledge obtained in the previous semester, IEP II further develops the student's ability to work in teams and to carry out and execute planning. The oral and written learning assessment (depicted in Figure 1) play an important role in skill development. It is an opportunity for the students to practice the oral presentation and written techniques presented in the 3rd semester. The teaching team provided a rubric to guide the presentations (available on the website).

IME students choose the engineering program only in the 5th semester. For this reason, IEP is a great opportunity for students to get additional knowledge about the program which they want to choose. It is important to highlight the motivational character of this course since most of the courses of the Department of Basics Sciences (ranging from the 1st to the 4th semester) are strongly theoretical.

COURSES EVALUATION

The courses evaluation, detailed as follows, aims to compare IEP courses to others, that occurred simultaneously at IME. These surveys intend to check and foster the adoption of good practices by the teachers, including active-learning methods. This evaluation demonstrated that IEP achieved superior results comparing to other courses, using the same reference-questions.

As part of the IME internal evaluation process, it is requested to all students to fulfill a survey form to evaluate all the courses from all the engineering programs. The survey is very broad and intent to cover all courses formats in IME. The analysis presented in this work compares the results obtained in IEP with the other courses from IME. The survey consists of 12 objective questions presented using a five-point Likert scale (Likert, 1932), divided in three main areas: Course Questions (related to the course methodology and contribution with the engineer formation); Project Questions (related to complexity, timeline and theory, and practice alignment); Students Questions (related to students motivation and performance).

Results of three different surveys are showed, students in 3rd (225 answers, 76% of the total students) and 4th (160 answers, 57% of the total students) semesters and teachers in the 4th semester (27 answers, 96% of the total teachers). The questions applied to the students are presented below:

1) Does the teaching process relate the theory to engineering practice?
2) Does the teacher relate the theory to the engineering practice in the EVALUATION process?
3) Does the teacher appropriately use various technologies such as overhead projector, Internet, among others, in a way that favors INTERACTION and student LEARNING?
4) Does the teacher use suitable teaching techniques to present the course - directed study, case study, lectures, group work, among others, in a way that favors students' INTERACTION and LEARNING?
5) How does the teacher classes promote student's MOTIVATION for course?
6) Does the RELATIONSHIP between teacher and students contribute to learning?
7) Does the teaching provided in the classroom EFFECTIVELY contributes to learning?
8) Can the teacher COMMUNICATE clearly what should be learned during the course?
9) Is the teacher AVAILABLE to clarify students' questions?

10) The content in the evaluations CORRESPONDS to what was taught during the course?
11) Does the difficulty of the tests CORRESPONDS to what was taught during the course?
12) Does the teacher establish relationships between his / her course with other areas of knowledge, favoring multidisciplinarity?
The questions applied to the teachers are presented below:

1) What is your opinion about the use of PM methodology in IEP II?
2) What is your opinion regarding the time available for the project development (14 weeks)?
3) What is your opinion regarding the organization of the course activities?
4) What is your opinion about the comparison of the students' learning results in IEP II and in the Scientific Theme (ST)?
5) What is your perception about the contribution of the course to the formation of the future engineer?
6) What is your opinion regarding the complexity of the work offered to the students?
7) Do you consider that the PROJECT can relate theory to engineering practice?
8) What is your opinion whether the project EVALUATION contributed to the engineering practice?
9) How much time did you have for this project?
10) What do you think about the students' results on the project?
11) What is your perception regarding students' motivation in the project?
12) To which extent your relationship with the students contributed to the project success?

Evaluation of IEP I and IEP II

Figure 2 and Figure 3 present students' evaluation to IEP I and IEP II, compared with remaining courses that occur in same semesters. The vertical axis presents the average of the answers and the horizontal axis indicates the question number presented to the students. The gray line shows the results of all IME students for each of the 12 questions. In Figure 2, the orange line shows the results for all the courses considering only the 3rd semester, that is, the courses that occur simultaneously to IEP I. Similarly, in Figure 3, the orange line indicates the results for all the courses that occur simultaneously to IEP II during the 4th semester. The blue line shows the results for IEP I & II in both figures.
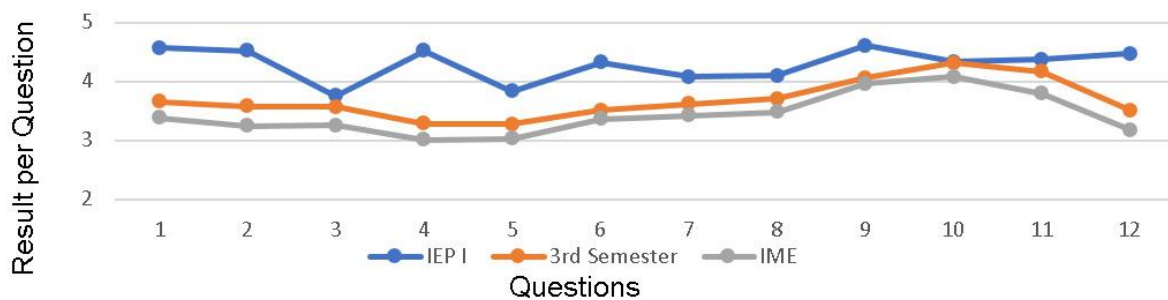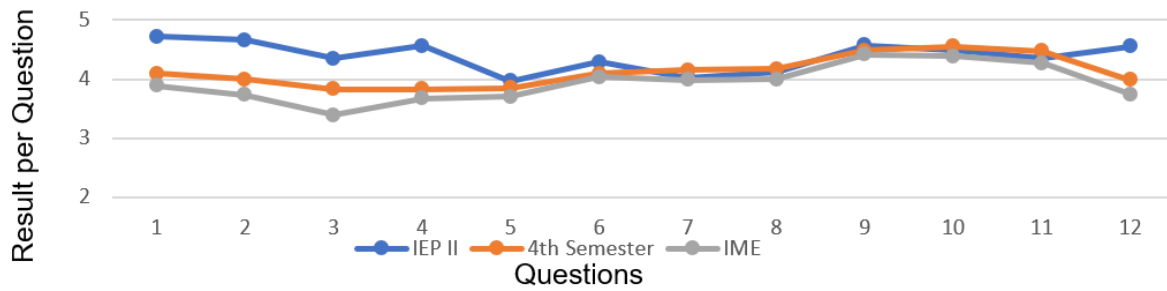

Figure 2 - IEP I Student Survey

Figure 3 - IEP II Student Survey

In Figures 2 and 3, comparing the results of all the courses from IME (gray line) with the results of the 3rd and 4th semesters (orange line), it is possible to verify that these semesters results present the same behavior as all the courses from IME.

Comparing the overall result of IEP I in Figure 2 (blue line) with the 3rd-semester courses (orange line) and all courses from IME (gray line), the results of IEP I were higher for all questions and very higher in several questions. It is important to mention that questions 1 and 2 (the relationship between theory and practice), question 4 (teaching techniques), question 6 (teacher-student relationship) and question 12 (multidisciplinarity) presents the higher positive difference for IEP I.

Comparing the overall result of IEP II in Figure 3 (blue line) with the 4th semester courses (orange line) and all courses from IME (gray line), the results of IEP II were higher for almost all questions, except questions 7, 8, 10 and 11 and very higher for questions 1, 2, 3, 4 and 12.

Considering the results analyzed above three aspects must be emphasized: the students' perception about the relationship between theory and practice, using active-learning techniques and multidisciplinarity. The competition of popsicle-stick bridges in the 3rd semester and the project development in the 4th semester were successful in providing significant learning experiences for the students. The use of PBL in the 3rd semester provided a different teaching experience for the students and was very welcome. The project development in the 4th semester, mixing disciplinary knowledge with project management in a real (or almost real) situation, was a valuable multidisciplinary activity.

Figure 4 presents the teacher survey results after the 4th semester. The vertical axis presents the average of the answers and the horizontal axis presents the questions presented to the teachers. The orange bar shows the Course-related Questions. The blue bar shows the results for Project Questions. The gray bar shows the results of Student-related questions.
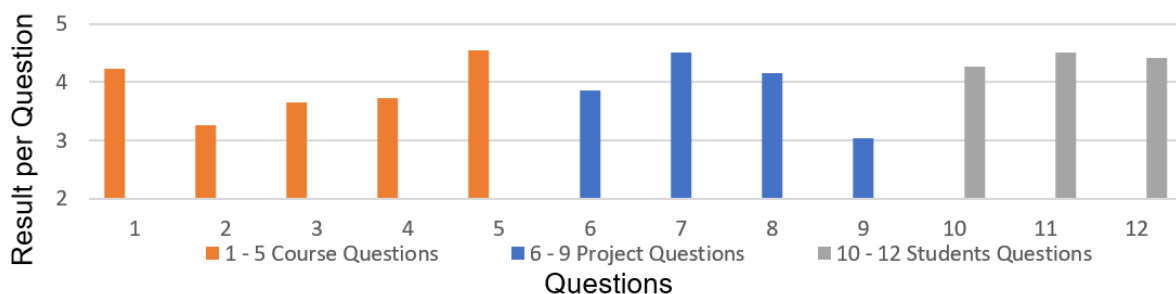

Figure 4 - IEP II Teachers Survey

In Figure 4, the highest numeric value (4.56) was obtained in question 5 (contribution of IEP II to the formation of future engineers). The second highest values presented in Figure 4 (4.52)

represents questions 7 (the relationship between theory and practice) and 11 (students' motivation). These results are very important for the teaching team and for the change process in general. It demonstrates that a broader set of teachers recognize the discipline value and may amplify the coalition group.

Questions 2 and 9 in Figure 4 presents the lowest results in teachers survey. Both questions are related to the available time. It is important to be careful during the themes selection in order to give an appropriated scope to the time available.

Qualitative evaluation of team working skills

The students had two valuable opportunities to work in teams during both semesters: first, with the competition of popsicle-stick bridges. After that, with the IEP II project conducted by the engineering departments. This statement is supported by interviews that were made with a sample of students and with the project advisors. The students had to divide tasks, solve conflicts, coordinate activities and aggregate the work of several individuals in both activities, to achieve the final result.

Qualitative evaluation of oral and written skills

In traditional lecture-classes, students have few chances to express their knowledge. However, IEP was completely conceived to be active-learning-based courses. It is very important to emphasize that the students were warned and motivated about the importance and opportunity that they would have to develop oral and written skills. In the end, it was possible to perceive their evolution.

During the problem-based learning sessions, that happened in IEP I, the teaching team could know the students and discover who is shy and who is not, who wants to participate naturally and who does not want. Because of the infrastructure provided, intrinsic motivation and the pressure for obtaining the grades it is possible to perceive that, at the end of IEP II, even the shy students improved their oral skills. It is easily assessed during the intermediate and final oral assessment (mentioned in Figure 1), where the students follow a rubric guideline to reach a good presentation performance.

CONCLUSIONS

The change promotion in engineering education is a current challenge that many HEI have handled in order to prepare the 21st-century engineer. In this context, there are two main outcomes of this work: to report the contribution of the design-implement course to the ongoing change process at IME and to provide a start-kit to groups that want to implement similar changes at their institutions.

The transformation process has been managed using John P. Kotter's 8-step model (Kotter, 1995). In this context, IME has adapted the curriculum of the Department of Basic Sciences. The first change was the substitution of science-focused course, called Scientific Theme (ST), by new design-implement courses (IEP I & II). A relevant result was the high level of motivation of students and teachers, bringing impacts to all engineering programs.

Based on the results of three different surveys involving students (3rd and 4th semesters) and teachers, it is clear that the new course connected theory to practice brought to IME an additional active-learning experience and promoted multidisciplinarity. Additionally, the students improved their oral and written skills, practiced team working and enhanced their

motivation as described in the result sections above. This perception was shared not only by students but also by the teachers involved.

Finally, we consider that other groups could benefit themselves from the start-kit available at http://www.iep.ime.eb.br. Although it is a work in progress, it includes the PBL workbook, the competition of popsicle-stick bridges description and video, besides the courses specifications.

ACKNOWLEDGMENTS

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CDIO CURRICULUM DESIGN FOR COMPUTING: A GRAPH-BASED APPROACH

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ABSTRACT

An essential activity in curriculum design is to specify the topics of the curriculum and the courses where those topics will be taught. Disciplines, such as Computing present several challenges in this regard, since the topics that students must learn tend to be fine-grained and highly interconnected. First, one must ensure that the most important topics of the curriculum are taught in at least one course. Second, for every topic taught, their prerequisites must have been covered previously in the same course or in a previous one. Third, courses must include topics that are highly cohesive and with minimal dependencies to topics taught in previous courses. To address the above challenges, this paper proposes a graph-based approach to analyze and design a curriculum, which also includes some Backward Design elements. Learning goals (desired results), topics, and courses are modeled as nodes in a graph. Prerequisite dependencies are modeled as edges. The relation between courses and topics are also modeled as edges. Graph analysis techniques are utilized to measure several aspects of a curriculum. Edges between topics are utilized to verify consistency between topics and prerequisite and corequisite relations between courses. Course-topic edges are used to calculate topic coverage of the curriculum. Topological sorting and course-topic relations are utilized to automatically generate the draft of course syllabi. We also describe the results of a real-life application and argue that this approach is essential to make visible and verify the overall structure of a curriculum.

KEYWORDS

Curriculum design, graph, syllabus, computing, CDIO standards 2, 3.

INTRODUCTION

CDIO initiative definitions involve several tasks for proper curriculum design. One of them is the specification of the disciplinary topics to teach to students and the decision of which courses should include those topics in their syllabi. In some knowledge areas, such as Computing, this challenge can be difficult to solve, because they may comprise many fine-grained and strongly inter-dependent topics. For instance, the ACM Computing Classification System (ACM, 2012) defines more than 2000 topics that could be included in a computing curriculum. Moreover, as described in this paper, many Computing topics are highly interrelated. To properly learn such topics, the student may need to learn several other topics previously.

The above situation introduces several challenges. First, the most important topics in the curriculum should be taught at least in one course. While this is a common issue, topics may be hard to properly prioritize when connections between them are complex. Courses should teach highly coherent topics, with minimal dependencies to prerequisite topics and with a proper course ordering that ensures that none of those prerequisites is untaught before each course.

To address the above challenges, this paper proposes an approach to support the definition of the body of knowledge of a program, to properly understand topics and their inter-dependencies, and to properly define course syllabi in disciplines such as Computing. The key element is to utilize a graph to represent the information to support the curriculum design process.

This graph specifies disciplinary topics, program courses, and program desired results as nodes. Prerequisite relations between topics are specified as edges. Similarly, associations between courses and their syllabi topics are modeled as edges. They are also utilized to specify the connections between topics and desired results.

Several metrics are utilized to identify curriculum issues related to the above challenges and also to guide in their resolution. Dependencies between topics and their relations to courses are used to verify consistency of current course prerequisites. Course-topic associations are utilized to calculate the topic coverage of the curriculum. Syllabi can be automatically generated from a topological sort of such topics.

This paper proposes an approach to integrate all of the above elements into the curriculum design process and also describes the real-world experience of implementing this process in the redesign of a Computing program.

The remainder of this document details all of the above elements: the overall approach and the graph utilized to model the knowledge base, the process to create and utilize this graph in curriculum design, the results of applying this approach in the curricular redesign at our university. There is a discussion of the results, a comparison with related work and the last section concludes and describes future work.

BACKGROUND

This section briefly describes the fundamental concepts to understand the proposed approach, and the nomenclature utilized in the remainder of this document.

Backwards Design

Aside from graph theory (Bondy & Murty, 1976), an important element in the proposed approach is Backwards Design. Backwards design is a component of Understanding by Design (Wiggins & McTighe, 2005), a framework to design curricula, assessment mechanisms, and teaching. Backwards Design comprises three main stages:

1. Identify desired results: This stage defines the expected results yielded by students at the end of their studies.

2. Determine assessment evidence: This stage defines the way to assess student

learning and the way this learning is evidenced.

3. Define instruction plan and learning experiences. The last stage creates a concrete plan to effectively teach all the concepts defined in the curriculum.

The proposed approach in this paper addresses stage 1, to define a set of desired results, and stage 3, to assist in the creation of the curriculum courses and their ordering

Nomenclature

For the purposes of this paper and to better understand our approach, it is necessary to define a basic nomenclature.

Desired Result: Something that the student will be able to do as a result of studying the proposed curriculum. This concept is directly based on Backwards Design (Wiggins & McTighe, 2005)

Topic: A relatively small unit of knowledge that the student will learn as part of the proposed curriculum. This is usually something that can be learned in a relatively small period, e.g., 1-2 weeks in a regular course with 2-4 credits, i.e., 2 to 4 hour of classroom work plus 4 to 8 hours of out-of-classroom work (see definition of credit below).

Credit: In our university 1 credit per semester is equivalent to 1 hour of classroom work per week, plus 2 hours of out-of-classroom work. A semester has 16 weeks.

Knowledge Area: A set of cohesive topics that form a well-known sub-discipline, e.g., Artificial Intelligence, Software Engineering, etc. A curriculum usually addresses one or more knowledge areas.

Course: A set of topics that the student will learn, usually during a semester.

Prerequisite: A relation between two courses or two topics that indicates the order in which courses/topics should be taught to the student. A prerequisite can also connect a topic and a desired result. In this case, it means that the student must learn that topic in order to achieve the desired result.
Course-topic association: A relation between a course and a topic that indicates that said topic is taught in that course, i.e., it is part of the course's syllabus.

GRAPH-BASED APPROACH FOR CURRICULUM DESIGN

This paper proposes the use of graphs to represent curriculum information and verify that the curriculum satisfies certain properties. Figure 1 shows the key components of the approach, and the information flows between them. The curriculum design process transitions from a current state to a desired state. The current state is the curriculum currently being taught at a university. Using this information, the process specifies the *desired results* of the new program. To achieve these results, the process also defines the *desired body of disciplinary knowledge* for the new program, i.e, the set of topics that every student should learn in the program. All of the above information is utilized to create the *desired curriculum*. The entire process is supported by a knowledge base in the form of a graph, which provides a structured way to store all of the information and to extract
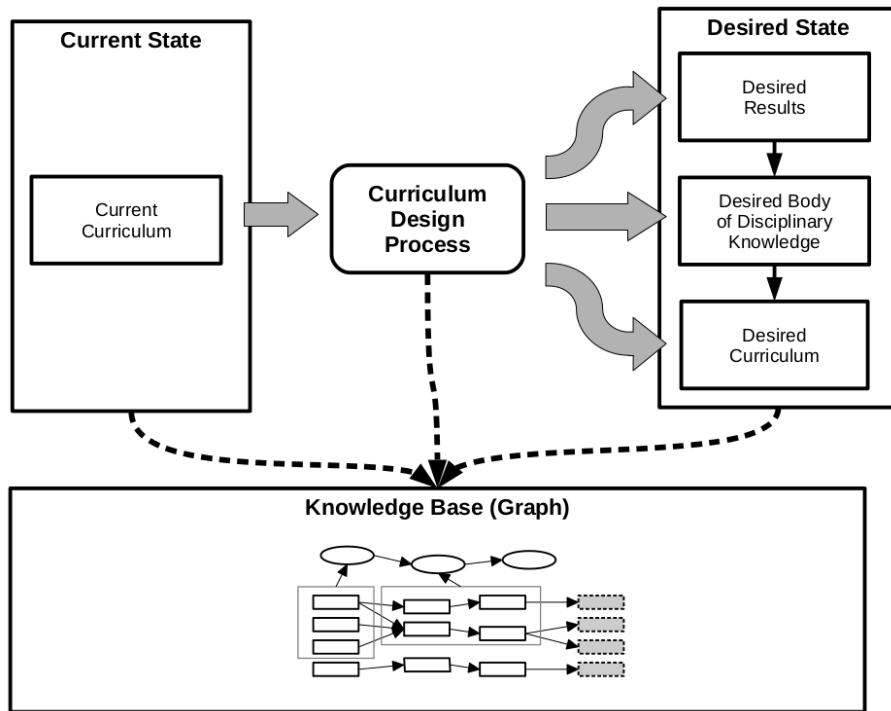
indicators to make decisions.

Figure 1: Overview of the Approach

The proposed approach relies on a directed graph to represent all of the above concepts. The graph represents desired results, courses, and topics as nodes, while prerequisite and course-topic associations are represented as edges. Figure 2 is an example of a curriculum graph. Courses are represented as ovals, topics are represented as rectangles, and desired results are represented as dashed rectangles. The course **Discrete Math** is prerequisite of **Data Structures** (the relation is depicted as a continuous arrow). The topics **Logic** and **Set theory** are part of the syllabus of the course **Discrete Math** (connected with dashed arrows). **Logic** and **Set Theory** are prerequisites of the desired result **Understand the basic concepts of discrete mathematics**.
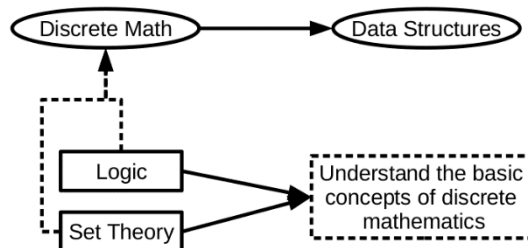

Figure 2: Example Graph

Formally, the knowledge base graph is defined as a tuple $G = (R, T, C, P, A, Q)$, where

- R is the set of desired result nodes

- T is the set of topic nodes

- C is the set of course nodes

- $P \subseteq (T \times (R \cup T)) \cup (C \times C)$ is the set of prerequisite edges

- $A \subseteq C \times T$ is the set of course-topic association edges

- $Q \subseteq C \times C$ is the set of corequisite edges

Curriculum Design Process

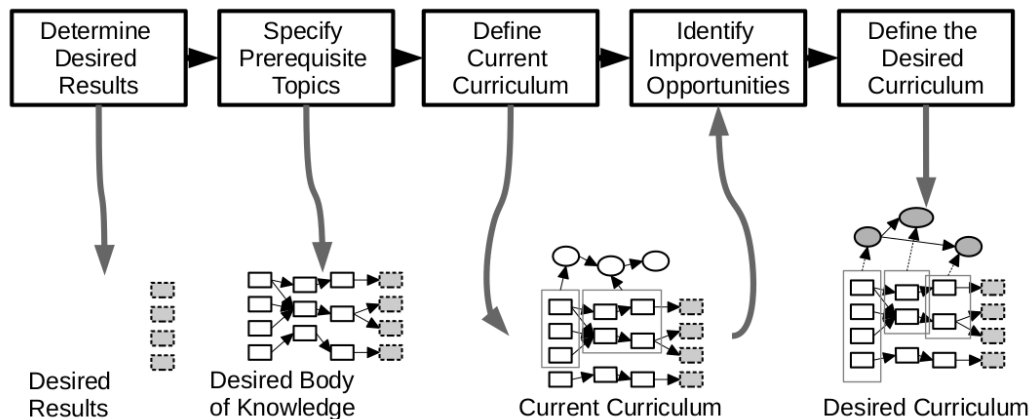Figure 3 details the proposed process. The following sections explain each stage in turn.

Figure 3: Proposed Process

Determine Desired Results

Similarly to Backwards Design Wiggins and McTighe (2005), the first stage is to determine the desired results the student will achieve after studying the courses in the curriculum. Desired results are written as short sentences that include the bloom level of attainment (Anderson et al., 2001) and the high-level subject of such result. For instance, the desired result **Understand the basic concepts of discrete mathematics** utilizes the verb *understand* to denote level 2 of attainment in the subject *discrete mathematics*. Each desired result is incorporated into the graph as nodes.

Specify Prerequisite Topics

The previous phase determines what the student should become at the end of his/her studies. The next step is to define all of the topics that the student should know at the end of the program. Each topic is specified as a node in the graph and their prerequisite relations are specified as edges. Some topics may also be prerequisites of desired results, which indicate that they are required to achieve those results.

Define the Current State of the Curriculum

At this point, the graph represents the desired *body of knowledge* that the student should learn and the goals of that are satisfied by learning that knowledge. It is necessary to understand the relation between the current curriculum and this body of knowledge. This stage adds to the graph the courses in the current curriculum, their prerequisites, and the connection to the topics that are part of their syllabi.

Identify Improvement Opportunities

The above data can be processed to find information of interest to improve the current curriculum. The results are the following indicators:

Curriculum Coverage (CC): This is the percentage of topics that are assigned to at least one course in the curriculum. It is recommended to also calculate this indicator aggregated by knowledge areas to have sufficiently detailed information about coverage. With this information, curriculum designers may decide to create new courses to cover unassigned topics, expand existing course syllabi, remove courses with unwanted topics, etc.

Course Interdependence (CI): This is a number that indicates the consistency between prerequisites of the topics belonging to courses. Given a graph $G = (R, T, C, P, A)$ and course nodes $a, b \in C$, course interdependence CI is calculated as follows:

$$CI(a, b) = \frac{dep(a, b)}{dep(a, b) + dep(b, a)}$$

Where $dep(a, b)$ is the amount of prerequisite dependencies between topics assigned to a and b.

$$dep(a, b) = |\{(t_a, t_b) \in P : (a, t_a) \in A \land (b, t_b) \in A\}|$$

A value of $CI(a, b)$ close to 1 means that most prerequisite relations are from topics in a course a to topics in course b, while a value close to 0.5 means that there is a similar amount of prerequisite relations from a to b and from b to a.

The CI indicator can be interpreted in two ways. First, if $CI(a, b)$ is close or equal to one, it may be interpreted as a being a clear prerequisite of b and this should be contrasted against the explicit course prerequisite relations in the graph, i.e., $a, b P.$ If such relation does not exist, a potential discussion among the curriculum designers would be to decide whether or not to denote a as explicit prerequisite of b.

Another way to interpret CI is when it has a value close to 0.5, which means that may be a strong mutual dependency between both courses. Curriculum designers may decide whether to combine both courses into a bigger one, to define a corequisite relation between them or to redistribute topics between courses to reduce the mutual dependency.

Define the Desired Curriculum

A new curriculum is designed that should address the improvement opportunities identified in the previous stage (among other goals outside the scope of this paper). In practice, this means to create, eliminate or modify existing courses, and assign the topics to be taught in each of them. This new curriculum can be analyzed similarly as in the previous phase, to verify that the new curriculum has

no inconsistencies.

At this point, curriculum designers can utilize the graph to automatically generate syllabi drafts.

These syllabi are constructed with two pieces of information:

- **Course-topic associations** to determine syllabi items.

- **Topic prerequisite relations** to topologically sort those topics and provide a recommended sequence to teach those topics in a course.

CASE STUDY

The proposed approach has been applied to the curriculum redesign of the Computing program at our university. The knowledge base graph includes 150 desired results (nodes surrounded with a green circle), 1232 topics and 2295 prerequisite edges. The current curriculum includes 61 courses, of which 42 are required courses and 19 are elective courses.

The analysis of the graph indicated curriculum coverage of 58.6% by required courses and 25.7% by elective courses with 15.7% of the topics not addressed by any course. The course interdependence analysis yielded 103 pairs of courses with a Course Interdependence (CI) of less than 1. After further analysis, 19 of them were deemed to require further examination and were distributed among teacher teams to determine potential improvement actions. Among the pairs of courses with $CI = 1$, seven of them were also assigned to teacher teams for examination, since they did not correspond with existing prerequisites.

The teams are currently designing the new curriculum, having at their disposal the following information: Curriculum coverage, decomposed by knowledge areas, course syllabi expressed in terms of topic nodes assigned to courses, interdependences between the 19 + 7 pairs of courses identified previously, and a searchable spreadsheet that comprises all of the information in the graph. We expect to apply a similar analysis to the new curriculum to further verify its consistency.

DISCUSSION

Overall, the approach provided useful information to understand the state of the current curriculum, and to identify potential improvements.

The key element of this approach is the prerequisite relation between topics and courses. This may be particularly useful for programs with several, strongly interrelated topics. For disciplines with less coupled, more independent topics, the course interdependence indicator (CI) may not be useful, although the curriculum coverage (CC) can still be useful.

The most demanding parts of the approach are the identification of the prerequisite topics. The team required approximately 4 months, 2 hours per week, to complete this stage. In our experience, this stage should be approached with caution, since it may generate a degree of rejection from the teachers. However, future curricular reflections may reuse the same graph with relatively small changes, thus reducing further efforts.

The current approach does not explicitly address other curriculum elements, such as assessments, scheduling, or resource assignment. These aspects are part of our ongoing work.

RELATED WORK

There are several attempts to use graphs to model curricula. Kabicher and Motschnig-Pitrik (2009) created a collaborative wiki space that utilizes graphs to store curricular information. Gestwicki (2008) and Zucker (2009) developed curriculum visualization applications that represent courses as vertices and prerequisites and corequisites as edges.

The work of Auvinen, Paavola, and Hartikainen (2014) has some similarities to ours. They use graphs to model both the courses, learning outcomes and their prerequisites and utilize this information to provide custom learning plans to students (suggested sequence of courses to take). Svetlik et al. (2017) has a similar goal but utilizes artificial intelligence techniques to automatically generate a curriculum graph. Both approaches only model an existing curriculum and not the desired body of knowledge, thus their approach cannot be directly used to verify the consistency of a curriculum. Similarly, Lie, Brennan, and Nygren (2018) use graphs to model courses, learning outcomes, assessments, and stakeholders. In contrast, our approach focuses on finer-grained topics, which facilitates interdependency analysis.

Other related applications (Gupta, Ludäscher & Moore, 2002; Ugljanin & Kajan, 2012) utilize ontologies to represent curriculum information. Their aim is to compare different curricula to find similarities. In contrast, our work is focused on curriculum design.

Lightfoot (2014) explores different graph metrics, such as in-degree, out-degree, centrality, clustering coefficients, to extract information of course graphs. This work complements our approach since it provides additional ways to analyze a desired curriculum. Further work is necessary to explore the usefulness of those same metrics in our graph, which provides much more detailed information about the components of those courses. Willcox and Huang (2017) utilize graphs to model courses and CDIO skills. As such it is also a useful complement to our work, which in contrast focuses on disciplinary topics.

CONCLUSIONS AND FUTURE WORK

This paper proposes an approach to curriculum design that utilizes graphs to specify a topic, courses, desired results, and their inter-dependencies. This paper also describes the experience of applying this approach in the curriculum design of a Computing program. These graphs provided useful information to understand the state of the previous curriculum, identify improvement opportunities, define the new curriculum, verify its course prerequisites, and adequately define course syllabi.

Although this approach requires an important amount of upfront work, it provides more precise means to support the curriculum design decisions and to verify any proposed curricula.

Future work is to improve some aspects in the current approach: to better tools to create the graph, capture more information about the association between topics and their courses and evaluate new graph-based metrics. In addition, we are currently applying an improved version of the approach to the design of the Master in Cybersecurity program that is being currently developed at the University.

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EFFECT OF FIRST-YEAR SERVICE-LEARNING PROJECTS IN CDIO SKILLS AND MOTIVATION

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ABSTRACT

The goal of this paper is to assess the effect that the exposure to a service learning project carried out during the first-year Civil Engineering introductory course had on students' academic motivation and personal, interpersonal and professional CDIO skills in a one-, three- and five-semester timeframe. The effect of the service-learning (S-L) project on students' CDIO skills was measured with an instrument built by the authors (*Effect of Service-Learning on CDIO Skills - ESLCS*) and the academic motivation was measured using the Academic Motivation Scale (AMS). Both instruments were applied to four cohorts (2015, 2016, 2017 & 2018), during the second semester of 2018. Among some of the results, a very strong correlation was found between the perception that students had on the effect that the S-L project had on their CDIO skills, their intrinsic motivation and their identified regulation.

KEYWORDS

Active learning, Service learning, Academic Motivation, CDIO skills, Introduction to Engineering. Standards: 4, 7, 8 and 11

INTRODUCTION

In the year 2011 the UCSC School of Engineering redesigned its five engineering programs using a CDIO-based approach (Crawley, Malmqvist, Ostlund & Brodeur, 2007), being Civil Engineering one of them. As a result, the Civil Engineering introductory course was redesigned according to CDIO Standard 4 and the course's learning outcomes were changed based on the CDIO Syllabus (Crawley, Malmqvist, Lucas & Brodeur, 2011). With eight hours a week, the goal was to properly introduce students to their chosen field of study, to familiarize them with the role of the engineer in today's society and to develop personal and interpersonal skills (Loyer et al., 2012). Students teamed up to work on designing and implementing simple well-structured projects. In spite of the positive results, as part of a continuous improvement process, in 2015 the course was re-structured by a multidisciplinary team. A service-learning methodology was adopted in order to broaden the scope and

impact of the project by placing students in real engineering situations, where they must conceive, design and implement solutions for the community partner's needs. (Loyer et al., 2016). Also, S-L helps students incorporate UCSC's core values, such as ethics, which is consistent with CDIO skill 2.5.1 (ethics, integrity and social responsibility).

Once the new introductory course was implemented, teachers' perceptions were that students were much more motivated and committed than previous years, resulting in better grades and a more positive attitude. This perception was shared by the faculty that had the same group of students the following semester, who even remarked upon their differences with students from other engineering programs (Loyer et al., 2016). This same study reported high proficiency levels of students' CDIO skills, which was consistent with other studies. But most studies don't properly assess the effect that S-L has on students' motivation.

In an effort to understand the effect that being exposed to a service learning project in the first year has on students' CDIO skills and academic motivation, this study will address the following questions: What are students' perceptions on the effect that the service learning project experience had on their CDIO skills after one, three and five semesters? Is there a relation between students' perceptions of the impact of the service-learning project on their CDIO skills and their academic motivation?

FRAMEWORK

Service-Learning

There are several definitions of Service-learning in the literature. Furco (1996) states that service-learning is a teaching method that combines academic instruction and community service, focusing on critical thinking, reflection and civil responsibility. Service-learning programs are distinguished from other approaches to experiential education by their intention to equally benefit the provider and the recipient of the service as well as to ensure equal focus on both the service being provided and the learning that is occurring.

Bringle and Hatcher (1996) view service-learning as a credit-bearing, educational experience in which students participate in organized service activities that meet community needs and reflect upon their service activities so as to better understand their course material, gain appreciation for their discipline and develop their civil responsibility. Also, service-learning has been shown to produce positive personal, social, and learning outcomes, such as improvements on personal identity, spiritual growth, moral development, commitment to service, and analytic and critical thinking skills (Eyler, Giles, Stenson & Gray, 2001).

Several studies have concluded that the implementation of service-learning in Engineering courses enhances generic skills such as communication, leadership and team-working, as well as specific engineering skills and learning outcomes (Cannon, Deb, Strawderman & Heiselt, 2016; Tsang Van Haneghan, Johnson, Newman, & Van Eck, 2001; Siniawski, Luca, Saez, & Pal, 2016; Wang & Calvano, 2018; Sevier, Chyung, Callahan & Schrader, 2012; Eyler et al., 2001), while increasing students' awareness of the diverse nature of their profession (Hernandez & Ritchie, 2015). However, none of these studies assess the effect that S-L has on students' academic motivation.

Motivation

Motivation is an internal process determined by biological, cultural, social, learning and cognitive aspects that impel a subject to initiate, develop or end a behavior (Jeno, Adachi, Grytnes, Vandvik & Deci, 2018). The importance of this construct lies mainly in its explanatory and predictive power of human behavior (Guay, Morin, Litalien, Valois & Vallerand, 2015).

The study of motivation has been approached from different theoretical paradigms, among which the self-determination theory (SDT) stands out (Ryan & Deci, 2000). According to SDT, motivation is not a global, undifferentiated concept. Rather, motivation is defined as a multidimensional concept that varies in terms of quality. SDT proposes different types of motivation that reflect different levels of self-determination (Ryan & Deci, 2000). SDT postulates that motivation is placed along a continuum where behavior can be amotivated, extrinsically motivated or intrinsically motivated, that is, going from the lack of control to self-determination (Ryan & Deci, 2000).

Amotivation is a state of lack of motivation that implies a perception of incompetence and inability to act, absence of intention or control to perform a certain behaviour, little or no valuation of the task, feelings of helplessness and lack of expectations and beliefs to produce or achieve the desired result. Subjects do not perceive that there is a relationship between their actions and their results (Guay, Morin, Litalien, Valois & Vallerand, 2015).

Extrinsic motivation is defined as a multidimensional construct. The four types of external motivation ordered from lowest to highest level of self-determination are: (1) external regulation, which refers to the performance of an activity in order to obtain rewards or avoid punishments; (2) introjected regulation, where behavior is partly controlled by the environment and the individual carries out his conduct to avoid guilt or anxiety or to enhance his ego or pride; (3) identified regulation, where the subject attributes a personal value to his/her behavior because he/she believes it is important and the activity is perceived as his/her own choice and, (4) integrated regulation, which occurs when the consequence of the behavior is congruent with personal values and needs (Deci, Eghrari, Patrick & Leone, 1994, Ryan and Deci, 2000).

Intrinsic motivation (IM) has to do with the development of an activity for the inherent satisfaction derived from it. It does not require external reinforcements and represents a natural tendency of human nature to seek novelty and challenge, expand and exercise his/her own abilities and explore and learn (Ryan and Deci, 2000). Intrinsic motivation is also considered as multidimensional. The three types of intrinsic motivation are: (1) IM to knowledge, which is related to concepts such as curiosity or motivation to learn; (2) IM to achievement, defined as the commitment in an activity for the pleasure and satisfaction experienced when trying to overcome obstacles or reach a new level; and (3) IM to stimulating experiences, which takes place when someone engages in an activity to have fun or to experience stimulating and positive sensations derived from their own dedication to the activity (Gagné & Deci, 2005).

For engineering students, motivation decreases during the first years in both men and women and motivation levels predict different academic performance results (Jones, Paretti, Hein & Knott, 2010). Also, engineering students exhibit a significant relationship between motivation and learning outcomes, adequate performance in the classroom and efficiently achieving academic performance (Silva, Villa-Navas & Curiel-Gómez, 2018).

Introduction to Civil Engineering course

Introduction to Civil Engineering is a freshman course that has three main goals: a) properly introduce students to their chosen fields of study and familiarize them with the role of the engineer in today's society b) emphasize CDIO standard 1, in terms of having them be aware that engineers conceive, design, implement and operate; c) develop specific personal, interpersonal and engineering skills. The courses' learning outcomes can be grouped in three dimensions: Engineering Role (ER), Oral and Written Communication Skills (OWC) and Development of Personal and Interpersonal Skills (DPIS), which are integrated through a Service Learning Project (SLP), as seen in figure 2 (Loyer et al., 2016).
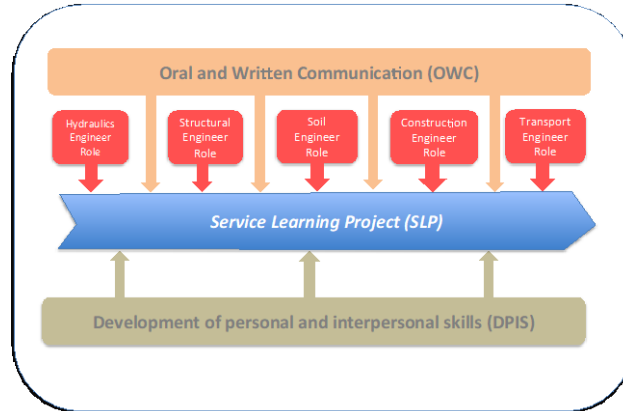

Figure 1. Introduction to Civil Engineering Course Structure (Loyer et al., 2016)

METHODS

Design

A descriptive-correlational, cross-sectional design was used to study students' perception of the impact that exposure to a service-learning project has on their CDIO skills and academic motivation, and the relationship between these variables.

Participants

A total of 123 Civil Engineering students selected through non-probabilistic accessibility sampling were surveyed from a university in the Province of Concepción in Chile. The questionnaires were applied during the second semester of 2018. 22.05% of the sample were first year students, 37.03% second year, 15.13% third year, 19.60% fourth year and 6.20% fifth year. The average age of subjects was 21.18 (SD = 2.78), with a minimum of 17 and a maximum of 36. With regard to gender, 50.79% were men and 48.92% were women.

Instruments

Effect of Service-Learning on CDIO Skills Scale (ESLCS)

The *ESLCS* instrument was built by the authors, based on the CDIO syllabus (Crawley et al., 2011). It is a unifactorial scale that aims to measure students' perception of their level of proficiency in CDIO skills after being exposed to a service-learning project as freshmen. It is a Likert scale self-report instrument with response options between 1 to 5, where 1 is not

applicable, 2 is strongly disagree, and 5 is very much in agreement. It has a total of 21 items regarding CDIO skills (Crawley et al., 2011), that are part of the learning outcomes of the course. Cognitive interviews were conducted to assess students' comprehension of the items. The trustworthiness of the instrument is high (see table 1). The conceiving, designing and implementing skills were assessed by the instructors using a project rubric.

Academic Motivation Scale (AMS)

Students' academic motivation was assessed using the Academic Motivation Scale (Núñez, Martín-Albo, Navarro & Suárez, 2010). This scale consists of 28 items, distributed in seven subscales: amotivation (AMO), external regulation (REGEX), introjected regulation (REGIN), identified regulation (RGID), intrinsic motivation to knowledge (MICON), intrinsic motivation to accomplishment (MILO) and intrinsic motivation to stimulating experiences (MIEXP). Each subscale has four items that refer to the reasons why students go to college. The answers were scored using a seven-point Likert scale, from (1) does not correspond at all, until (7) corresponds exactly, with a mid score of (4) being corresponds moderately. This scale has shown adequate psychometric properties in previous studies with a reliability between α=0.73 and α=0.88 (Núñez et al., 2010). In this study it also had a high reliability in all 7 sub-scales, fluctuating between α=0.73 and α=0.87 (See table 1). Prior to the application, cognitive interviews were conducted to assess students' comprehension of the items.

Table 1. Reliability of the dimensions of the ESLCS Scale and the AMS

Dimension	Alpha	Omega
ESLCS	*0.93*	*0.95*
Academic Motivation Scale:		
AMO	0.87	0.91
REGEX	0.84	0.89
REGINT	0.79	0.83
REGID	0.73	0.78
MICON	0.85	0.87
MILO	0.83	0.85
MIEXP	0.78	0.84

The Cronbach alpha coefficient (α) is used to measure the scale's reliability, but it has several limitations: it is affected by the number of items, the number of response alternatives and the proportion of the variance of the test. Also, it only considers continuous variables, which is not the case with social science variables such as motivation and is influenced by the sampling error. The omega coefficient (ω), unlike the alpha coefficient, works with the factorial loads, which are the weighted sum of the standardized variables, a transformation that makes the calculations more stable and reflects the true level of reliability. It does not depend on the number of items and it's considered an adequate measure of reliability if the principle of such equivalence is not met, which can be violated if the coefficients of the items that make up a factorial solution matrix have very different values.

RESULTS

The results of the application of the Effect of Service-Learning on CDIO Skills Scale are shown in Figure 2. Even though all cohorts scored high on all skills, students from 2018 reported the highest proficiency levels in CDIO skills obtained because of the S-L project.
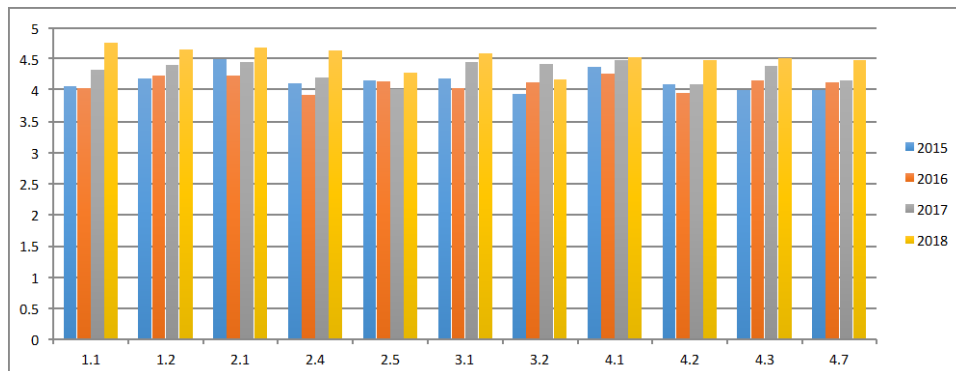
Figure 2. Average Results of the Effect of Service Learning on CDIO Skills (ESLCS) Scale

In terms of academic motivation, students reported higher levels of intrinsic motivation to knowledge (6.06), identified motivation (6.01), and intrinsic motivation to accomplishment (5.58), as shown in figure 3 and table 2.
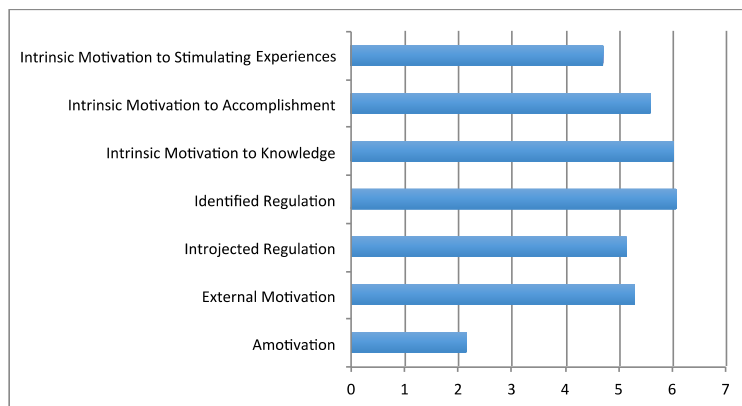

Figure 3. Average Results of the ESLCS Scale for all cohorts

Table 2. Descriptive variables for all cohorts

Variable	n	Mean	Sd	Skew	Kurtosis	Shapiro .wilk	Alpha
ESLCS	120	4.23	0.64	-1.46	4.17	6E-08	0.93
AMO	123	2.13	1.67	1.59	1.4	3E-14	0.86
REGEX	123	5.28	1.4	-0.76	0.26	9E-06	0.83
REGINTRO	123	5.13	1.46	-0.69	-0.33	1E-05	0.78
REGID	123	6.06	0.99	-1.11	0.26	5E-10	0.71
MICON	123	6.01	1.03	-1.11	0.4	1E-09	0.85
MILO	123	5.58	1.27	-0.92	0.47	4E-07	0.82
MIEXP	123	4.7	1.42	-0.55	-0.13	0.0016	0.78

Note: ESLCS: CDIO Skills Scale; AMO: Amotivation; REGEX: External Regulation; REGINTRO: Introjected Regulation; REGID: Identified Regulation; MICON: Intrinsic Motivation to Knowledge; MILO: Intrinsic Motivation to Accomplishment; MIEXP: Intrinsic Motivation to Stimulating Experiences

In terms of gender, there was no significant difference in any of the dimensions (Table 3)

Table 3. Comparison of results according to gender

Variable	Mean F	DE F	Mean M	DE M	Test statistic	p
ESLCS	4.33	0.79	4.22	0.57	U=1640.50	0.09
AMO	2.25	1.75	2.08	1.65	U=1699.50	0.35
REGEX	5.46	1.12	5.21	1.49	U=1625.50	0.63
REGINTRO	5.41	1.58	5.02	1.4	U=1857.50	0.07
REGID	6.11	0.98	6.04	1	U=1612.00	0.69
MICON	6.09	1.01	5.99	1.03	U=1634.00	0.6
MILO	5.86	1.19	5.47	1.29	U=1822.50	0.1
MIEXP	4.79	1.46	4.66	1.4	U=1619.00	0.66

* p < .05

As shown in table 4, no significant difference was found in any of the motivation factors between cohorts. The same cannot be said when comparing the effect that the S-L project had on students' CDIO skills between cohorts. This suggests that students were equally motivated, regardless of how long ago they enrolled in the university but those who enrolled more recently perceived a greater effect of the S-L project on their own CDIO skills.

Table 4. Results for each cohort

Dimen.	2013(sd)	2014(sd)	2015(sd)	2016(sd)	2017(sd)	2018(sd)	Test Statistic ($X^2(6)=$)	p
ESLCS	3.44(1.27)	4.04(0.63)	4.13(0.50)	4.02(0.68)	4.28(0.49)	4.53(0.42)	20.09	0.00*
AMO	1.33(0.44)	1.50(1.00)	1.63(0.91)	1.68(1.00)	2.32(2.01)	2.74(1.97)	9.98	0.12
REGEX	5.54(0.93)	4.98(1.42)	5.13(1.65)	5.35(1.51)	5.04(1.29)	5.50(1.41)	3.44	0.75
REGIN	4.83(1.48)	5.22(1.00)	5.34(1.29)	5.05(1.63)	4.82(1.70)	5.37(1.31)	3.4	0.76
REGID	6.08(0.79)	6.31(1.10)	6.09(0.98)	5.82(1.19)	6.13(0.89)	6.15(0.95)	3.52	0.74
MICON	5.67(1.04)	6.22(1.29)	5.82(1.38)	5.86(1.13)	5.91(1.06)	6.31(0.63)	5.32	0.5
MILO	5.08(1.48)	6.19(0.78)	5.61(1.41)	5.13(1.55)	5.56(1.32)	5.80(1.05)	5.86	0.44
MIEXP	4.44(0.46)	4.91(1.13)	5.11(1.17)	4.56(1.50)	4.96(1.23)	4.49(1.68)	5.85	0.4

* p < .05

As seen in table 5, a very significant correlation was found between the effect of the S-L project on CDIO skills and all the intrinsic motivation factors, and with the identified regulation factor, which is the dimension of external motivation with the highest level of self-determination.

Table 5. Correlation between the AMS Dimensions and ESLCS

Dimensions	ING	AMO	REGEX	REGIN	REGID	MICON	MILO	MIEXP
ESLCS	–	0.11	0.08	0.24*	0.39**	0.45**	0.40**	0.29**
AMO		–	0.29**	0.22*	–0.21*	–0.02	0.06	–0.11
REGEX			–	0.50**	0.35**	0.20*	0.17	0.05
REGIN				–	0.46**	0.53**	0.57**	0.42**
REGID					–	0.58**	0.58**	0.63**
MICON						–	0.69**	0.51**
MILO							–	0.57**
MIEXP								–

* p < .05; ** p < .01

CONCLUSIONS

This study focused on analyzing the effect that the service learning project experience had on students' CDIO skills and academic motivation for different cohorts and if there was a relation between students' perceptions of the impact of the service-learning project on their CDIO skills and their academic motivation.

All cohorts scored high on all of the CDIO skills obtained because of the S-L project, but the 2018 cohort scored the highest. These results could mean that students perceive that the service-learning project has a very strong effect on their CDIO skills and students who developed the S-L project more recently perceive this effect as even greater.

In terms of academic motivation, students scored higher in intrinsic motivation dimensions. No significant difference was found of the academic motivation between the four cohorts analyzed, which suggests that students were equally motivated, regardless of how long ago they enrolled in the university.

Finally, there is a very strong correlation between CDIO skills developed through the S-L project and all of the intrinsic motivation dimensions, as well as with the identified regulation, which is an external motivation dimension that's associated with higher levels of self-determination.

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EVALUATION OF ALTERNATIVES TO IMPLEMENT A CDIO PROGRAM USING GMA

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ABSTRACT

The implementation of a CDIO program depends on the context where it is located as well as the institutional mission and program goals. Additionally, it is essential to take into account relevant administrative issues and strategical aspects for an effective adoption of the CDIO standards. In order to select the most appropriate strategies for the implementation of a CDIO program, it is necessary to consider different dimensions that turn this task out a complex problem. Under this consideration, this article applies the general morphological analysis (GMA) for the definition of the implementation strategies for a CDIO program. The results were contextualized to the Electronic Engineering Program at the Universidad del Quindío, Colombia, analyzing four relevant cases: the current state, the desired state, the state with institutional elements, and the state with program elements. The proposed cases can be adapted to other institutions seeking to implement a CDIO program with similar features.

KEYWORDS

CDIO Implementation, Complex Problems, General Morphological Analysis (GMA), Administrative Structure, Standards: 7, 8, 9, 10.

INTRODUCTION

The implementation of a CDIO academic program must consider different elements such as curricular design, pedagogical strategies for the development and evaluation of disciplinary, personal, interpersonal and professional skills, and training of the faculty, among others. Given the importance of the adoption of these academic and administrative elements to achieve the educational needs in a global context, it is imperative to clarify the dynamics between their components, aligned with the missional goals of both the institution and the program.

Starting from an integrated curriculum already designed, it is important to consider the reference points for the insertion of the elements mentioned above, specifically curricular administration, human resources and classroom strategies. Since multiple parameters are involved in this process, which depends on the context, the curricular implementation behaves as a complex or wicked problem, a term coined by Horst Rittel in the 70s (Rittel &

Webber, 1973). This type of problem is recognized because there is no definitive formulation of the problem, differing from the simple or tame problems in which the problem definition is clearly stated from the beginning. Although complex problems may have a feasible solution, it is not necessarily simple to implement. Among the methods for dealing with these problems (Kosow & Gaßner, 2008), General Morphological Analysis (GMA), a method developed by Fritz Zwicky in the 60s, is recognized to be a useful tool (Ritchey, 2011). This method attempts to investigate and to structure the whole set of relationships contained in a multidimensional and non-quantifiable complex problem.

In a CDIO academic program, it is essential to answer the following question: "What is the set of curricular and administrative strategies, systematically organized, to train the students in the skills projected in a curricular plan?". In this sense, the GMA methodology was applied to the curricular proposal of the Electronic Engineering Program at the Universidad del Quindío, Colombia, to identify these strategies under the assumption of different scenarios.

In this paper, based on the CDIO standards 7, 8, 9 and 10, eleven (11) parameters or dimensions for the proposed problem were defined. Then, considering each parameter individually, values that are potential solutions were proposed and selected. This set of values and parameters constitutes a problem space with a total of 4608000 initial solution alternatives. With the application of the GMA methodology, the solution space is reduced by 98.69%. Within the solution space, four (4) scenarios were reviewed: two scenarios contrast the current state and the desired state of the curricular implementation, and the other two scenarios contrast the institutional elements with those of the academic program. As a result, alternative solutions were obtained and evaluated qualitatively from the solutions provided by the analytical tool.

BACKGROUND AND CONTEXT

In this section, a brief description of the GMA methodology is presented, followed by the analysis of the current institutional and administrative context. This analysis provides a framework for the definition of the parameters and values that are used in the GMA methodology.

GMA methodology

One of the main features of a complex problem is that it has several stakeholders with different expectations (Rittel & Webber, 1973). Hence, the identification of the most suitable way to implement a CDIO program is as a complex or wicked problem, since students, faculty, administrators, alumni, industry partners, among others, are seeking out for different goals in the educational process. In this paper, we use the General Morphological Analysis (GMA) to deal with this complex problem. In GMA, we start identifying the set of parameters (or dimensions) that structure a problem, and for each parameter, we define the set of values that are alternative solutions within the context of the given parameter (Ritchey, 2011). Subsequently, alternative solutions that are compatible with the values across different parameters are analyzed by means of the cross-consistency assessment technique, providing a consistent and coherent solution space for the complex problem.

The CDIO Implementation at Universidad del Quindío

To understand the implications of implementing a program in the CDIO initiative, it is important to analyze a particular context, in this case, the Electronic Engineering Program at the Universidad del Quindío, Colombia. In the GMA methodology, these implications establish the problem parameters and their possible solutions. Other programs and institutions may have similar situations. Hence, the following discussion is emphasized not only in the particular issues at our university but also in the ideal case and situations in other institutions.

The University of Quindío joined to the CDIO initiative in 2014, with Electronic Engineering being the pilot program for the implementation. The institution has general guidelines for the curricular design of academic programs, a regulation for faculty hiring and training, faculty evaluation and student evaluation.

With respect to the curricular design, the University has a Curricular Academic Policy that defines the distribution of academic activities, establishes the mandatory courses for all students, and provides flexibility for the programs to define the curricular structure of the professional component. On the total credits for a given program, approximately 80% is defined by each academic program. Likewise, for all engineering programs, a common core has been defined, which establishes certain common courses in mathematics, physics and administration for all engineering students at the university. This policy also defines that the educational framework should be based on competences, which are compatible with the intended learning outcomes (ILOs), as established in the CDIO initiative (Biggs & Tang, 2011; E. Crawley et al., 2007). In some institutions, the curricular design may be less flexible, and the courses are commonly structured in learning objectives rather than ILOs, which are inappropriate for a CDIO-based approach.

Regarding the regulation of the faculty hiring, there are two types of contracts, full-time professors and partial-time professors. The first ones have a dedication 100% of the time to the University. In addition to their teaching activities, these professors have recognition in their weekly schedule to provide students' advisory, and to develop research and outreach activities. On the other hand, partial-time professors are hired on the hour-basis to attend exclusively classroom activities with no recognition for students' advisory, research or outreach activities, as they are usually people working in other institutions or companies. In the Electronic Engineering Program, there are a slightly higher number of full-time professors (62%) than partial-time professors (38%). This hiring model is widespread in all public institutions in Colombia, where most of them are partial-time professors. This model may differ from the context of the majority of higher education institutions in other countries, where a larger number of faculty staff is dedicated exclusively to the academy. On the other hand, not all faculty members are joined exclusively to the program, since some courses such as mathematics and physics are taught by professors from other academic units. These professors are usually no committed with the articulation of the CDIO. This last situation is common in other institutions, where departments on mathematics and physics offer generic courses for a diverse group of students.

Full-time teachers are the only ones who have the right to access the majority of the benefits of the faculty training plan. Similarly, financial resources for training are very limited, so it is not always possible to provide full funding for all teachers in a particular activity. To deal with this situation, our program constituted a weekly two-hour faculty meeting since 2010, where

continuous training workshops are held to implement the CDIO initiative, and relevant issues for the curricular enhancement are also discussed.

In the institutional regulation for faculty evaluation, standardized instruments are applied for all professors without considering specific conditions. For example, a professor who does not research is also evaluated for this condition. Only surveys aimed at students and the director of the program are employed to collect the evaluation evidence. However, no effective feedback mechanisms are provided for the teacher beyond a quantitative value for purposes of ranking and hiring. The usefulness of this faculty evaluation approach has been strongly criticized, and it has been recently under review. In contrast, one of the ideal conditions w.r.t. faculty evaluation for an efficient CDIO implementation is to have varied instruments and based on diagnostics, to provide teacher advisory in his/her pedagogical practices. This ideal model suggests the existence of institutional supporting units.

For the organization of the academic activities, all the academic programs at the University follow the national guidelines, which are structured in academic credits. An academic credit is a measure of the student's time, including class hours, advisory and independent work. Although faculty have academic freedom to organize their work at the classroom level, institutional regulations require that instructional activities are carried out under a competency-based approach, and planned according to academic credits, so that they do not exceed the number of weekly hours defined in the curricular design. Although this approach is common to many nationwide and international institutions, there are regulation gaps regarding the guidelines for development and assessment of personal, interpersonal, and professional skills, as it will be addressed below.

Regarding the evaluation of the students, the current institutional regulation defines that each professor must define a minimum of three (3) assessments along the semester, in a cumulative fashion, and the result of each assessment must be known as a minimum one week after applied. Although this situation is similar in many institutions, this approach is incompatible with CDIO, since monitoring the development of personal, interpersonal and professional skills implies a formative instead of cumulative evaluation along the semester. To carry out a student evaluation compatible with CDIO and the institutional regulations, some professors have used a hybrid model that includes formative evaluation and cumulative evaluation in projects deliverables or particular topics.

METHODOLOGY

As explained in Section 2.1, under the GMA methodology, we start by defining the parameters (or dimensions) and the values (alternative solutions) for each parameter. Since we are particularly interested in the CDIO implementation given a previous curriculum design, this paper is mainly addressed by the classroom strategies, administrative issues, faculty skills, and the faculty relation with the external environment. Hence, the parameters of this complex problem are based on the CDIO standards 7 (Integrated Learning Experiences), 8 (Active Learning), 9 (Enhancement of Faculty Competence), and 10 (Enhancement of Faculty Teaching Competence). Eleven (11) parameters were selected, and their values are shown in Table 1. For each parameter, potential solutions or values were identified. These parameters and values are detailed as follow:

Table 1. Parameters and values of the problem space

A	B	C	D	E	F	G	H	I	J	K
v1	v1	v1	v1	v1	v1	v1	v1	v1	v1	v1
v2	v2	v2	v2	v2	v2	v2	v2	v2	v2	v2
v3	v3	v3	v3	v3	v3	v3	v3	v3	v3	v3
v4	v4	v4	v4	v4	v4	v4		v4	v4	
v5		v5			v5					

A. Mechanisms to implement learning experiences for the simultaneous development of personal, interpersonal, disciplinary and CDIO skills.
  v1. Compulsory assessment at each cohort (semester, year, core) for personal, interpersonal, disciplinary and CDIO skills.
  v2. Freedom of each teacher in their academic space to decide how to implement strategies for skills' development.
  v3. Compulsory evaluation at each course for personal, interpersonal, disciplinary and CDIO skills.
  v4. Specialized academic spaces for training of disciplinary, personal, interpersonal and CDIO skills.
  v5. Co-curricular challenges in which students of different levels and programs interact each other or with external professionals (e.g. contests, hackathons, mentoring, etc.).

B. Management of the relationship with the external environment (industry partners, graduates and stakeholders) for the definition of learning experiences.
  v1. Support on institutional bodies for the search of external problems and their solution with students
  v2. Administrative unit at the program responsible for the identification of interested parties and external problems that may be addressed by students.
  v3. Teachers and researchers in contact with the industry, responsible for problem identification and development of projects with students
  v4. Classroom challenges where students in association with companies identify problems and seek out their solution in a given academic space.

C. Evidence for the implementation of integrated learning experiences.
  v1. Only Syllabus. Course syllabus incorporates projected activities as integrated learning experiences, and it is the only evidence of application.
  v2. Term report. Teacher's report with statistics on the learning experiences conducted in the courses and student projects.
  v3. Survey. Survey applied to the actors of the learning process (students and teachers) on learning experiences integrated to classroom activities, tutoring, etc.
  v4. Compilation of logbooks. Implementation of logbooks for all student activities, signed by the involved actors (students, tutors, stakeholders, etc.).
  v5. Compilation of rubrics. Design and application of rubrics with visible criteria for integration of skills in a given academic space.

D. Guidelines for the application of active learning strategies according to topic cores, functional ILOs, and declarative ILOs.
  v1. Definition of active learning strategies in the syllabus.
  v2. Freedom of each teacher in their academic space.

v3. Definition of active learning strategies by topic core.

v4. List of suggested active learning strategies for each academic space.

E. Evidence for the implementation of active learning strategies.

v1. Only Syllabus. Course syllabus incorporates projected activities as active learning experiences, and it is the only evidence of application.

v2. Term report. Teacher's report with statistics on the active learning experiences conducted in the courses and student projects

v3. Survey. Survey applied to the actors of the learning process (students and teachers) on active learning strategies used in the classroom.

v4. Compilation of logbooks. Implementation of logbooks for all student activities, signed by the involved actors (students, tutors, stakeholders, etc.).

F. Criteria for the definition of the faculty profile (professional and pedagogical skills)

v1. Basic profile in pedagogical and professional skills to hire new faculty members, and desired profile to engage faculty in an enhancement plan.

v2. Definition of two (2) profiles for different faculty members: a) Teacher/researcher; b) Teacher/External collaborator; with minimal pedagogical skills.

v3. Generic profile defined by the Program Council for all faculty members.

v4. Unified profiles based on the skills established for each topic core.

v5. Individual profiles based on the skills stipulated in the course syllabus.

G. Guidelines for the training the faculty members in professional skills

v1. Compulsory linking of the faculty with industry partners (to participate in internships or to develop projects).

v2. Generic training for all faculty members.

v3. Personalized training according to the individual conditions of the faculty members.

v4. Definition of faculty training by areas.

H. Management of the faculty relationship with external stakeholders.

v1. Support on institutional bodies for faculty internships or project collaboration with industry partners.

v2. Administrative unit at the program responsible for the management of faculty internships or project collaboration with industry partners.

v3. Individual efforts. The faculty himself must seek and manage his opportunities for internship or project collaboration with industry partners.

I. Diagnosis of faculty competences in pedagogical skills

v1. Document resulting from the faculty meetings, where teachers share experiences.

v2. Test on pedagogical skills.

v3. Use of institutional instruments for the diagnosis of pedagogical skills.

v4. Survey aimed teachers on pedagogical competences.

J. Guidelines for the training the faculty members in pedagogical skills

v1. Compulsory participation in a minimum number of pedagogical events per year.

v2. Trainings by groups of teachers according to diagnosis.

v3. Individual training based on self-diagnosis.

v4. Generic training for all teachers.

K. Management of the faculty relationship with academic networks
    v1. Support in agreements with academic networks for academic mobility and cooperation.
    v2. Administrative unit at the program responsible for the publication and targeting of alternatives for participation in academic networks.
    v3. Individual efforts. The teacher seeks and participates in academic networks, also propose the creation of new networks.

According to the GMA methodology, the convenience (or compatibility) of each value in a given parameter was analyzed with all the remaining parameter values, obtaining a consistence matrix that is used for the analysis presented in the next section. This matrix was introduced in a software tool, developed by the authors, to visualize the values that could exist under the criterion of compatibility and convenience. Likewise, this tool allows selecting exclusively a value from each parameter of interest and contrasting it with the compatible values of the remaining parameters, according to the GMA methodology.

RESULTS

The problem space analyzed in this paper is composed of eleven (11) parameters, whose values were described in the previous section. The original problem space provides a total of 4608000 solution alternatives before applying the GMA. With the application of the analysis, the solution space is reduced by 98.69% (60455 solution alternatives).

In order to reduce the complexity of the problem, two subspaces were also proposed. The first sub-space considers five (5) parameters (A through E) related to the training strategies (standards 7-8) and the second subspace considers six (6) parameters (F through K) associated with the qualification of the human resource (standards 9-10). In the first subspace, 322 morphotypes were found, while in the second subspace, 476, for a total of 153272 solution alternatives. This would represent an increase of the solution space of 153.53%. As a result, it is convenient to analyze the problem with a single space of 11 parameters.

Starting from the solution space with eleven (11) parameters, we decided to analyze four (4) scenarios, which are the most relevant according to the policies and guidelines for academic programs in Colombia. These four (4) scenarios correspond to the current state and desired aspects of the curricular implementation, as well as institutional elements and those of the academic program. Alternative solutions were obtained based on these scenarios, and they were evaluated qualitatively by the analysis tool. The proposed scenarios respond to different institutional contexts, which would allow the application of these results to other academic programs. For each scenario, different solutions were analyzed by selecting some parameters and values, according to the situation that defines it, and the tool indicates the path of compatible values. To perform the analysis, a hierarchical analysis was established in the parameter order A, D, K, H, B, F, I, C, E, G, and J. In the following scenario descriptions, the selected parameters and values are written in the following way: *Parameter-Value*, e.g. A-v2.

Scenario 1: Current State. This scenario obeys to the current situations of the academic program and the institution, described in Section 2.2. This scenario is based on the

professor's freedom for planning activities, integration of the CDIO initiative in his courses, and his absolute responsibility in the insertion on academic networks. In this scenario, the definition of faculty profiles is also established as the responsibility of the Program Council of the program.

- *Selected values:* A-v2; D-v2; K-v3; H-v3; B-v1 (restricted by the tool); F-v3;
- *Result:* It was identified that supporting units or institutional offices are necessary for the faculty enhancement on professional skills and the development of activities with external stakeholders. Likewise, the documents (term reports or surveys), carried out in the faculty meetings at the end of each academic term, are the preferred tools for diagnosing teachers' competences and monitoring the implementation processes. In this scenario, it is also concluded that teachers are responsible for seeking mechanisms to develop their professional skills.

Scenario 2: Desired. It arises from ideal conditions, which would be expected to have the institution and the academic program. This scenario proposes the presence of specialized academic spaces for training the skills projected in the graduate profiles. With respect to the remaining academic spaces, the active learning strategies must be clearly specified in their respective syllabus. It also considers the existence of a committee or administrative unit in the academic program for the interaction with external stakeholders and academic networks. Besides, this scenario takes into account the definition of a basic faculty profile in pedagogical and professional skills for new hiring or engagement in a faculty training plan.

- *Selected values:* A-v4; D. v1; K. v2; H. v2; B. v2; F. v1; I. v1
- *Result:* In this scenario, the mechanisms for collecting evidence are flexible, excluding the strategy based exclusively on the syllabus. In terms of faculty training, there is also flexibility, but the alternative of a specialized training by areas is not feasible.

Scenario 3: Institutional line. In this scenario, values are selected based on the mechanisms and guidelines currently supported by the institution. This scenario is characterized by the dependence on departments or institutional offices for the realization of agreements, training, access to academic networks, etc. At the classroom level, there is a clear definition of active learning strategies in the syllabus for each academic space, as well as the mandatory application of assessment tools in each course for the monitoring of skills.

- *Selected values:* A-v3; D-v1; K-v1; H-v1; B-v1; F-v3; I-v3
- *Result:* In this scenario, the mechanism for collecting evidences of the implementation of integrated learning and active learning experiences are reduced to the compilation of logbooks. For the specific case of integrated learning experiences, the option of compilation of rubrics is also valid. Among the guidelines for faculty training, the availability of generic training and personalized training stands out.
  If the selection of the value for the parameter A (integrated learning experiences) is changed to v4 (co-curricular challenges), the valid mechanism for collecting evidence is only the compilation of rubrics.

Scenario 4: Program Line. The values selected for this scenario are based on the mechanisms and guidelines currently supported in the program. This scenario is characterized by the existence of an administrative unit in the academic program for the relationship with the external stakeholders. At the classroom level, there is a clear definition of active learning strategies in the syllabus for each academic space, as well as the mandatory application of assessment tools at each course for the monitoring of skills.

- *Selected values:* A-v3; D-v1; K-v2; H-v2; B-v2; F-v3; I-v1

- *Result:* The mechanisms for collecting evidence to monitor the implementation of integrated learning and active learning experiences are flexible, allowing the use of term reports, surveys or compilation of logbooks or rubrics. The alternative based exclusively on the syllabus is not feasible. The faculty training can be generic or personalized. If the selection of the value for the parameter A (integrated learning experiences) is changed to v4 (co-curricular challenges), the allowed mechanisms for collecting evidence are the survey and the compilation of logbooks.

As a general observation for all scenarios, the selection of the freedom of each teacher in their academic space for the parameter D (guidelines for the application of active learning strategies) reduces significantly the solution space. However, this selection is inconvenient because it constrains the available values in the remaining parameters, and it is incompatible with the integrated curriculum, which is an essential element in the CDIO approach.

In the current context, the professor has the freedom to implement strategies for active learning (parameter D), and assessment of personal, interpersonal and professional skills (parameter A). Besides, in the current context, the relationship with external stakeholders and academic networks relies exclusively on individual efforts of the faculty (parameters B, H an K). In contrast, the GMA analysis suggests that an efficient implementation of the CDIO initiative involves the adoption of clear strategies and policies, at the program and institutional levels, as well as the existence of administrative units to lead these processes. The latter issues are suggested by the values obtained for scenarios 2, 3 and 4.

CONCLUSIONS

In this paper, the general morphological analysis (GMA) was applied to identify suitable solution alternatives for the implementation of a CDIO program according to standards 7, 8, 9 and 10. In our analysis, we assume that the curricular design (standards 1-4) was previously performed. Therefore, we are focused on learning strategies, and administrative and faculty issues. Based on the standards, we proposed eleven (11) parameters and their corresponding values. By using GMA, the solution space is significantly reduced. This solution space is analyzed under four (4) scenarios: the current state, the desired state, a state based exclusively on institutional guidelines, and a state based on both institutional and program guidelines. Solutions for these scenarios were clearly exposed and important remarks are discussed. The proposed scenarios can be fitted to different institutional contexts, according to the proposed parameters and values. Hence, this analysis can be applied to other academic programs to assess and project qualitatively and quantitatively their curricular profiles.

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VOCATIONAL STUDENTS IN A CDIO PROGRAMME – A LONGITUDINAL STUDY

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ABSTRACT

CDIO was born from a recognition that an entirely academic and scientific curriculum and approach does not necessarily deliver graduates able to cope with the much broader personal, interpersonal, problem solving, project and practical skills required by industry. CDIO developed a much more vocational learning model to help address this. Within the UK and elsewhere students joining University courses can often come from different backgrounds, both personally and educationally. Many students undertaking University degrees in engineering will join from conventional academic backgrounds but others will have more vocational qualifications and backgrounds. Data tends to show these students perform less well at University but does CDIO in itself, with its vocational emphasis address this issue in itself or is more required? This paper reports on a retrospective study of students on a particular CDIO programme, looks at outcomes and reports on some steps taken to help vocational students on their degrees.

KEYWORDS

Vocational, Academic, Outcomes, Progression, Standards: 3, 8, 12.

INTRODUCTION

The CDIO initiative was born out of a need to address concerns that "engineering education had evolved into the teaching of engineering science. Teaching engineering practice had become increasingly de-emphasized" (CDIO 2019). Commonly a research emphasis in engineering schools had focused education and faculty recruitment around a highly academic and sometimes narrow research science scope. The result of this was that the broader practical engineering and personal skills needed by industry lacked emphasis, with graduates sometimes being uneasy fits into the industrial workplace.

The CDIO standards and syllabus were drawn up as a means to help address this and emphasize an integrated and practical approach to developing new engineers for their careers. With a more practical and industrially applied approach that may be present in conventional programmes, it was decided to examine whether CDIO has the potential to attract, retain and develop students entering degrees from vocational as opposed to purely academic routes.

Within the English educational system, there are a number of qualification routes to access University which may involve traditional academic or more vocational routes. It is therefore of interest to see how students with academic or vocational entry qualifications perform once on a CDIO degree.
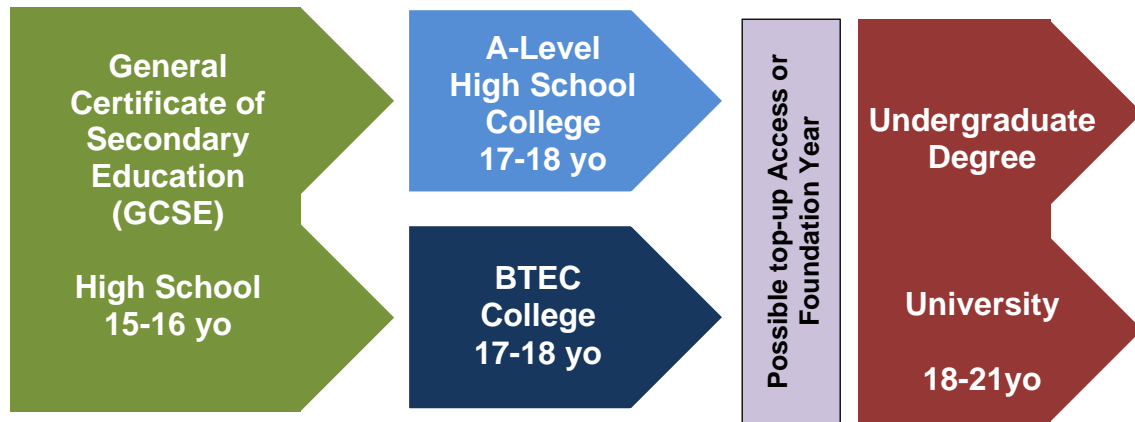

Figure 1. Typical Access Routes to Undergraduate Degrees at English Universities

Figure 1 shows typical access routes to Universities for students in the English educational system.

Most students will enter a High School at around age 11 and will do a broad-based curriculum for three years before selecting up to 11 subjects to be taken at 'General Certificate of Secondary Education' (GCSE) with these being assessed when the student is around 16. At this stage, students may embark on work-based apprenticeships but for those remaining in full-time formal education there tend to be two options, the academic A-level or the more vocational BTEC.

The A-level is a long-established qualification dating back nearly 70 years. It has an academic basis and is typically taught in sixth-form colleges which are often offshoots of high schools. Students would normally study 3 A-levels over two years with the subjects chosen by students often classic topics such as English, Physics, Mathematics or a modern language though it is also possible to do A-levels in more applied areas such as Music Technology or Food Studies. Assessment patterns vary by subject but, particularly for classic subjects, will tend to be dominated by formal written examinations. Access to A-level programmes and providers is often predicated on adequate GCSE performance.

An alternative for students is the more vocational based BTEC (Business and Technology Education Council) diploma which date back to the mid 1980s. These qualifications tend to be focused on vocational pathways with students taking a single course in topics including engineering, public services or travel and tourism. In the words of the awarding body "BTECs are all about learning by doing and that means BTEC students put what they learn into practice straight away. Throughout the course, they work on a series of assignments set in real-life scenarios, developing the practical knowledge and skills employers and universities are looking for." (Pearson 2018).

Each BTEC consists of a range of compulsory and optional units which for the engineering BTEC would include mandatory units in mechanical principles and applications, mathematics for engineering technicians and an engineering project. BTECs have often been assessed purely by coursework however examinations are starting to find their way into these qualifications. BTECs are sometimes augmented by an A-level in a supporting subject.

A relevant BTEC with distinctions would be considered as an equivalence to 3 good (B grade) A-levels with most Universities offering access to degree courses for both types of students based around these equivalences. For students missing out on grades at either BTEC or A-level, the opportunity to access University is often possible via a top-up up foundation year or a third party access course.

While A-level students are still the dominant single category of students entering University, students with BTECs or a BTEC combined with an A-level are becoming increasingly common and make up a significant part of entry cohorts in many institutions particularly those with low to middle level entry tariffs. The uptake of students taking BTECs has grown dramatically over the last decade growing from 50,000 to 150,000 between 2006 and 2014 though some tailing off has been observed more recently (Richards 2016).

For the 2016 application cycle, 54% of students accepted onto a University course nationally held only A-levels with 18% holding only BTECs and a further 8% holding a combination of the two. (Gicheva N, Petrie K, (2018), Havergal, C., (2016))

It should also be noted that there are notable socio-economic differences in the characteristics of many students taking vocational over academic qualifications with factors such as parental occupations and historic participation of the community in University education linked to a choice of qualification taken.

This can be seen in Figure 2 which shows that students being offered places at University nationally are more likely to have done so via vocational qualifications where they have come from low participation areas or their parents have manual rather than professional occupations. (Gicheva N, Petrie K, 2018). Similar indicators can also be found for the greater likelihood of vocational qualifications among students receiving free school meals, a common proxy for low income family background (Richards (2016)).

Related to this are concerns that students entering University with vocational qualifications, even if nominally equivalent in tariff to their academic counterparts, do not perform so well once on their degree, whether due to syllabus mismatch, learning and assessment modes, preparation, perception of self, or socio-economic factors. (Shields, R & Masardo, A, (2018), HEFCE (2018), Gartland C.E., & Smith C., (2018), Gill T., (2018)).

Acceptance by particpation rate of local area (Q1 lowest university participation quintile, Q5 highest) and parental occupation
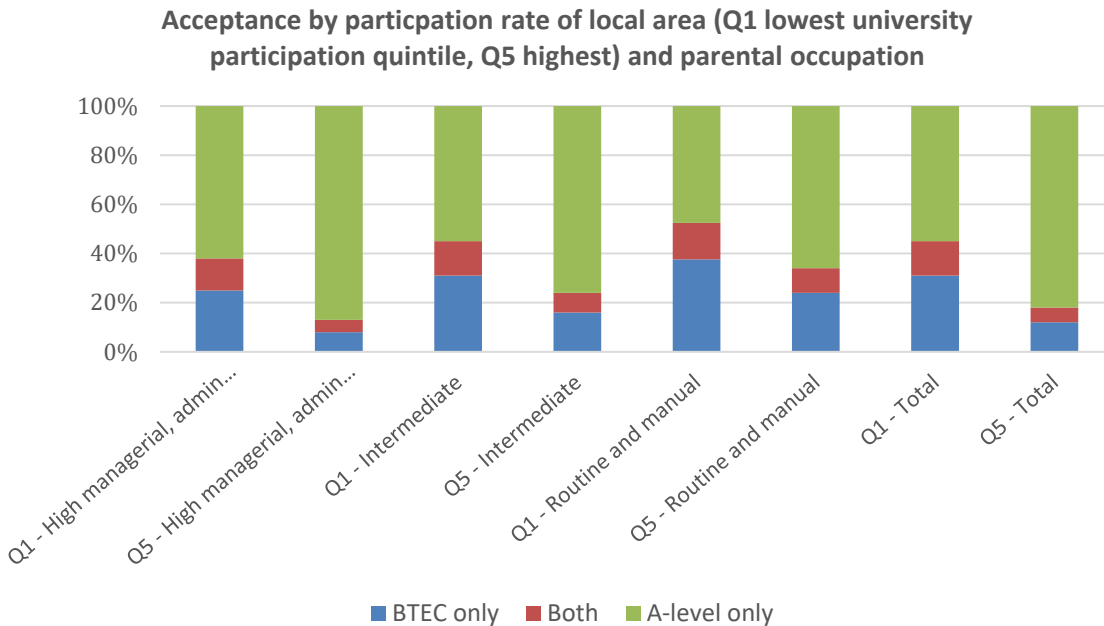
Figure 2: Acceptance by participation rate of the local area (Q1 lowest university participation quintile, Q5 highest) and parental occupation, (Gicheva N, Petrie K, 2018)

As an academic at a University with around 8 years of operating CDIO programmes, I decided to look to see if our adoption of CDIO had made a difference in terms of recruitment to our programmes, how this was reflected in different access routes and the outcomes for students from these different routes.

INVESTIGATION

Two cohorts were examined in detail. The entry year 2010-11 was our last pre-CDIO cohort and entry year 2014-15, the most recent graduating cohort. These latter students experienced a moderately mature iteration of our CDIO approach; however the 2017-18 entry cohort was also examined to see if some more recent changes to our approach had altered outcomes in the crucial first year of their degree.

Data on entry qualifications, outcomes over the course of the programme and performance of the type of student on different module types are also examined.

RESULTS AND DISCUSSION

Figure 3 shows the distribution of entry qualifications for our 2010, 2014 and 2017 intakes. Over the period our intake of students has increased significantly from 66 to over 130. During this time the number of A-level students joining us initially remained broadly static as did the numbers coming through our own foundation year (FY) though both have shown upturns in the most recent intakes. The initial rise in students since 2010 was however largely achieved through a large increase in BTEC applicants and students joining from access to HE courses

by third party providers. The pattern of intake between BTEC (rising numbers of students) and A-level (stable) is broadly consistent with the statistics of students taking these qualifications reported more generally (Richards 2016).

Anecdotally, experience at open days has shown that while potential students from a vocational background can feel a draw to our CDIO project-based approach, the bulk of the rise of BTEC entrants is likely to be largely through the national increase in numbers of these students and the increasing tendency for these to use this qualification as a route to HE rather than work.

Programme Growth by Access Route
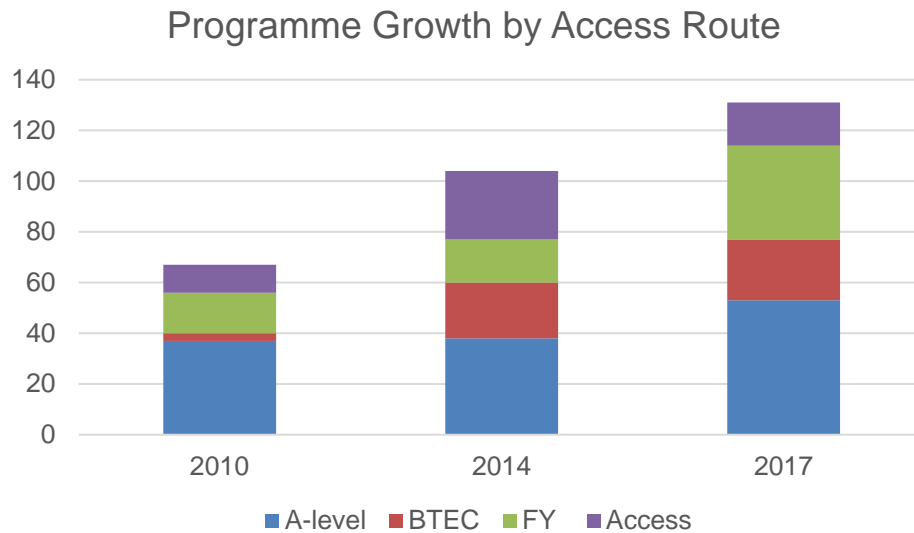
Figure 3: Entry qualification types for the entry year 2010 (pre-CDIO), 2014 (CDIO programme and most recent graduating cohort) and 2017 (most recent 1st year on CDIO programme)

Figures 4 and 5 compare the outcomes of the two cohorts, pre and post-CDIO to see if the shift of programme culture from a traditional lecture and exam based academic approach to one with a much greater degree of applied and practical learning has had an impact on the outcomes for students on the whole and for particular entry types in particular.

For both pre and post-CDIO cohorts, students joining the programme with academic A-level qualifications have generally had very good outcomes with small numbers of students withdrawing and the majority of students leaving with good degrees (Integrated Masters, 1st class or upper second class degrees).
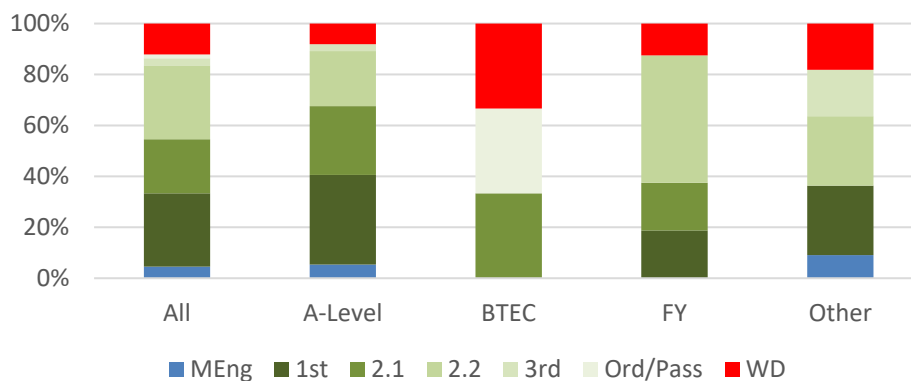
Figure 4: Degree outcome broken down by Entry Qualification
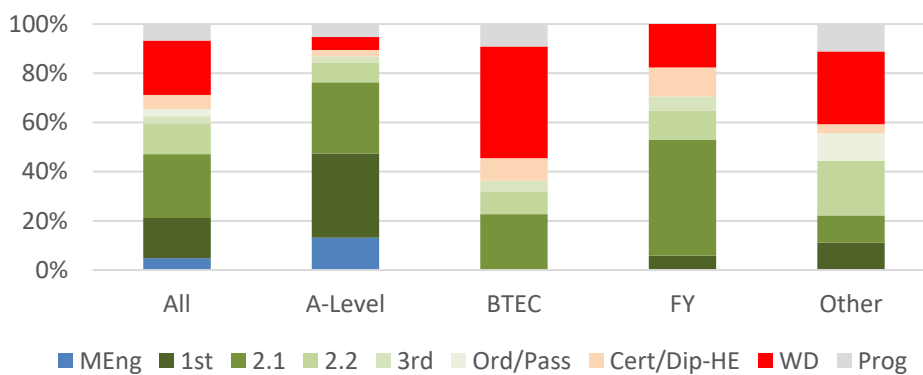(2010 entry – pre CDIO)

Figure 5: Degree outcome broken down by Entry Qualification
(2014 entry – CDIO and most recent graduating cohort)

Unfortunately, for the purposes of the study, the number of students joining us with a BTEC in 2010, pre-CDIO, was very small (n=3, see also figure 3) and it, therefore, makes it impossible to use this as a baseline metric to evaluate how CDIO methodologies have impacted our vocational students.

Nonetheless looking at figure 5 for the most recent graduating cohort it is also clear that the outcomes for students joining with primarily vocational BTEC qualifications are significantly poorer than their A-level classmates with lower overall grades and a much higher degree of withdrawal despite the practical bias of our degrees,

While this is much in line with data reported elsewhere it is not ideal for the students involved or the University itself. To examine why this might be I looked at the first year of our degrees and the performance of students on this. For us, this year is made up of two 15 ECTS project modules very much directly built around the CDIO philosophy coupled to 20 ECTS of hybrid practical/lecture/tutorial engineering science modules and 10 ECTS of mathematics taught quite traditionally.

Figure 6 shows the mean performance of our most recent graduating year when in the first year (2014-15) split by module type and entry qualification.
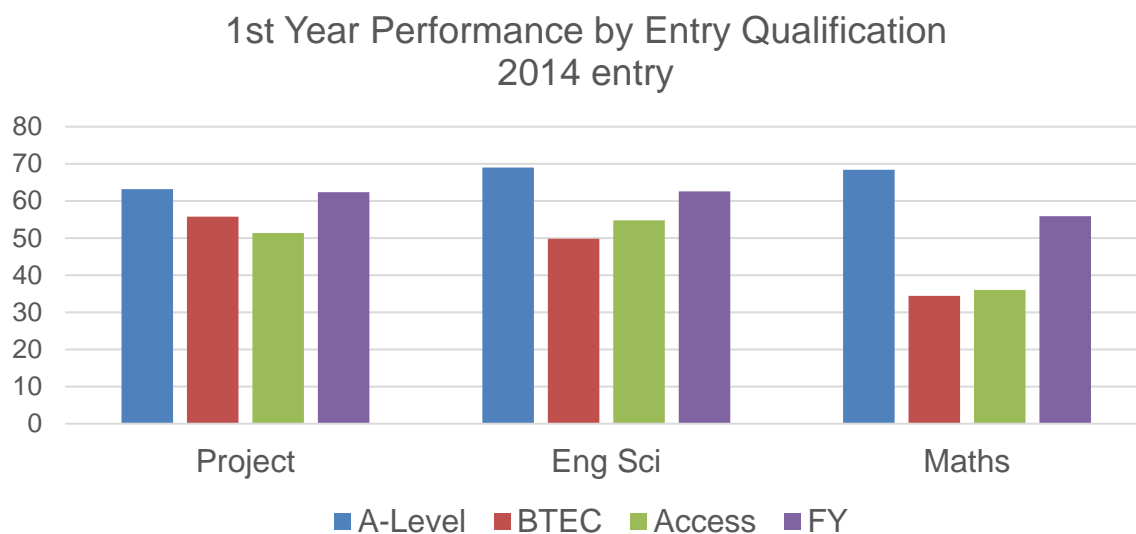
1st Year Performance by Entry Qualification
2014 entry

Figure 6: 1st year performance – entry year 2014-15

It can be seen that in the project modules the difference in outcome between the academic A-level students and vocational BTEC students is relatively modest. For the conventionally taught and assessed Mathematics however the A-level students very notably out-performed their BTEC peers with the result the latter were vulnerable to dropping out, unable to clear the Maths modules even after retakes.

As stated earlier such issues are not uncommon in many degrees enrolling BTEC students and support approaches to help these individuals or the class as a whole very often have to be implemented.

To address this issue in our case the BTEC students have for example been allocated to specific and experienced personal tutors to help provide specific targeted support.

In addition, some modifications have more been made to the Mathematics module to address some general issues which also impacted BTEC students in particular.

Previously Mathematics had been a very large cross-school – one size fits all - module with classes of approaching 500 taught to all engineers regardless of a specific discipline. This was more recently devolved down to individual programmes to create their own mathematics modules which not only gave smaller class sizes but also afforded more opportunity for a more relevant syllabus and teaching mode.

Figure 7 shows the outcomes at first year for the 2017-18 cohort taking the new model of mathematics module which was framed much more closely around the CDIO philosophy coupling project work with core maths principles. Further details on this work are reported elsewhere. (Peters & Prince, (2019))
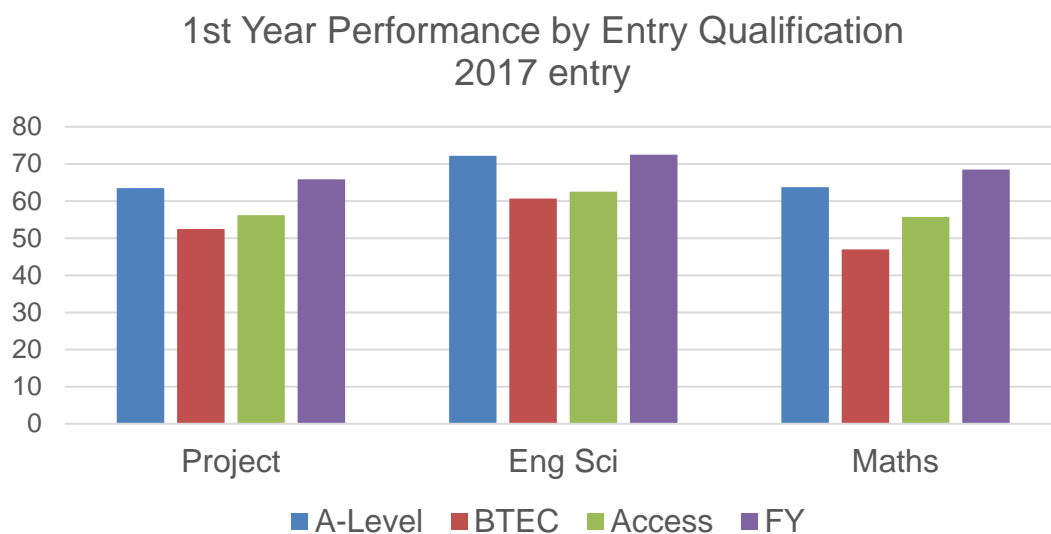

Figure 7 : 1ˢᵗ year performance – entry year 2017-18

It can be seen that while the BTEC students still lag their peers in Mathematics, the difference is much less marked than previously and is closer to the performance in other subject types. This approach will be followed up and evolved in due course to see if these changes impact overall degree outcomes.

CONCLUSIONS

Best practice in education is to recognize the fact that different students will enroll in programmes with different backgrounds, support networks, experiences, qualifications and learning style preferences. While recognizing each student as an individual, access qualifications at the pre-University level may cause a certain coalescence of some of these characteristics around certain qualifications. In the case of the English context, while most

students enter with academic A-level, access or foundation qualifications a significant proportion will enter degrees with vocational BTEC type qualifications. While other countries will have different pre-university education system it is likely that entries at all Universities are likely to either formally or informally have proportions of students with primarily vocational experiences or learning profiles.

While CDIO, with its practical applied focus, should be a good match for these students, the experience here as shown that this has not always been the case. While students may fare quite well on practical activities, more core academic content can sometimes, if taught conventionally or without extra support, be a block to progress. To address this a more fully integrated approach is being developed to support students with greater emphasis on integrated and practical learning together with a greater focus on the needs of these students to ensure they can meet their potential has been developed and is moving outcomes in a positive direction.

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Evaluation of the Result and Benefit from international summer camp using CDIO framework

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ABSTRACT

In this study, we are going to display the result and evaluation of the 1st CDIO summer camp hosted by Feng Chia University in July 2018. Forty-five students from four countries and five different schools, Taiwan, Singapore, Vietnam and Malaysia, have worked together and completed the project of "i-Night Market". The greatest challenge in this camp is that the students had to go through the process of "conceive, design, implement and operate" in just 1 week, and also, to make the actual product prototype. In order to evaluate the effectiveness of the camp, we've used the Kirkpatrick Model (1959) to design the questionnaire and asked the students to fill it out in the beginning and at the end of the camp. Post project appraisal has shown that the CDIO framework is very suitable for operating a camp and letting the students understand the learning objective of each phase. Seeing the actual performances from the students, we think the CDIO Summer Camp in the future could be adjusted to the "online and offline" framework. Students could then finish the C and D phases on the online platform and begin with the I and O phases right after forming the team.

KEYWORDS

Keywords: i-Night Market, Multinational, Multidisciplinary, CDIO, Active Learning, Standards: 1, 2, 3, 4, 5, 7, 8, 11.

INTRODUCTION

Background

In the year 2015, Feng Chia university had learnt and realized a way for innovative engineering education, the CDIO framework, and had first undergone a reformation to the engineering

related departments. Being a part of a comprehensive University as Feng Chia University, we have also tried to assimilate the CDIO framework into the PBL courses from the finance and humanities departments as we were promoting it. We have learnt that after the students went through the "conceive, design, implement and operate" phases in the seminar, the effectiveness of learning in classes has improved. Moreover, the process also assisted the learning effectiveness in other classes. With the positive results, Feng Chia University would like to promote the CDIO framework, allowing more students to get to know this kind of learning framework. At the same time, we hope to add some element of cross-country cooperation in the seminar, thus enhancing the opportunities of international communication for students.

Figures 1. Photograph of 2018 CDIO Summer Camp

July and August are summer vacation for students in Taiwan. Therefore, we hosted the 2018 CDIO Summer Camp during this period while the campus was empty, and turned the campus into a place for cross-country communication. We invited schools from Singapore, Malaysia and Vietnam, including Singapore University of Technology and Design, Singapore University of Social Sciences, National University of Malaysia, Thai Nguyen University, Ton Duc Thang University in total 32 students from 5 universities, along with 13 students from Feng Chia University, to go through a 10-day's journey to experience the full CDIO process.

In addition to the most crucial components of project, conceive, design, implement and operate, the Summer Camp also includes many other activities, like field exploration, lecture for cultural observation, introductory lecture, and group construction…etc. Students went through two major presentations, process examination and achievement display, and numerous minor oral presentations, sharing concepts, designs, prototypes with each other and having peer examination at the same time. We've specifically accommodated all students in the university dormitory, allowing them to discuss the seminar at night after their classes or activities. At the

end of the camp, students had to complete their final task by integrating what they've learnt in the camp and propose a solution to "how to make Feng Chia night market intellectual".

Feng Chia night market is located beside Feng Chia University and is the biggest night market in central Taiwan. The night market is full of delicious foods, it's very entertaining and is easy to shop through. Therefore, it is a must-go attraction for both local and foreign tourists when visiting Taichung city. According to the statistics from the Feng Chia University's statistical marketing research group on the night market, there are about 20,000 people visiting the night market per day during non-holiday and more than 50,000 people per day during holidays. The idea of University social responsibility has been brought up in recent years, and Feng Chia University is striving to improve and promote Feng Chia night market. The main theme, "i-Night Market", is set to respond to the mainstream of the current global trend, that is intellect. Students should design a plan or proposal to enhance the capability of the night market in facing such a huge flow of people. On the other hand, we also hope that our foreign students could get to know about Taiwanese night market culture while working through the project.

This study focuses on introducing how Feng Chia university designed the curriculum for the camp, allowing students to experience the 4 stages of "concept, design, implementation and operation", and to output the actual product prototype. In the end, we analyzed the questionnaires students filled out in the beginning and the end of the camp and discussed the result and advantages of applying CDIO in an international summer camp.

Method

In the past 5 years of the annual conference held by the CDIO Initiative, the only article that shares a similar concept like in this study is "Capstone Bootcamp Concept Catalyzing Project-based Learning", published by University of Turku and Fudan University. Therefore, in this camp arrangement, we refer to the CDIO Standards method used by Capstone Bootcamp, focusing on Standard 1, 2, 3, 4, 7, 8, 11. In addition, since 2016, Feng Chia University participated in several CDIO Initiative CDIO Academy to observe how to handle transnational CDIO topics in a short time. Based on the two experiences mentioned above, the first edition of the structure for CDIO Summer Camp in Taiwan was created.

In order to evaluate the result and advantages of applying the CDIO framework on an international summer camp, this study is using the theory that Donald L. Kirkpatrick proposed in 1959, the four levels of evaluation model: reaction, learning, behavior, and result to design the questionnaires. The Kirkpatrick evaluation model emphasized observing the knowledge transfer and skill acquisition of the student after learning. And also made valuable contributions to training evaluation thinking and practice. It has helped focus on training evaluation practice on outcomes (Newstrom, 1995). In Kirkpatrick's model, the distinction between learning level (the second level of the theory) and behavior level (the third level of the theory) has drawn increased attention to the importance of the learning transfer process in making training truly effective. (Alliger & Janak, 1989). Therefore, this model underscored the importance of examining multiple measures of training effectiveness. (Wang, 2003). Furthermore, the model also emphasizes on the variation of the student's ability in the application and actual practices. This study believes that by implementing this evaluation system, we could understand student's level of outcomes in the four stages of "conceive, design, implement and operate" after completing the CDIO process, and then adjust the content of the camp accordingly.

Table 1. The pre-test questionnaires

SD: Strongly Disagree / D: Disagree / A: Agree / SA: Strongly Agree

	Reaction Please base on your experience measure your satisfaction and reception of the curriculum planning.	**SD**	**D**	**A**	**SA**
1	From the past learning experiences, teachers taught or encouraged students to apply the design thinking tool in class.				
2	From the past learning experiences, teachers taught or encouraged students to think innovatively or distinctively in class.				
3	From the past learning experiences, teachers cultivated ability to discover the problems from surroundings and solve them with creative design in class.				
4	From the past learning experiences, teachers taught or encouraged students to share and integrate information in class.				
5	From the past learning experiences, teachers encouraged students to have teamwork in class.				
6	From the past learning experiences, teachers taught or encouraged students to communicate with interdisciplinary team members in class.				
7	From the past learning experiences, teachers taught or encouraged students to brainstorm the relative issues in class.				
8	From the past learning experiences, teachers taught or encouraged students to design the prototype in class.				
9	From the past learning experiences, teachers taught or encouraged students to produce the prototype in class.				
10	From the past learning experiences, teachers taught or encouraged students to present and promote the object in class.				
11	From the past learning experiences, teachers applied the project-learning strategies in class.				

Table 2. The post-test questionnaires

	Behavior Please complete a self-evaluation of whether you can practically apply those previously learned strategies to the project in class after the learning stages.	**SD**	**D**	**A**	**SA**
1	In this lecture, I applied the design thinking tool in class.				
2	In this lecture, I tried to think innovatively or distinctively.				
3	In this lecture, I discovered the problems from the surroundings and solved them with creative design in class.				
4	In this lecture, I shared and integrated information with classmates in class.				
5	In this lecture, I had teamwork with my classmates in class.				
6	In this lecture, I communicated with my interdisciplinary team members in class.				
7	In this lecture, I brainstormed the issues in class.				
8	In this lecture, I designed a prototype in class.				
9	In this lecture, I produced a prototype in class.				
10	In this lecture, I presented and promoted an object in class.				
11	In this lecture, I executed a complete project in class.				

The questionnaire designed the experience of several stages of CDIO, teamwork, and project learning. The pre-test and post-test questionnaires are set in the same way. The pre-test is based on "from the past learning experiences" (Table 1.). We would like to know the learning experience of the students before joining the camp. The post-test starts with "in this lecture" (Table 2.) and want to know the students' effectiveness in four levels of reaction, learning, behavior, and results.

CDIO SUMMER CAMP IN FENG CHIA UNIVERSITY

How to design a camp based on the CDIO framework
CDIO is an innovative pattern of teaching. Apart from integrating the framework into engineering-related departments, Feng Chia university also applies it on business and humanities studies. We have discovered that the "conceive, design, implementation and operation" structure could complete the learning of a seminar. Therefore, we've imported the CDIO standards when designing the camp, hoping that the students from different countries could provide their specialties to the team and propose a plan for "How to make Feng Chia night market intellectual".

The camp preparation team has set a final learning goal based on the Learning outcome (standard 2), expecting the students to grasp the knowledge of terminologies related to intellectual city, and accustoming to new teaching and learning methods, for example: learning by doing, compound learning, peer learning, and abilities to communicate with groups and present on stage. After setting the learning goals mentioned above, we assisted the students with the integrated curriculum (standard 3) like: seminar lecture, introductory lecture, conceiving tool, questionnaire design and analyzation, team construction…etc. It allows students to strengthen their personal skills, social skills and other seminar constructive skills through an integrated learning experience and active way of teaching (standard 7, 8).

Before the camp started, we first introduced the process and core value of CDIO, according to standard 1 and 4. Then, we explained ways and methods for the final proposal, field background, design and implementation process in the process of proposal and moreover, the individual and social skills needed in the course. The entire period of the camp consists of 2 design-implement experience (standard 5), which are the design and implementation for questionnaire and proposal. Since this summer camp mainly emphasizes on international communication and the promotion of the CDIO framework, the learning assessment (standard 11) is based on student's self-value on their learning effectiveness.

Intended Learning Outcomes and Connections with PBL & CDIO

After a series of comparisons, Edstrom & Kolmos (2014) proposed that CDIO and PBL (project-based learning) are complementary. If the two are combined, a better curriculum could be designed and a more advanced learning outcome could be developed. In fact, Feng Chia University has been promoting PBL for quite some time already. The CDIO summer camp we organized has combined CDIO and PBL, hoping that students from all countries and schools could experience and understand the application of the CDIO framework. Xing Guo (2015) mentioned that if a short and intensive camp is to be held, it is necessary to arrange lectures and design the "practice" part, which must be alternated. For example, prototyping and team building can improve student learning effect. When Feng Chia University planned the camp, it integrated this idea.

The main content of the CDIO summer camp will be described in the following article followed by an explanation of the learning outcome set by the design team and its relevance to PBL and CDIO in Table 3:

- Lecture: We invited a specialist from abroad to lecture "Intellectual city and intellectual application in countries around the world". Other introductory lectures are mainly taught by teachers from Feng Chia University and industrial lecturers from industries related to

Taiwan's intellectual transportation. They introduce various AI identification systems for transportation, smart storage and parking lots.

- Field investigation: We combined field exploration with group activities and competitions, allowing students to enter Feng Chia night market with a layman's perspective. This assists them during the conceive stage of the project.
- Creative thinking: By teaching brainstorming 6-3-5, 5W2H and two-dimensional quadrant method, students could make the best use of their creativity and collect numerous ideas.
- Questionnaire: The principles and cognition of the questionnaire are taught to enable students to use a micro version of "design-implementation" to assist the overall proposal from the design phase to the implementation phase, and to approach and meet the user's needs.
- Prototype production: Through the various processes of divergence, convergence, and validation, students who have confirmed the content of the proposal must produce prototypes of the products, processes, or systems that drive their solutions.
- Result display: Students will have 8 to 10 minutes to elaborate the CDIO process they've experienced and to propose a plan of "How to make Feng Chia night market intellectual", with the key product, process or system that could perform the plan.

Table 3. The learning outcome relevance to PBL and CDIO

Program	Intended Learning Outcomes	Connection with PBL Principles	Connection with CDIO systems
Lecture	Master the application of the intellectual city and the relevant terminologies.	Cognitive Learning/ Content	C
Field investigation	Team construction, teamwork, to view the field of the seminar from different perspectives	Content	C&D
Creative thinking	Learn and apply skills for creative thinking, practice trying new and unique ideas	Cognitive Learning/ Content	C&D
Questionnaire	Have the ability to perform ideas through "design-implement", learn how to survey and analyze questionnaire	Collaborative Learning	D&I
Prototype production	Have the ability to perform ideas through "design-implement", strengthen personal and social skill through the process of making the prototype	All three principles above	I
Achievement report	By presenting their result, students show all the intended learning outcomes mentioned above	All three principles above	O

DATA ANALYSIS

Sample

The samples this study collected are from forty-five students who attended the CDIO Summer Camp. There are thirteen students from the Taiwan University of Feng Chia, six students from Singapore University of Technology and Design and University of Social Sciences, eight students from the National University of Malaysia, and eighteen students from Vietnam University of Thai Nguyen and Ton Duc Thang University. The questionnaire designed from the Kirkpatrick evaluation model was given twice in total. The first time was before classes began, and the second time was after all the classes ended. The overall response rate and validity of the questionnaires was 100%.

Process

The questionnaire is divided into four parts, the first part, personal information, the second part is about the satisfaction rate from former learning experiences and the overall learning experience of the camp; there are in total 5 questions in this section. The third part was designed based on Kirkpatrick's four levels of learning, which contains the level of reaction, learning, behavior and result. This part has a total of 16 questions. The first three levels each have 11 questions and are about the process, conception and teamwork of CDIO. The result level had 4 questions about comprehensive ability. The fourth part contains 3 short answer questions to help understand student's opinion on international communication, cross-field teamwork, integrating CDIO into classes and the activities. All scales were based on the four terms from Likert scale. It takes 15 to 20 minutes on average to finish each questionnaire.

Result

The study analysed the four levels of reaction, learning, behavior, and result. First, based on the analysis of the distribution of statistics (Figure 2.), students have experience in conceiving, DIY and teamwork before participating in the camp. The most lack of experience is "Design the Prototype", so the students' responses are falls in 1 or 2 scores.

Figure 2. The Pre-test Frequency analysis
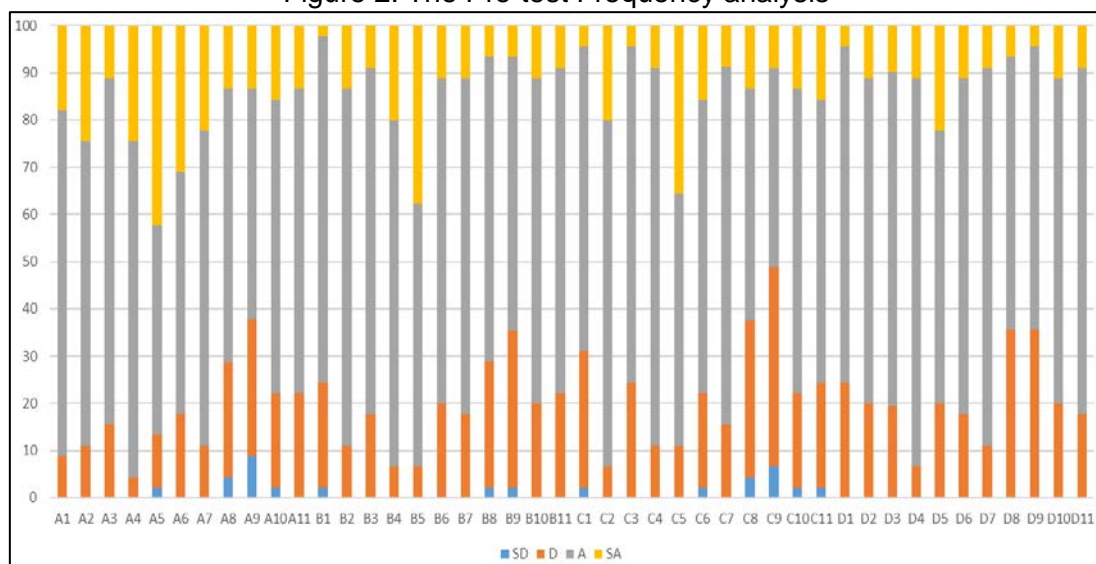
After training for the entire summer camp, the results of the post-test statistical analysis (Figure 3.) found that more than 80% students were satisfied with the reaction, learning, behavior and results of each level. There are 11 questions for all students to fill in the score is 3 or 4. Among

them, there are five questions focused on the reaction stage, showing that students are very satisfied with the procedure of the camp. Comparing Figure 2. and Figure 3.it can be observed that the learning outcomes of students' reaction, learning, behavior and result have significantly improved.

Figure 3. The Post-test Frequency analysis
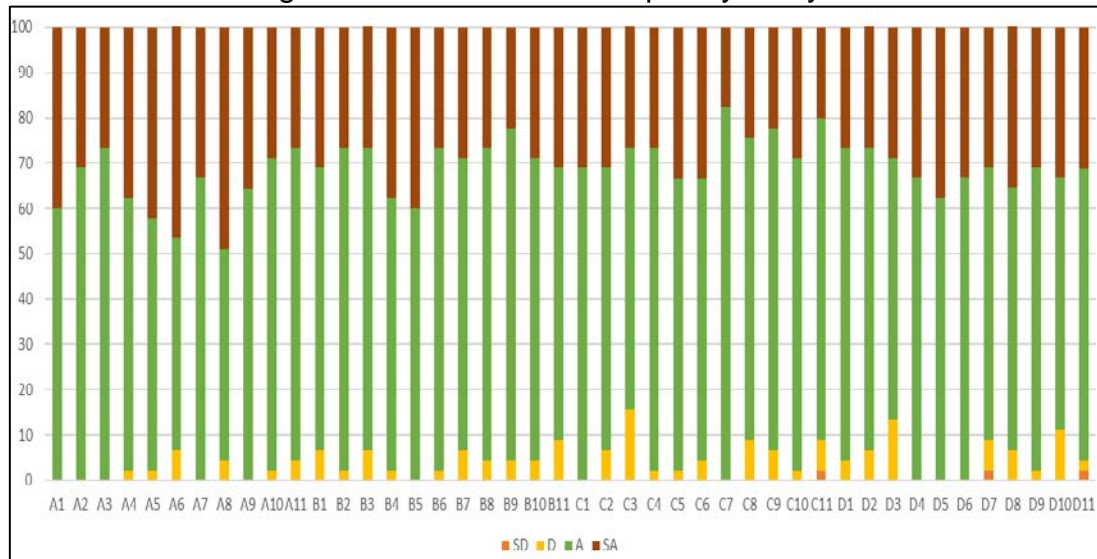
Next, with the paired sample t-test can be more objectively analyzed. The team members show their results in the four stages of the Kirkpatrick model (Table 4.). In the statistical analysis, ρ < 0.05 means a significant difference, and ρ < 0.01 means a very significant difference. In the t-test results of the camp, the reaction level has significant learning results, and the three levels of learning, behavior and results are very significant growth. Therefore, we believe that this summer camp is successful for CDIO procedure, teamwork, and project learning.

Table 4. The Result of the Paired Sample t-test

|	N	M		SD	T	ρ
		Pre-test	Post-test			
Reaction	45	3.00	3.25	.360	2.222	.050
Learning	45	2.92	3.25	.121	8.827	.000
Behavior	45	2.88	3.20	.181	5.883	.000
Result	45	2.90	3.26	.142	8.219	.000

Finally, we make the average of the 11 questions answered by the students into a line graph, and compare the pre- and post-tests to observe the detail differences between the students' before and after learning. The best learning outcomes are "Teamwork" and "Design the Prototype". It is seen from the two line graphs that the students' "reaction" and "result" stages are quite close, indicating that the students have learned both skills.

Table 5. Learning Outcomes of Camp Participants-Positive
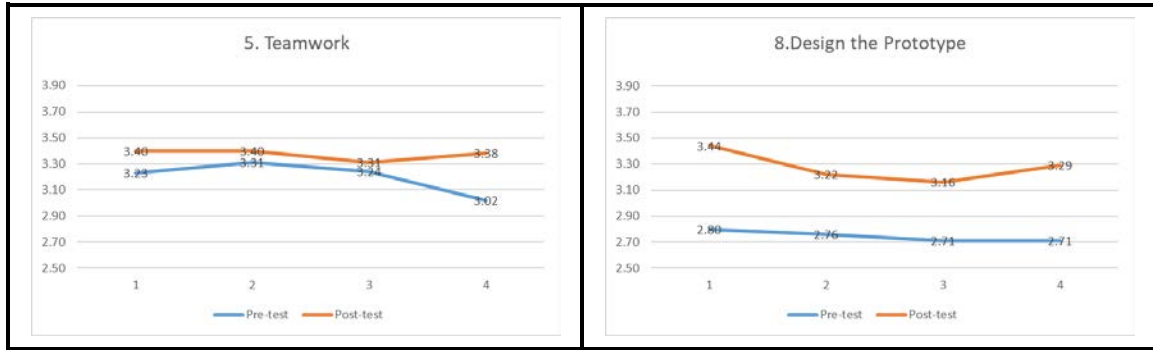
From the "Discover / Solve the Problems" and "Produce the Prototype" line graphs observations, the minimum value falls in the "behavior" stage, indicating that students are unable to apply these two skills smoothly during the course. This is the main points that we should expect ourselves to become better when we plan to design the team next year.

Table 6. Learning Outcomes of Camp Participants- To Be Strengthened
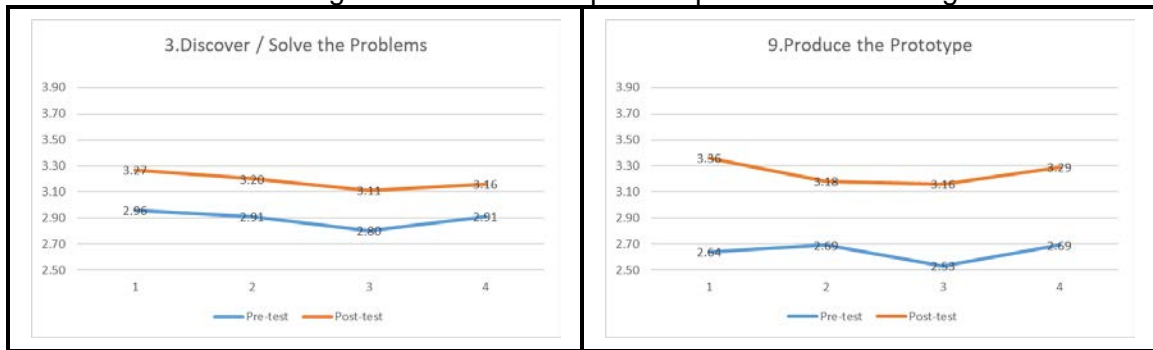
CONCLUSION

The CDIO Summer Camp is the first time that Feng Chia university integrated international communication with the CDIO framework. On one hand, the university hopes to promote the CDIO framework. On the other hand, it hopes to build and create different proposals for "i-Night Market" through the brainstorming from different countries and fields. In order to evaluate the result and advantages of integrating CDIO into the camp, we've performed questionnaire surveys at both the beginning and the end of the camp. The curriculum and activities designed based on the guidelines of concept, design, implementation and operation are truly helpful for the enhancement of student's learning results. In terms of the proposals, products, processes or systems that each team proposed in the end, they all showed a good scale of feasibility.

From the analysis and observation of the questionnaire, we can understand that the learning outcomes of the self-assessment of the students are also doing well. In the comparison of the pre and post t-tests, it can be seen that after the participants have participated in the camp, the learning results of the CDIO at different stages, teamwork and project learning experience have been significantly improved. This shows that the CDIO framework is suitable to integrate into a camp and become the guideline for curriculum or activity design.

For the planning team of the camp, the most difficult part is to distribute CDIO into the curriculum and activities in proportion, allowing students to experience the process of CDIO in

a short amount of time. In fact, while we did self-evaluation, we all agreed that C and D are important phases, but they've also taken up too much time from the camp. This opinion is also consistent with the results we got from the questionnaire. Therefore, the CDIO Summer Camp in the future will be adjusted to the form of O2O, hoping to achieve the same thing as in the CDIO academy, letting students conduct the C and D phases through the online platform. In that case, when being face to face in the camp, students could immerse deeply in the phases of implementation and operation.

ACKNOWLEDGMENTS

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Senior-year internships impact assessment in engineering programs at UCSC

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ABSTRACT

In this work, we aim to evaluate the impact of internships on recent graduates entering the workforce for four UCSC School of Engineering programs. Civil Engineering and Geological Engineering students take a 400-hour internship, generally during the summer months preceding their senior year. Computer Science and Industrial Engineering students optionally take a semester-long senior-year internship. These professional internships are integrated learning experiences in an organization (CDIO standard 7) which foster student disciplinary knowledge (CDIO 1), analytic reasoning and problem solving (CDIO 2.1), perseverance and flexibility (CDIO 2.4.2), critical thinking (CDIO 2.4.4), teamwork (CDIO 3.1), communication skills (CDIO 3.2), and conceiving, designing, implementing and operating systems in a real context (CDIO 4). This study considers data gathered through an online perception survey applied to all those program graduates that signed up for an internship from 2016 onwards, and have graduated at least a semester ago. It also shows that graduates from all programs state that the internships strengthened their technical knowledge, personal and interpersonal skills. Regarding product, process, and system building skills, these numbers increase to over 90%, except for their ability to operate them (CDIO 4.6), which is closer to 75% for Civil and Geological Engineering. Our results also show that about 70% of graduates who did a semester-long internship feel the internship helped them find a job within six months of graduating, whereas less than a third of students doing the shorter internship felt so. Around 40% of graduates entered into a contractual relationship with their internship company, except for graduates of the Industrial Engineering program, where this number doubles. Students were also asked to identify those strengths and weaknesses that helped and hindered them during their internship. Among their strengths, they identified their teamwork and leadership skills, and among their weaknesses, they identified their lack of self-confidence and experience.

KEYWORDS

Experiential learning, internship impact, recent graduates follow-up, Standards: 7, 11, 12.

INTRODUCTION

In 2011, the School of Engineering of the Universidad Católica de la Santísima Concepción (UCSC) underwent a curricular reform process based on the CDIO Initiative (Crawley et al., 2007; Loyer et al., 2011). As a result of this reform process, program learning outcomes were reformulated based on the CDIO Syllabus (Crawley et al., 2011). Recognizing the importance of providing students with learning opportunities for them to experience professional practice and activities, all programs incorporated mandatory internships. Since 2016, as a result of our continuous improvement process, the School of Engineering lets students choose to spend their last semester working on a research project, an applied engineering project or in a semester-long senior-year internship. The Computer Science and Industrial Engineering programs have implemented all three options, being a semester-long senior-year internship the most popular by far, while the Civil Engineering and Geological Engineering programs have only implemented the first two options.

In all internships, students' performances are assessed regarding their professional, personal and interpersonal CDIO skills by a supervisor in the company and by a faculty member (CDIO Standard 11). As evidence of the achievement of the programs' learning objectives (CDIO Standard 12), the School of Engineering analyzed the senior-year internship supervisors' evaluations and comments about student performance for the Computer Science and Industrial Engineering programs from 2016 up to the first semester of 2018 (Muñoz et al., 2018). These supervisors' evaluations and comments, which offer an external view of student performance during their professional internships, show that, while student skills at the beginning of the internships are adequate for the assigned tasks, they improve throughout the internship, reaching high achievement levels in most cases. Moreover, they also state that there are opportunities for improvement in student communication skills. In this work, we complement this study by gathering program graduates' perceptions of the impact of these internships once they have graduated, and on their usefulness for later employment.

INTERNSHIP GOALS

The major goal of an internship, a short-term practical work experience, is to offer students a smooth transition from academia to industry, as it is a natural bridge between universities and the labour market. Internships are win-win investments for all major stakeholders: students, industry and academia. The benefits of internships are many: they improve students' chances of employment, enhance students' job and social skills, and help students decide their career paths. Likewise, employers benefit from having access to a source of inexpensive and qualified labour, from saving on recruiting costs, and from having stronger bonds with academia. Lastly, universities benefit from enhanced visibility and reputation, from a natural showcase to attract potential students, and from increased collaboration opportunities with industry (Haag, Guilbeau & Goble, 2006; Sanahuja & Ribes, 2015).

Internships

The Civil Engineering and Geological Engineering programs include an internship, lasting at least 400 hours and generally done during the summer months preceding the senior year. This internship gives students the chance to put their knowledge, abilities, and skills into practice in a

professional environment, either in a public or private organization. A company supervisor assesses student performance regarding technical knowledge (CDIO 1.3), personal and professional skills (CDIO 2.4), ethics (CDIO 2.5.1) and interpersonal skills such as teamwork (CDIO 3.1) and effective communication (CDIO 3.2). Also, a faculty member assesses a technical report written by the student about the internship work. In the case of Geological Engineering, a student self-evaluation report is additionally considered.

Senior-year Internships

In the case of the Computer Science and Industrial Engineering programs, students who choose to do a senior-year internship must do 700 hours of training in a company or organization. These senior-year internships are integrated learning experiences in a real context (CDIO standard 7) which foster student disciplinary knowledge (CDIO 1), analytic reasoning and problem solving (CDIO 2.1), perseverance and flexibility (CDIO 2.4.2), teamwork (CDIO 3.1), communication skills (CDIO 3.2), and product, process, and system building skills (CDIO 4). Each student is supervised by a company professional. In the case of the Computer Science program, a faculty member also mentors the whole process. Students' performances are assessed regarding their professional, personal and interpersonal CDIO skills by the company supervisor through intermediate and final evaluations, and by a faculty member via a final technical report written by the student about the internship work.

METHODS

In order to assess the impact of these internships on the programs' graduates, a Google Forms survey delivered by electronic mail was designed to gather graduates' perceptions of these effects. Survey responses were confidential and anonymous. In particular, the online survey covered the internship impact on those program learning objectives related to disciplinary knowledge, personal and professional skills and attributes (CDIO 2.1, 2.4.2, 2.4.4, 2.5.1, 2.5.2 and 2.5.5), interpersonal skills (3.1 and 3.2), CDIO in context (4.3, 4.4, 4.5 and 4.6) . Additionally, graduates were asked about the usefulness of the experiential learning activities they had during their studies (e.g. project-based learning, service-learning, internships, among others) for their job placement. Finally, the survey included open questions asking graduates to identify the top two weaknesses that affected their internship performance, and the top two skills they improved during the internship.

Data collection

This survey was sent to all those graduates of the four programs that signed up for an internship from 2016 onwards, and that have graduated at least a semester ago. Table 1 shows the number of surveys sent for each program, and the number of responses received, separated according to the semester in which the respondent did the internship.

Table 1. Survey coverage

Engineering program	Surveys sent	Responses received						
		2016-I	2016-II	2017-I	2017-II	2018-I	Total	Response rate
Civil Engineering	59	10	7	7	3	3	30	51%
Geological Engineering	36	1	3	8	2	1	15	42%

Industrial Engineering	111	1	16	8	31	17	73	66%
Computer Science	35			1	4	11	16	46%

RESULTS AND DISCUSSION

Figure 1 shows survey results for each program, regarding the program graduates' perception of whether their internship strengthened specific CDIO personal and professional skills and attitudes, such as: analytical reasoning and problem solving (CDIO 2.1), perseverance and flexibility (CDIO 2.4.2), critical thinking (CDIO 2.4.4), ethics, integrity and social responsibility (CDIO 2.5.1), professional behaviour (CDIO 2.5.2) and equity and diversity (CDIO 2.5.5). As can be seen in the figure, graduates from all four programs perceive internships as having a bolstering effect on the above mentioned CDIO skills. Worthy of note are analytical reasoning and problem solving for the Computer Science and Geological Engineering programs, and perseverance and flexibility, for all program graduates. On the other hand, fewer students perceived an improvement in the ethics, integrity and social responsibility item due to their internships.

Figure 2 shows survey results for each program, regarding the program graduates' perception of whether their internship strengthened particular CDIO interpersonal skills: teamwork (CDIO 3.1) and communications (CDIO 3.2). All results are high, over 75%.
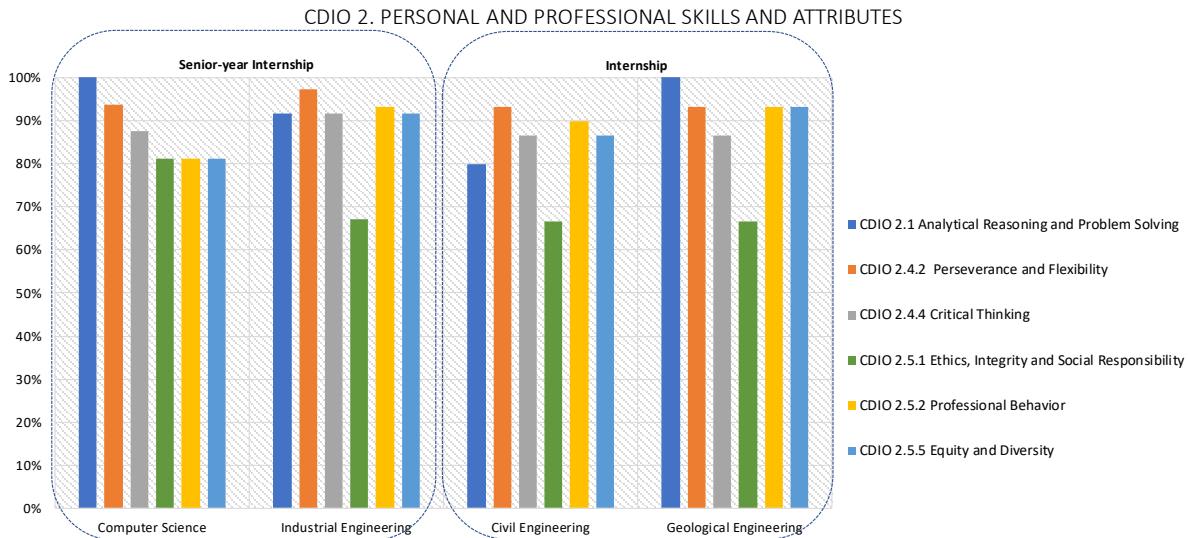

Figure 1. Program graduates' perception of strengthening of personal and professional skills

Figure 3 shows survey results for each program, regarding the program graduates' perception of whether their internship strengthened specific CDIO skills related to conceiving, designing, implementing and operating systems in the enterprise, societal and environmental context, in particular: conceiving, system engineering and management (CDIO 4.3), designing (CDIO 4.4), implementing (CDIO 4.5) and operating (CDIO 4.6). Results show that graduates from all programs regard their internships as very helpful in developing the first three skills, but slightly less so for the last skill. In particular, this value is lower for graduates from the Civil Engineering and Geological Engineering programs, which had a shorter internship.
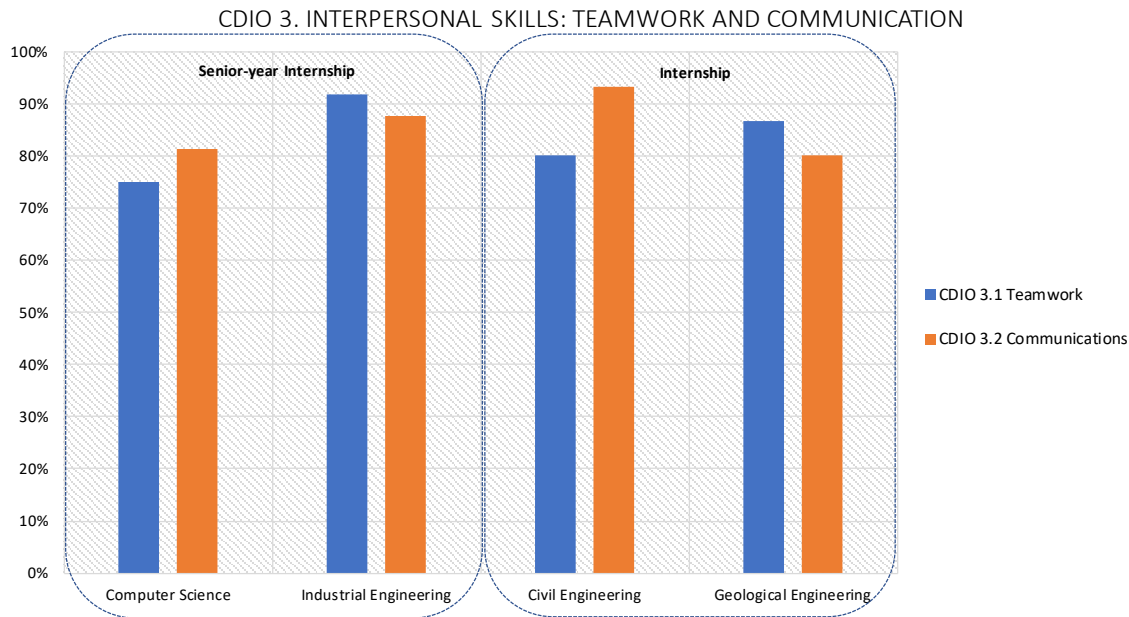
CDIO 3. INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

Figure 2. Program graduates' perception of strengthening of interpersonal skills

CDIO 4. CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS
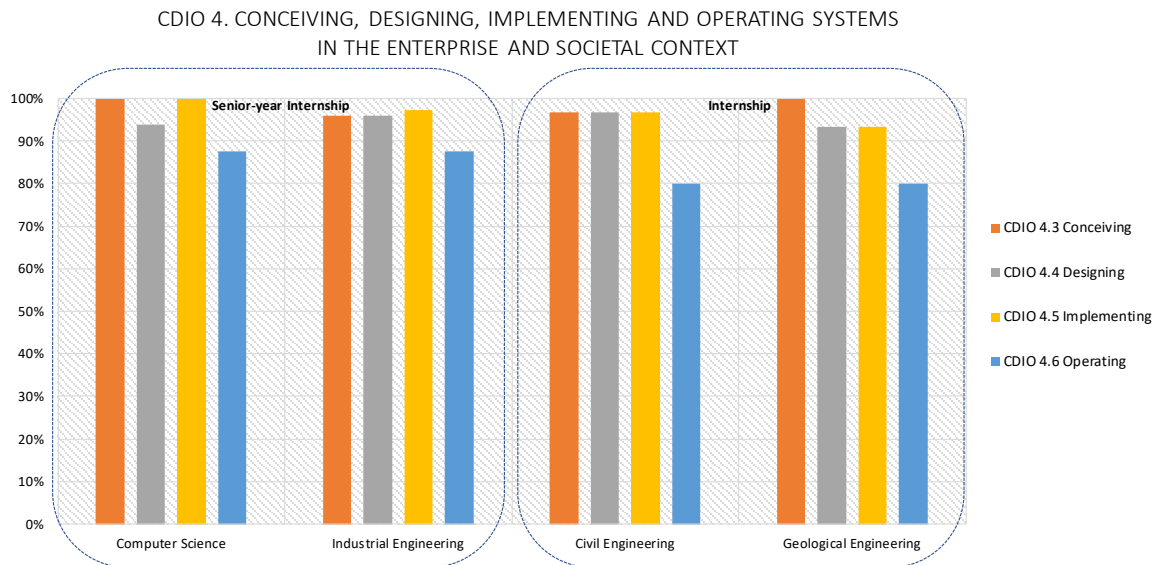IN THE ENTERPRISE AND SOCIETAL CONTEXT

Figure 3. Program graduates' perception of strengthening of CDIO skills

Figure 4 shows that about 70% of graduates of the two programs that have a senior-year internship, Computer Science and Industrial Engineering, state that their senior-year internship helped them get a job within 6 months of graduating. Graduates from the Civil Engineering and Geological Engineering programs, which have a shorter internship a year before graduating, report lower numbers. Graduates from all programs state that the internship helped boost their self-esteem, results being slightly higher for the Industrial Engineering program (75%). Graduates from all programs may take an employability skills workshop, which is given in an online manner to all programs except for Computer Science. Graduates from this last program highly rated the usefulness of this workshop for job placement.
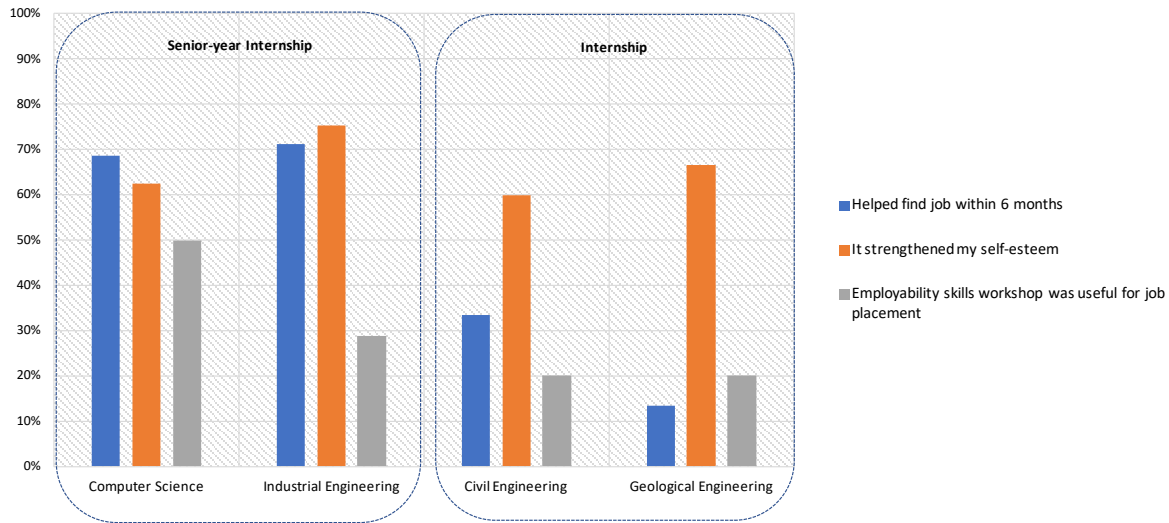
Figure 4. Impact of internships on employability

Table 2 presents survey results regarding the perceived usefulness of experiential learning activities such as project-based learning, service-learning, internships, among others, to the program graduates' job placement. Graduates from the Computer Science and Industrial Engineering rate this usefulness slightly higher (75%) than graduates from the Civil Engineering and Geological Engineering programs (above 60%). Most graduates highly rate their internship experiences regarding the strengthening of their technical skills, above 82% in all cases. Finally, as shown in Table 2, over a third of all graduates entered into a contractual relationship with the company that hosted them during their internships. This number is particularly noteworthy for graduates of the Industrial Engineering program, where 60% of graduates continued working for their internship company after graduating.

Table 2. Graduates' opinions about the usefulness of experiential learning

Statements	Computer Science	Industrial Engineering	Civil Engineering	Geological Engineering
The active learning activities in a real context I had during my studies (project-based learning, service-learning, among others) helped my job placement	75%	75%	60%	67%
My internship strengthened my technical skills	94%	82%	83%	87%
After my internship, I had a contractual relationship with the company	44%	60%	40%	33%

Figures 5 to 8 show the results for the survey's open questions, where program graduates were asked to identify the top two weaknesses that hampered their internship performance, and the top two skills they improved during their internship. All comments were classified, sorted by frequency, and associated to particular knowledge, skill or attitude of the CDIO Syllabus (Crawley et al., 2011). These figures show the resulting comment mappings, classified as either strengths or weaknesses and their frequencies.
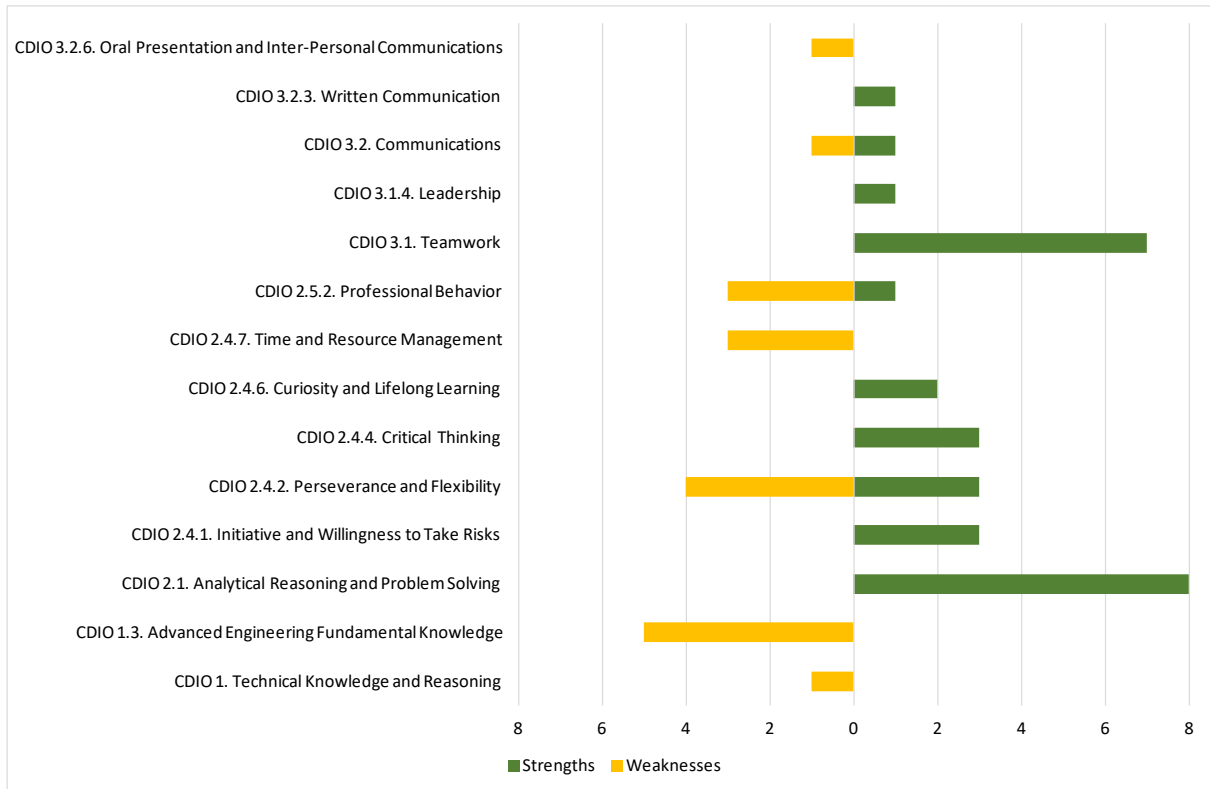
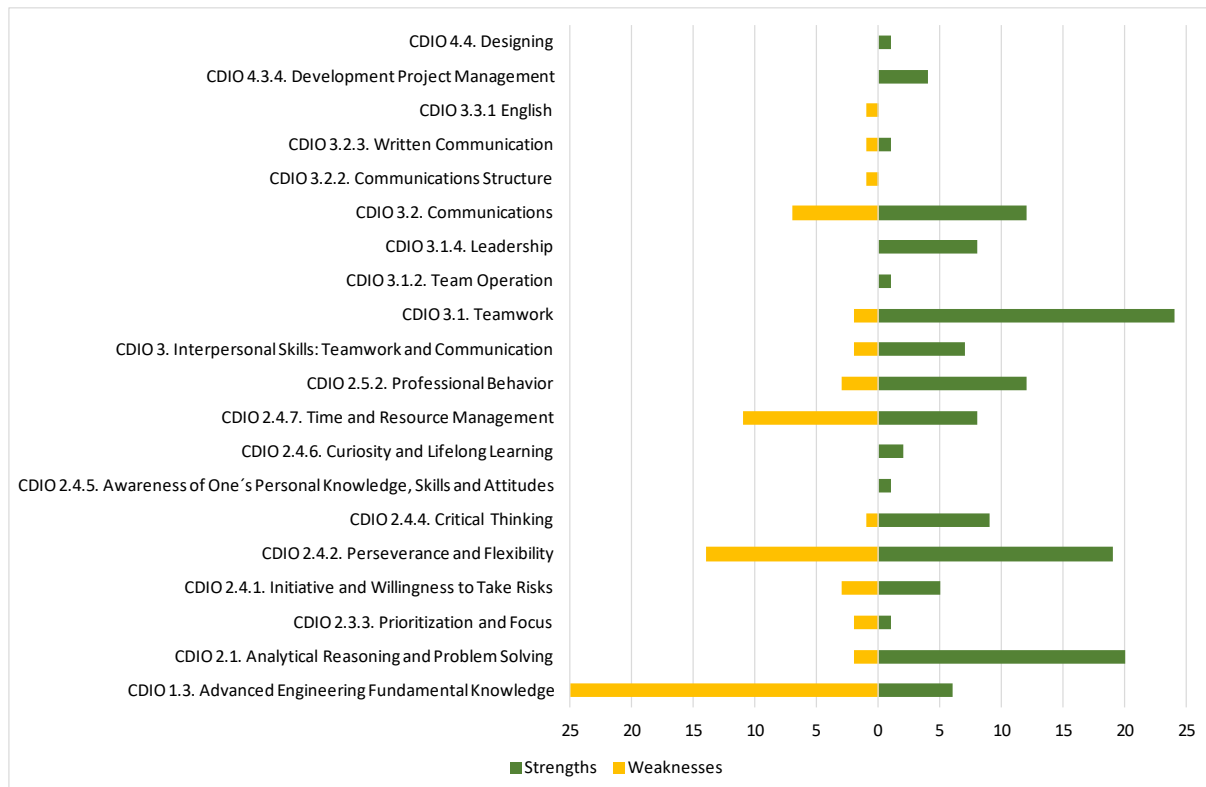Figure 5. Computer Science (16 program graduates surveyed)

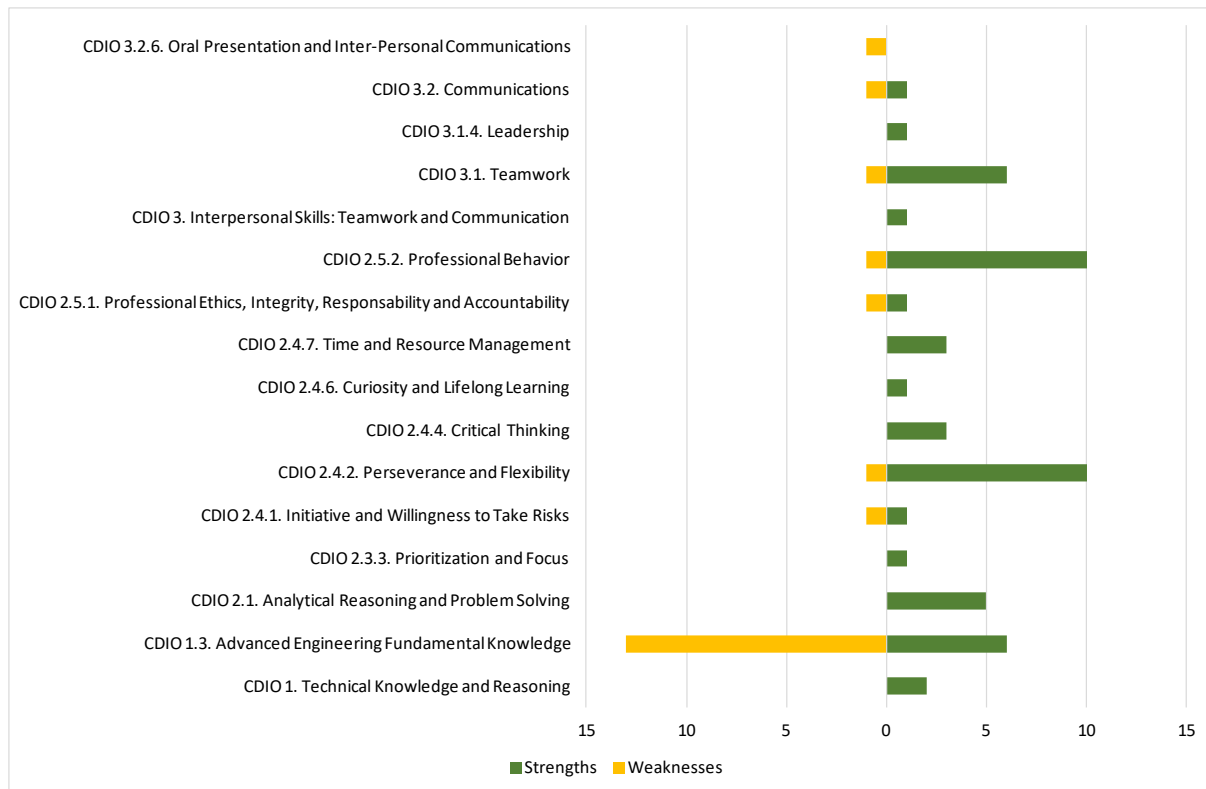Figure 6 Industrial Engineering (73 program graduates surveyed)

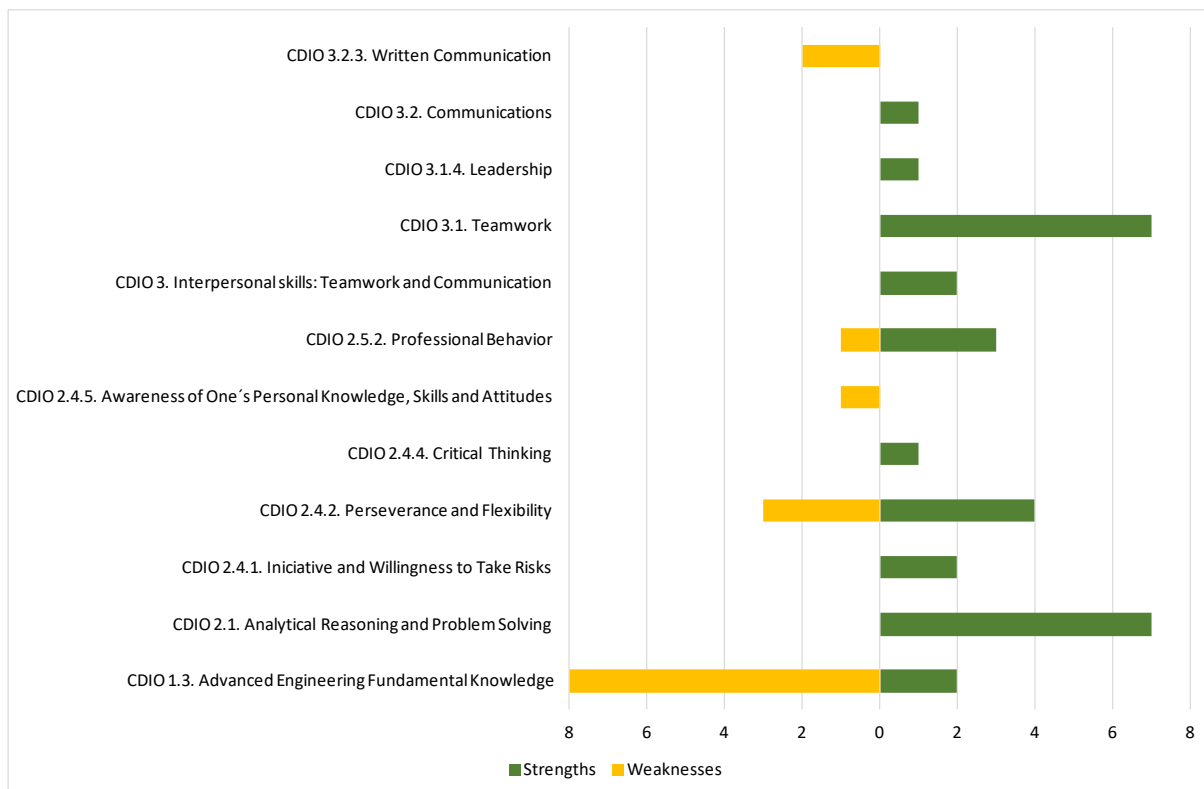Figure 7 Civil Engineering (30 program graduates surveyed)

Figure 8 Geological Engineering (15 program graduates surveyed)

Figures 5 to 8 show that graduates from the Computer Science, Industrial Engineering and Geological Engineering programs mention teamwork (CDIO 3.1) and analytical reasoning and problem solving (CDIO 2.1) as the top two skills they improved during the internship, while Civil Engineering graduates mention perseverance and flexibility (CDIO 2.4.2) and professional behaviour (CDIO 2.5.2) with the two highest frequencies. Regarding the weaknesses that affected their internship performance, graduates from all programs mention with the two highest frequencies their advanced engineering fundamental knowledge, methods and tools (CDIO 1.3), and perseverance and flexibility (CDIO 2.4.2) with the exception of Civil Engineering that has this last one as a strength. It is worth noting that, in general, students do not frequently mention their communication skills as one of their top two weaknesses. However, the study of Muñoz et al. (2018) shows that supervisors find that there is some room for improvement in that skill.

Regarding the online survey's response rates, several possible reasons for a low response rate have been reported in the literature (Saleh & Bista, 2017) that may apply to our case, such as: having an obsolete and/or inaccurate email address list, the email checking habits of people with more than one email address, etc. In our case, program graduates were contacted mainly through their university email address. However, given that they have been graduates for at least a semester, they may not check this address as frequently as was expected.

CONCLUSIONS

Internships, as educational and professional experiences, have been shown to yield many benefits. From our results, graduates' perceptions of the internship's impact are the improvement of their skills and competencies, the rise of their self-esteem and the increase in their employment opportunities, results which agree with the literature. These effects are further emphasized in the case of the longer senior-year internships. Graduates feel that having had a senior-year internship as their last curricular activity helped them decrease job search time and find a job within six months of graduating. As future work, we intend to leverage these positive internships experiences into stronger and tighter collaboration bonds between academia and industry.

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REFINING ENGINEERING MSc THESES WITH A FOCUS ENHANCING STRUCTURE MODEL

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ABSTRACT

We discuss a conceptual thesis structure model and visual tool for enhancing the writing process in the context of an engineering Master's thesis. Our model is based on visualizing the thesis as a series of funnels that adjust the writing focus to the desired scope in each individual chapter. At the end of the thesis, the focus is widened back into the original topic area with a reflection on how the solutions proposed in the thesis have impacted or potentially will impact the field. Using our model gives students the opportunity to write a good master's thesis in various engineering disciplines. In our experience, the Focus Funnel approach has been very useful and effective, resulting in an overall improvement in the quality of engineering Master's theses in our degree program.

KEYWORDS

Engineering education, Master's thesis, Final Project, Learning tools, Standards: 2, 5, 7, 8, 11.

INTRODUCTION

For students studying towards a Master's degree in engineering disciplines, the Master's thesis and the related engineering project in the final year of studies are a demanding and challenging effort. For some, the thesis may be the first extensive independent academic writing task they have encountered, far more demanding than the Bachelor's thesis of their previous degree. To complete the Master's thesis, the students need to apply their technological skills, abilities and learnedness into identifying an engineering problem, studying its relevance to the field, proposing and designing a solution to the problem, testing and analyzing the solution and evaluating its merit. The thesis is very often commissioned by a company, meaning that an efficient and capable thesis student may get directly employed by the thesis commissioning company, potentially leading to a successful career in the industry. On the other hand, a scholarly oriented student would seek a thesis topic in a research group, striving for a salaried PhD candidate position upon completion of an academically excellent Master's thesis.

For any Master's thesis to be completed, a carefully crafted thesis plan is needed. It is a long way from a potentially interesting topic area to identifying a relevant problem, let alone to compose a solid thesis plan aiming to study the topic and to solve the problem in a way that will positively contribute to the discipline and the field. In the planning, a vital part of the process is for the supervisor to provide the student both with a wide view of the problem area and simultaneously a sufficiently narrow focus within which the thesis topic is defined. The process

takes many iterations from the initial idea to a real-world implementable plan requiring significant time and effort from both the student and the supervisor. Therefore, all tools and methods that expedite the process and make it more systematic are of extremely high value.

In this paper, we present our structure model and visual tool for systematic thesis planning and supervision called the *Focus Funnel*. Focus as an abstract concept can be difficult for students to understand in sufficient depth, and as a result, many theses exhibit issues with defining the scope and width of the topic area and the lack of focus on a specific problem or field. The main concept in the Focus Funnel is to efficiently bring the topic area of the thesis into focus while at the same time improving the readability, coherence and overall impact of a thesis. Within the focus, content is narrowed down to the specific problem at hand and its applicable area, problem statement, design and implementation of the proposed solution, and analysis of results. At the end of the thesis, the focus is widened back into the original topic area with a reflection on how the solutions proposed in the thesis have impacted or potentially will impact the field.

While research literature on academic writing is plentiful, relevant previous work on the design of an academic engineering thesis regarding writing focus and structural models is sparse. Research focusing on assessment (see c.f. (Kim, 2010; Valderrama et al., 2009; Vijayalakshmi, Desai, & Joshi, 2012)) and writing practices in engineering (see c.f. (Berdanier & Zerbe, 2018; Braine, 1989; Goldsmith, Willey, & Boud, 2019) can be found, but research and discussion on formal structural models and conceptual tools for engineering theses are yet lacking in the literature. The goal of this paper is to provide a starting point for further discussion.

In our experience, the Focus Funnel has been a very useful and effective tool the use of which has resulted in an overall improvement in the quality of engineering Master's theses in our degree program.

The rest of the paper is organized as follows. Section 2 describes the engineering degree structure within which our model is applied. Section 3 discusses the thesis planning process and goals. Section 4 presents the Focus Funnel model and Section 5 discusses its application in thesis design. Section 6 briefly discusses the role of an overall thesis plan, and the paper ends with a discussion in Section 7.

ENGINEERING DEGREES AT UNIVERSITY OF TURKU

The universities in Finland adhere to the agreements between European countries to ensure comparability in the standards and quality of higher education qualifications, also known as the Bologna process. The study credits are measured in European Credit Transfer and Accumulation System (ECTS) study points, where 1 ECTS credit corresponds to 27 hours of work, and the workload of one academic year is 60 ECTS credit points. The Finnish implementation in scientific universities (like our university, the University of Turku) is a 180 ECTS Bachelor's degree (3 years) in the first cycle of higher education and a 120 ECTS Master's degree (2 years) in the second cycle. Finnish universities of applied science have a different implementation in terms of ECTS credits per cycle for degrees. In the engineering sciences, the second cycle degree awarded by scientific universities is Master of Science in Technology, M.Sc.(Tech.). At the University of Turku, the M.Sc.(Tech.) degree consists of compulsory study modules in the major subject, a compulsory minor subject, elective studies and the Master of Science in Technology thesis. Figure 1 presents the degree structure in detail including the ECTS credit points required for each study module.

Master's Thesis 30 ECTS

Major Subject Compulsory Studies 40 ECTS

Minor Subject 20 ECTS

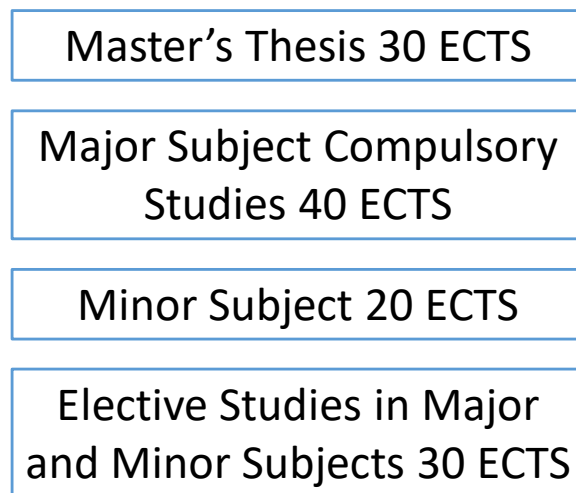| Elective Studies in Major and Minor Subjects 30 ECTS |
|---|

Figure 1. Structure of the Master of Science in Technology degree at the University of Turku.

The minor subject is individually selected to each student to build a special expertise profile according to the student's desired specialization; for example, in our Master's Degree Programme in Information Security and Cryptography, the major subject would be *Security of Networked Systems*, and the minor subject could, for example, be *Information Technology Management* for students considering a career path towards the duties of a Chief Information Officer (CIO) or similar.

During the final year of the studies, the students complete the Master's thesis, yielding 30 ECTS credit points and corresponding to six months of full-time work in the ECTS system. At the University of Turku, the Master of Science in Technology thesis the student must show the ability to do scientific work, management of research methods, knowledge of the research field, and the skills in scientific writing. The goal is to train the student to do theoretical (based on scientific literature) and practical analyses of research problems, conceive and propose solutions to them, design and test the solutions or a subset of them and to report the results in written form. The thesis process increases the student's knowledge and learnedness in the topic at hand, building in part the student's own special expertise profile. A well-made thesis may also lay a basis for continuing studies towards a doctorate. All completed theses at the University of Turku are public documents and the material contained in the published thesis cannot be controlled by a non-disclosure agreement.

THESIS PROCESS AND INITIAL PLANNING

The process of starting a master's thesis varies between universities. In some, there may be an application process and a formal permission is required for starting a thesis. In others, the process may be quite informal. At the University of Turku for theses in the engineering disciplines, the process is closer to the latter. When a student is ready to start writing a thesis, the first contact is with a designated faculty member who has an initial discussion with the student on their plans. Some students have a ready topic and plan, often from the company, the student works at, while others may have no topic at all in their mind.

In an engineering thesis, the goal, in general, is to provide a solution to an engineering problem through a systematic process of design, testing, analysis and improvement. The emphasis of an engineering thesis is on the practical part, and therefore it is beneficial to the student to quickly get to the "meat" of the issue at hand. When writing the thesis, the student needs to proceed from theoretical frameworks to practical questions relatively quickly, but without sacrificing scientific robustness and wider context to the theoretical background. At the end of the thesis, when the engineering problem has been solved, it is also important to contextualize practical observations made in previous chapters back to relevant theoretical frameworks presented earlier in the thesis.

Because the solution-oriented approach described above is often taken when writing a thesis in engineering fields, we have found that a common structural template is suitable for a significant part of theses. We will discuss the structural thesis template that we use in our lab later in this paper, but first, it is necessary to introduce the conceptual model that is used in conjunction with the structural thesis template.

FOCUS FUNNEL MODEL

The Focus Funnel conceptual thesis model is based on a visual funnel-like approach to bringing the topic area into focus and improving the readability, coherence and impact of a thesis. By following and checking their work against this model, the student can more easily maintain the writing focus and improve the quality, readability and impact of their thesis.

The Focus Funnel model is shown in Figure 2. This is how the model is presented to prospective thesis workers when discussing thesis structure and how to approach writing a thesis in our lab. Starting from the wider topic area description and background information in
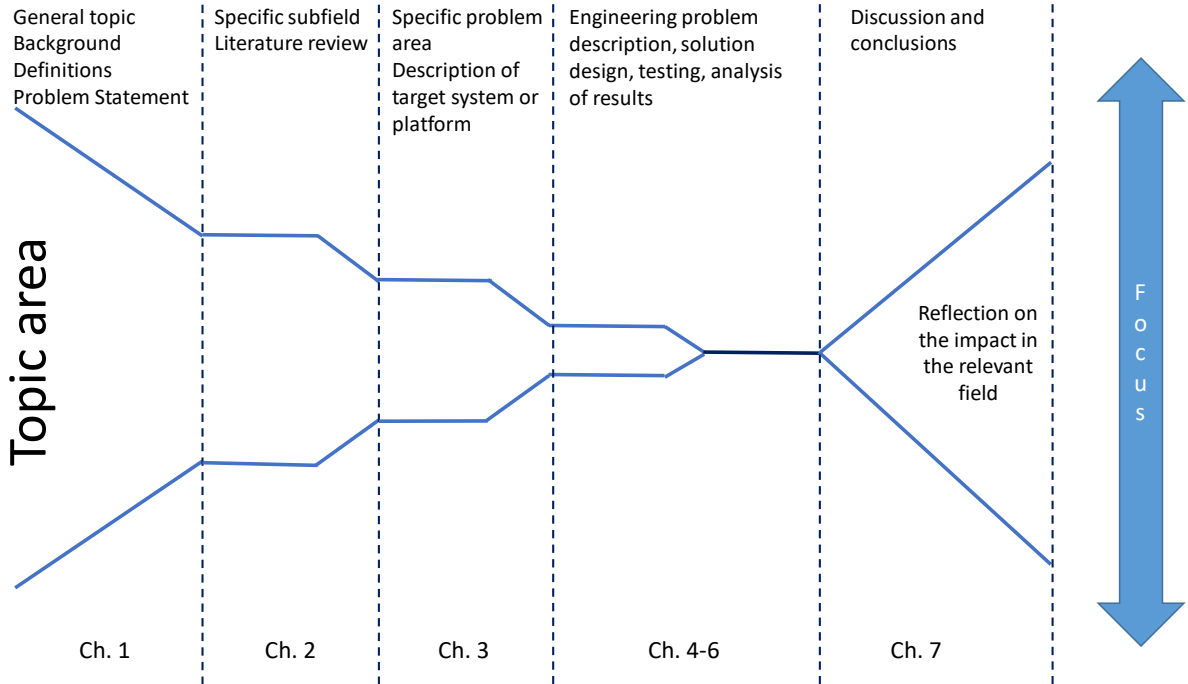

Figure 2. Thesis Focus Funnel model.

the first chapter, the Focus Funnel instructs the writer to narrow the focus of the thesis quickly into the specific sub-field of the thesis in the next chapter. Subsequent chapters should further narrow the focus down to the specific problem at hand, its applicable area, and finally to the engineering problem statement that is at the core of an engineering thesis. Next, design and implementation of a solution to the presented engineering problem follow. The results of testing the implementation are analyzed next, giving insight into how well the proposed solution solves the original core problem according to the metrics chosen for the measurement. Finally, at the end of the thesis, the focus should be widened back into the original topic area with a reflection on how the solutions proposed in the thesis have impacted the field. For many students, getting to this phase can already be laborious, but this last and perhaps most important part of the thesis is often overlooked. Often a student reiterates their results from the previous chapter and concludes that the core engineering problem of the thesis has been solved (or not, followed by analysis on *why* not) in the reference frame in which the research question is posed.

What is often missing, and what our Focus Funnel model emphasizes upon, is wider reflection on the general relevance of the results to the field. Granted, more academically inclined students will gravitate towards this approach, perhaps reflecting a better grasp at the "big picture" – something that is a necessity when aiming for PhD studies. This part is often overlooked by students and inexperienced supervisors, and it is thus important to stress the importance of widening the focus of the thesis in the discussion phase, up to creating a model such as this and systematically driving all students to consider this when writing their thesis.

APPLICATION IN DESIGN OF THESIS

To facilitate the structural design of the thesis based on the Focus Funnel, we have developed a common structural template based on the funnel. The structural template is suitable for a significant part of the engineering MSc theses, and together with the Focus Funnel, it forms the basis for creating the initial thesis plan. The structural template is a description of the typical chapter-wise content of a proper thesis. The following presents the chapter-wise guidelines provided to students after they are introduced to the Focus Funnel. The chapter numbers are not fixed in the process; the structural plan includes Chapter numbers as a point of reference only. For example, what is listed as Chapters 2-3 below might be three chapters in one thesis and just one in another thesis, depending on the exact topic of the thesis.

Chapter 1 of the thesis is the Introduction. It should present a general introduction to the topic area, leading up to identifying some problem(s), shortcoming(s) and/or R&D need(s) that are relevant and will be discussed in the thesis. The last two paragraphs of the introduction are extremely important in terms of identification of the problem, motivation of the overall content, and mapping the content together to form a whole:

- **"In this thesis a new ... is proposed ..."**: This is where the student identifies the main thing done in the thesis, why it is important and relevant (and to whom), how should it be solved, what parts of it are solved in this thesis and what is left for future work, how will the field be affected by the thesis. We ask the student to consider in which way the world will be a better place after this thesis is published.

- **"The rest of the thesis is organized as follows"**: The student is instructed to give an outline of the thesis, explaining how the chapters of the thesis are relevant for the problem identified in the previous paragraph and how the chapters relate to each other. When such a description of the organization of the thesis is provided here, no reader

will need to question it later when reading the thesis as the student already has explicitly stated the necessity of each chapter.

Chapters 2 and 3 of the thesis review relevant background information, literature and/or scientific theory. It should contain for example relevant findings from history, industry and the state-of-the-art. The covered theoretical background is necessary for the reader to understand the rest of the thesis and the choices made by the student in it. There can be more than one of these background chapters if necessary; for example, there could be one chapter dealing with background and literature and another one dealing with the details of some specific communication protocol that needs to be understood in order to understand the rest of the thesis.

Chapter 4 is the description of an existing target system used in the thesis as the platform or the technological basis for the design and implementation of the main contribution. It is a continuation of the background information provided to the reader in order to understand the main contribution of the thesis. The target system could, for example, be a firewall/intrusion prevention system, a microprocessor, an embedded system, a software suite, an SDK or an outdated in-house product on top of which the new contribution is built in the thesis. There can be more than one of these existing system chapters if necessary; for example, one chapter presents an in-house platform and another one presents the development environment used for the design and implementation.

Chapter 5 presents the specification and design of something new based on the information presented in earlier chapters. This could, for example, be improving a part of the target system based on a theoretical analysis and an analysis of shortcomings of the existing system, based on the needs of the company that has commissioned the thesis.

Chapter 6 presents the implementation and verification of (a part of) the newly specified and designed contribution as described in Chapter 5, including the analysis of results and a discussion of the significance and success of the implementation as well as the shortcomings of the solution. Instead of the physical implementation, this may also be a simulation and an analysis of simulation results, depending on the thesis topic.

Chapter 7 is the conclusion of the thesis. It provides concluding remarks, a discussion of the relevance and significance of the obtained results and how generalizable they are beyond this thesis. This chapter also outlines the sorts of future work that is already planned or could be done based on the work presented in this thesis. The author should revisit the original broader topic area and provide a reflection on how the solutions proposed in the thesis have impacted or will impact the field.

The Conclusion chapter is followed by a properly formatted list of referenced literature. The student may choose which style of referencing is used and it must be followed consistently throughout the thesis.

THESIS PLAN

After discussing the Focus Funnel, the thesis structural template and overall thesis planning with the student, the student is tasked to start crafting the initial thesis plan. As the plan, the student is required to provide one sheet of paper containing the following:

- A working title for the thesis.

    A 3-5 -line description of the thesis content: what is the problem to be solved, why is it relevant, how does the student plan to solve the problem and test the solution, and what are the expected outcomes once the thesis is published.

- A draft table of contents, including descriptive main chapter titles and titles for 1-2 levels of subsection headings.

In the planning, the student is encouraged to consider that the thesis length should be 50-100 pages, page 1 being the first page of the Introduction chapter. In a minimum length thesis, page 50 would be the last page of the Conclusion chapter.

After a suitable planning time, for example, 1-2 weeks, a meeting is scheduled with the student to jointly review the initial plan. From here onwards, the planning is an iterative process and the plan will evolve throughout the thesis process, for example, to reflect new information acquired during the work and the possibly received additional requirements from the company commissioning the thesis. The Focus Funnel and the structural template are in a key role from the beginning of the thesis project all the way to the publication of the completed thesis.

DISCUSSION

An important observation we have made is that the same Focus Funnel can be applied to individual chapters within a thesis, thus creating a structure of embedded Focus Funnels within the thesis. When we place the model in context with an individual chapter, we can identify similarities in how the focus area of a chapter is first defined, then the focus is further narrowed down to the target level for the chapter (literature review, introduction of more complex concepts, design of solution, etc.). By designing individual chapters with applying the Focus Funnel approach to subsections, a student can keep the narrative plot of the thesis intact and assure that the individual chapters do not veer away from the focus area of the thesis. This also assures that by expanding the focus of the chapter in the final section, the issues discussed within are also brought into a wider context, therefore improving the readability and impact of individual chapters, and the whole thesis, to the reader.

While we do not claim that the Focus Funnel is the One True Way to write an engineering master's thesis, we have observed that following the Focus Funnel model makes it easier for students to write a good thesis. It helps to visualize the thesis writing process and helps significantly with the difficult task of selecting and digesting relevant literature in the literature review phase.

The success of the thesis model can be further substantiated with further study on how the use of the model affects the thesis process. We are planning a systematic study on how the use of the Focus Funnel affects the quality of engineering theses at our department, and gathering more data from other institutions, if possible.

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INTEGRATED EDUCATION FOR
MID-ADOLESCENT ENGINEERING STUDENTS IN KOSEN

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ABSTRACT

This study examines methods for imparting first-through-third-grade engineering students in KOSEN (one of the Japanese tertiary educational institutions, the National Institute of Technology, which conducts 5- or 7-year-rapid growth of engineers after grade 9) with fundamental reading competence in response to our finding that some students have difficulty understanding textbooks and dictionaries. We used the Reading Skill Test (RST) to determine students' reading competencies in October 2018. Students' results were relatively insufficient in some component skills such as paraphrasing, representing figures or tables with sentences, and instantiating with given definitions. In response, we aimed to develop effective methods to increase the reading skills of 15- to 18-year-old KOSEN students. Such students must acquire basic literacy to understand various types of documents and diverse topics in engineering. In our recent research, we have identified some potentially successful methods, such as keeping a short journal in a business diary to establish self-management skills; reflecting on lectures in Japanese focusing on connecting two sentences with conjunctions; and using figures and tables to comprehend English also verified the RST results with a language skill assessment. In this paper, we report our recent practices.

KEYWORDS

Reading comprehension, Reading Skill Test, TOEIC/TOEIC-IP, KOSEN, Standards: 8, 11.

INTRODUCTION

The implementation of active learning methods has urged educators to improve their lectures using several strategies such as group work, discussions, and flipped learning. However, these student-centered attempts cannot produce positive effects unless students themselves shift their learning attitudes to become more autonomous. Teachers should encourage students to be persistent and independent learners during the lectures as well as before and after class and outside school. According to *OECD Reviews of Tertiary Education: Japan* (2009), one of Japanese tertiary educational institutions, the National Institute of Technology, commonly known as KOSEN, provides educational opportunities in business and technology for "students who are not theoretically inclined in a college of technology after grade 9, focusing over the next 5 to 7 years," "while in other OECD countries such students may simply drop out of high

school, ending further education" (54). In fact, some students have high aspirations to become engineers or scientists, and others have difficulty understanding textbooks and dictionaries. This problem makes it difficult for such students to establish self-directed learning habits and also leads to the stagnation of lecture quality. Therefore, in this study, we focused on developing students' basic self-administration skills as well as their reading comprehension.

In 2016, we enhanced first-year students' fundamental competencies through homeroom activities in terms of "Fundamental Competencies for Working Persons," which consists of three competencies with twelve competency factors and defines the basic abilities required for working with various people in the workplace and in local communities, set forth by the Ministry of Economy, Trade and Industry in February 2006. We introduced a schedule book to train students in basic self-administration skills. In October 2018, we employed the Reading Skill Test (RST) to determine 81 students' reading competence. The results showed that some of the students' component skills were relatively insufficient, such as "representing tables and figures." As it goes without saying that these are compulsory skills for engineering students, we intentionally introduced figures and tables to aid students' comprehension of English articles. We also introduced reflection activities, in which students were required to connect two sentences with conjunctions in Japanese. Additionally, in this study we investigate the mutual relationship between RST and English competency, comparing the RST results with an English skill assessment, Global Test of English Communication (GTEC).

It is necessary to impart students with these basic skills in the early stage of engineering education, from the ages of 15 to 18. In this paper, we report the results of our attempt and future prospects in terms of facilitating students' literacy.

MATERIALS AND METHODS

・ Analysis of *Self-Assessment of Fundamental Competencies for Working Persons*
・ Individual coaching with a schedule book
・ Structured Group Encounter (SGE) in Homeroom Activities
・ Reading Skill Test (RST)
・ Improving English Lectures: Diagrams, Precedent Vocabulary Test, and Reflection
・ Comparison of the RST results with GTEC

RESULTS AND DISCUSSION

Fundamental Competencies for Working Persons, schedule book, and SGE in 2016

In 2016, we focused on the "Fundamental Competencies for Working Persons" to enhance first-year students' fundamental competencies through non-curricular activities: introducing a schedule book or diary to coach students individually and provide them with basic self-administration skills; providing students with activities to improve their interpersonal and communicative skills; and conducting questionnaire surveys to examine the efficacy of these approaches (Sekine et al., 2016).

Individual Coaching with a Schedule Book

In April, five first-year classes were recruited to use a schedule book, *Foresight FURIKAERI-RYOKU KOUJOU (improving the ability to review) TECHOU*. We then examine students' schedule books and offered personalized advice if necessary in order to encourage them to utilize the diary as a means for compiling their to-do lists, learning portfolio, and drafts of their reflections on their learning plans for examinations from the viewpoint of establishing the plan-do-check-action (PDCA) cycle. Many students mentioned that after using this schedule book, they became more motivated and were able to study systematically. In 2017, we supplied

students with the *KOSEN TECHOU Schedule book*, which was a small dairy specializing in KOSEN Education that was produced by KOSEN students and teachers, to continue to facilitate their basic self-administration skills.

Structured Group Encounter (SGE) in Homeroom Activities

Soon after entering college, students are required to discuss various topics as part of their homeroom activities, such as the division of duties and school festival events, even though they barely know each other. We promoted this time as an opportunity for arguments or discussions to enhance students' personal and interpersonal skills, such as consensus building, with some methods based on Structured Group Encounters (SGE). These activities contributed to a friendlier atmosphere.

Analysis of Self-Assessment of Fundamental Competencies for Working Persons

We conducted a questionnaire survey, a self-assessment of *Fundamental Competencies for Working Persons*, in the three first-year classes in July and February. Participating students were asked to evaluate "12 Competency Factors" with 36 questions using four scales: 4 corresponds to "Strongly agree," 3 to "Agree a little," 2 to "Disagree a little," and 1 to "Strongly disagree." The results and transitions are shown in Table 1. Given that the results indicated that average values all increased, the changes may account for the efficacy of our attempts to improve their feelings of self-esteem in Figure 1.

Table 1. Results of the Self-Assessment of Fundamental Competencies for Working Persons

3 Competencies	12 Competency Factors	Average		Standard Deviation	
		Jul. 2016	Feb. 2017	Jul. 2016	Feb. 2017
Action	Initiative	2.94	3.03	0.55	0.55
	Ability to infuluence others	2.99	3.08	0.62	0.67
	Execution Skill	2.95	3.00	0.59	0.60
Thinking	Ability to detect issues	2.93	3.14	0.55	0.59
	Planning skills	2.82	2.98	0.58	0.60
	Creativity	2.87	2.91	0.67	0.62
Teamwork	Ability to deliver messages	2.85	2.96	0.57	0.63
	Ability to listen closely and carefully	3.18	3.23	0.56	0.53
	Flexibility	3.16	3.21	0.60	0.53
	Ability to analyze situations	2.94	3.08	0.62	0.62
	Ability to apply rules and regulations	3.36	3.44	0.52	0.52
	Ability to control stress	2.94	3.04	0.76	0.72

Many students evaluated these factors as significantly low, and some factors indicated a bimodal or trimodal wave in July. Although the tendency still existed in February, the deflections seemed to have improved; the lower group decreased (A) while the upper markedly elevated (B) in these eight factors. According to Yano et al. (2018), early and long-term engineering education and overcrowded curriculum in KOSEN could be inconsistent with mid-adolescent students' aspirations (18). Therefore, we should notice that the increase of the deviation in "Ability to control stress" (C) indicates the need for teachers to approach 15-year-old engineering students proactively because they might be dissatisfied their own choices of specialty or encounter problems in their school lives.
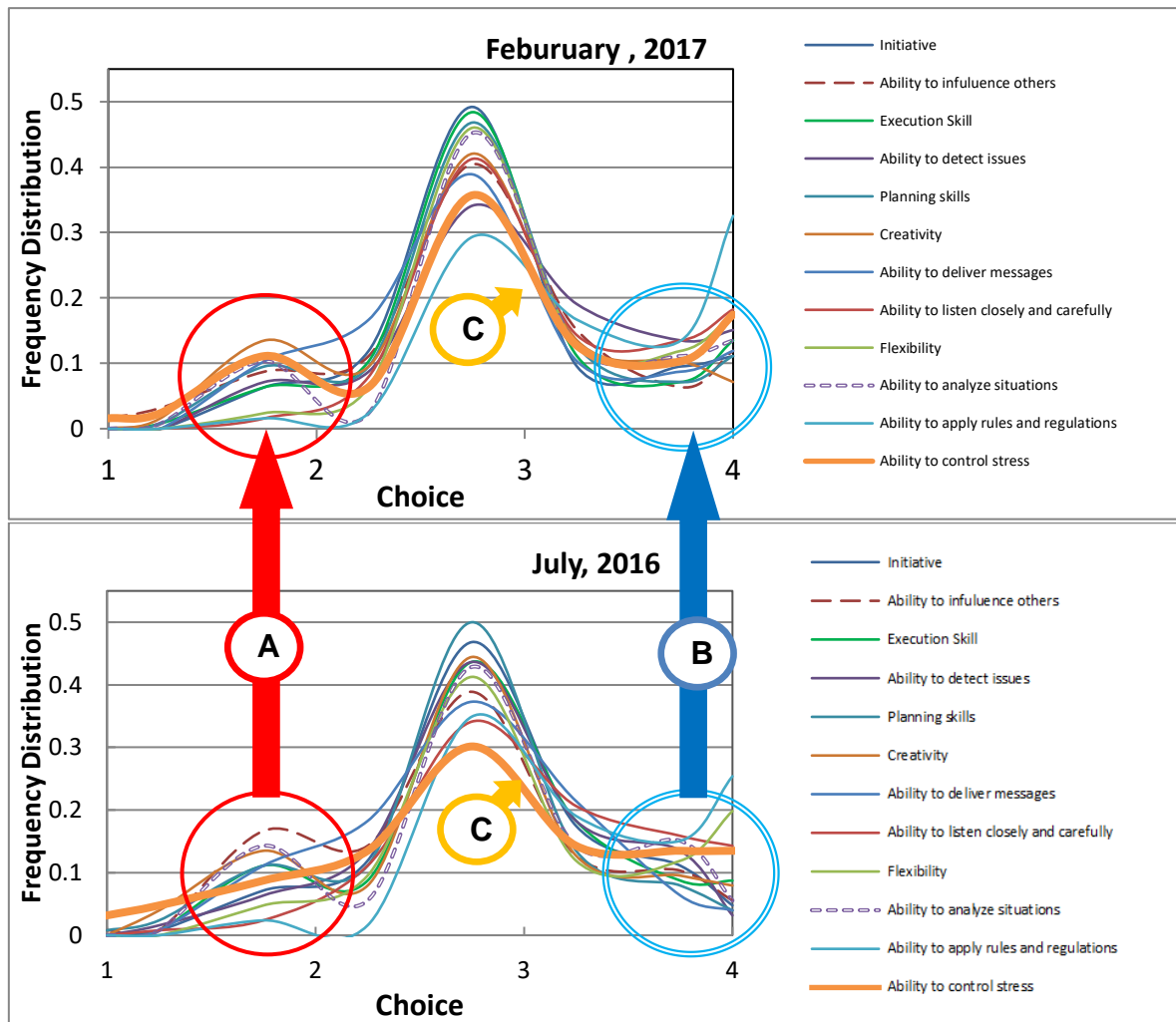
Figure 1. Transition of the Extracted Eight Competency Factors

RST and English Comprehension in 2018

We employed the Reading Skill Test (RST) because we found that many students had trouble understanding and reading textbooks or dictionaries and a remarkable number of students were not able to follow lectures. We then developed English lessons on the RST results (Sekine et al., 2019).

Analysis of RST results in October

According to Arai et al. (2017), RST is a new reading skills test that assesses examinees' basic language skills involved in the comprehension of texts. The test consists of sentences taken from junior high and high school textbooks and dictionaries. Arai et al., defined six component skills relevant to reading:

1. Dependency Analysis (DEP): the ability to recognize dependency relations between words and phrases in a given sentence.
2. Anaphora Resolution (ANA): the ability to understand references to earlier or later items in a text.
3. Paraphrasing (PARA): the ability to recognize similarities between sentences.

4. Logical inference (INF): the ability to determine what can be inferred from a sentence, what conflicts with it, and what does not relate to it.
5. Representation (REP): the ability to represent an image (figure or table) by comprehending a sentence of the textbook.
6. Instantiation (INST): the skill of understanding how to use a term correctly according to a given definition of the term. INST is comprised of two elements, INST1 (definitions taken from the dictionary) and INST2 (definitions taken from mathematics and science).

(Arai et al., 2018)

In October, we conducted RST to investigate 81 students' reading competence (42 first-year students and 39 third-years). The obtained results are shown in Figure 2; some of the component skills are relatively insufficient, such as paraphrasing (PARA), representing (REP), and instantiating (INST). In addition, bimodality is presented in several component skills. The results confirmed our impression that a certain number of students have trouble understanding the textbook, dictionaries, and teachers' explanations in KOSEN.
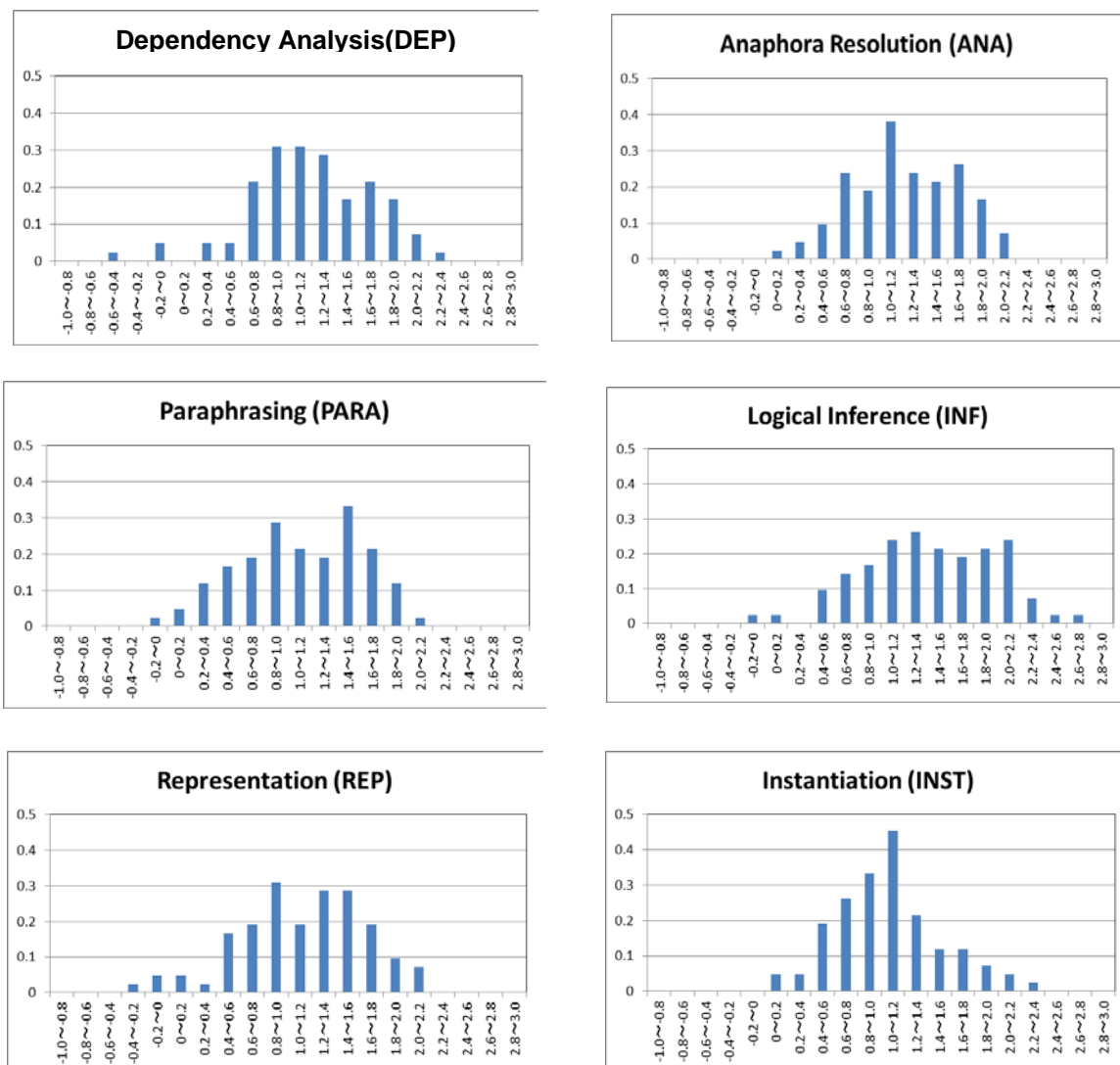

Figure 2. The results of RST in Six Component Skills (October 2018)

Improving English Lectures for Third-graders

As RST Component Skills may be adapted to English learning, we assume that the findings from RST can support recommendations to deal with English materials related to those three component skills. Accordingly, we developed some activities in English classes to help students develop basic literacy:

1. Figures and Tables to comprehend English articles: Tables and/or figures are used to summarize English articles. Students cooperate to determine the outline of texts in groups.
2. Precedent Vocabulary Test: Quick vocabulary tests have been included at the beginning of classes since May 2018. The questions on these tests are related to the words or phrases that will be discussed in the following lesson. The main purpose of this is to stimulate students to prepare for lectures autonomously and to make it easier for them to understand the contents of lectures.
3. Reflection to establish learning habits: Students review preparations, attitudes, and understandings.
4. Others: Assignments are given on definitions of newly presented or important words to provide students with paraphrasing skills. An experimental English class was carried out on December 17, 2018, to share teaching methods with other KOSEN teachers.

We frequently conduct questionnaire surveys to develop the lectures for third-graders. First, we can see the variation of the students' learning time per week and the difference between their preparation and review time per week in Figure 3. The students estimated their "learning time" for their English classes alone, including their autonomous learning for TOEIC or English conversation classes outside school. We can infer from the results that the Precedent Vocabulary Test is quite effective for preparation. In addition, many students wrote in their reflection papers that they realized the importance of preparation because preparation makes it easier for them to understand lectures. However, it is also necessary to introduce activities that will encourage students to review lectures.

Second, the results of class evaluations show the effectiveness of our approaches: around 80% of students regarded these activities as effective strategies (Figure 4).

We also assessed students' English competency with an objective assessment and compared with their RST scores. We will conduct RST again and verify the effect on Japanese reading skills and the causal nexus between Japanese and English reading skills with the TOEIC-IP scores in February 2019.
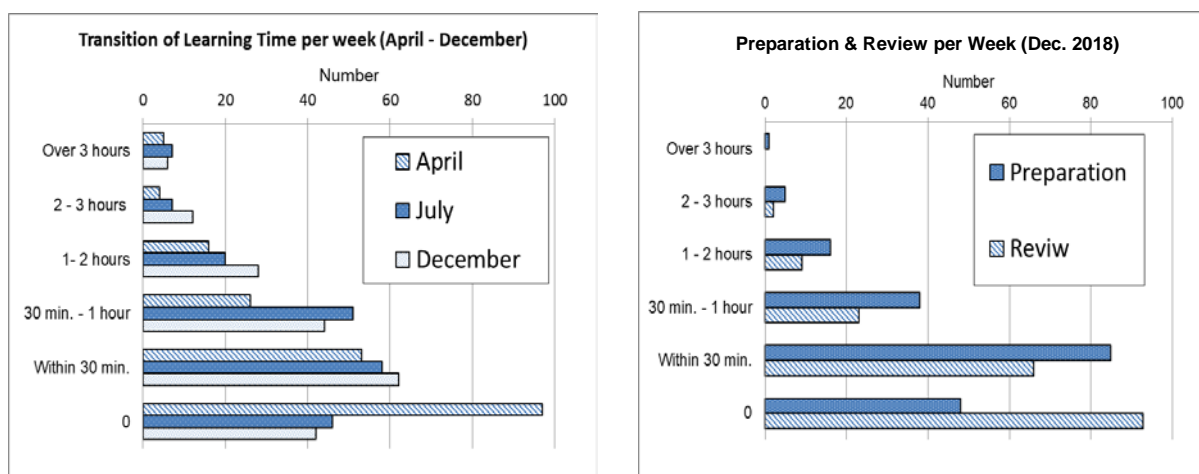

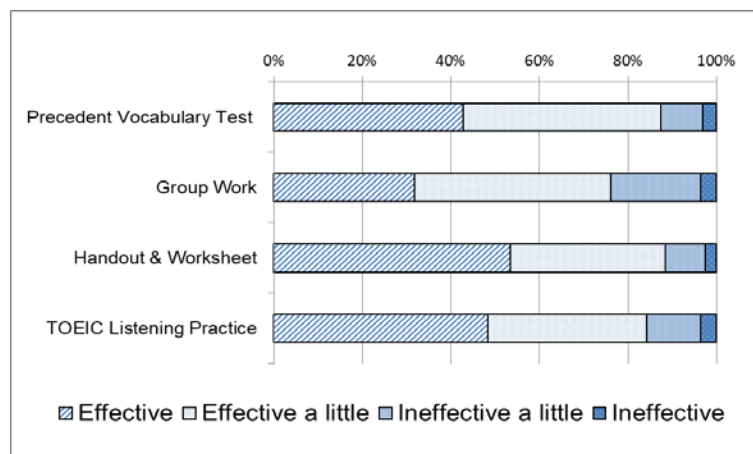Figure 3. Students' Learning Time Per Week for English Classes

Figure 4. Questionnaire Survey Results of Students' Class Evaluation

Comparison of RST with English Assessment

First, we compared students' RST results and their scores on GTEC (paper-based), which is an English Skills certification examination produced by Benesse Corporation in Japan. The examinees were 41 first-graders that took both GTEC Core (April 2018) and RST (October 2018) and 38 third-graders that took both GTEC Basic (October 2017) and RST (October 2018). The scatter plots (Figure 5) indicate the interrelations between the RST average score (5=high, 1=low) of Six Component Skills and GTEC Reading (◆), Listening (□), and Writing (△) scores. This figure shows that students' Reading and Listening scores have some correlations with RST, while there is very little correlation between RST and Writing scores in both grades.
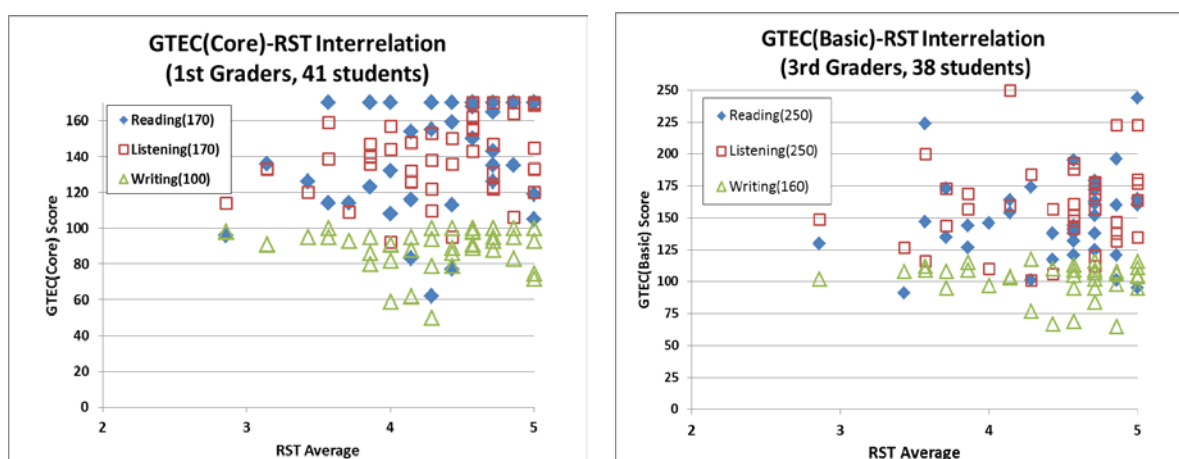

Figure 5. RST-GTEC Score Interrelations

Second, we classified the examinees into groups using the RST numerical values of Six Component Skills and compared the GTEC average points, because we had confirmed that some students had low values (3 or less) mixed with high (4 or 5) in RST Six Component Skills. Given that the low component skills substantially influence their Reading sequence, the comparison of those classified groups can clarify the mutual relation between RST and English Reading and Listening competency. As a result, we showed that the first-graders had remarkable gaps in Reading, and the third-graders had a slight difference in the Reading average points of the two classified groups (Table 2).

Table 2. Comparison of GTEC Average (Reading and Listening) Classified with the Evaluation of RST Six Component Skills

	Classification with RST Six Component Skills	1st Graders			3rd Graders		
		Number	R(170)	L(170)	Number	R(250)	L(250)
(a1)	With "3 or less"	22	139.5	132.8	18	148.7	161.6
(a2)	All "4 or 5"	19	145.6	145.8	20	149.8	157.9
(b1)	With Multiple "3 or less"	13	134.2	133.7	11	148.6	159.5
(b2)	With Single "3 or less" and All "4 or 5"	28	146.0	141.2	27	150.7	159.0
	Examinees (Class)	41	142.3	138.8	38	150.1	159.2
	Grade	195	143.5	142.0	204	152.1	159.1

Third, we investigated the frequency of the classified groups. It is suggested that (D) the first-grade examinees bearing multiple "3 or less" in RST Six Component Skills could compose the lower group of bimodal or trimodal in Reading and Listening (Figure 3), and that (E) the third-graders with multiple "3 or less" also could compose the lower group in Reading and Listening (Figure 4).
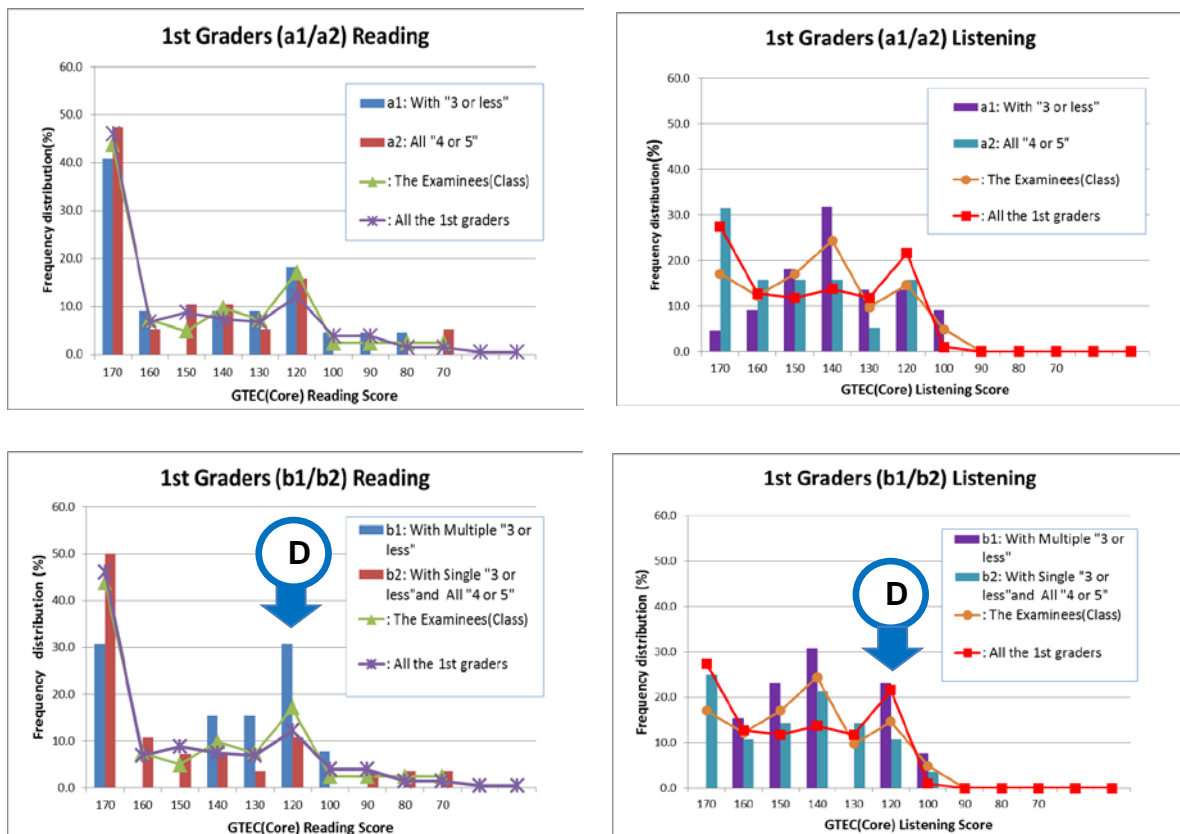

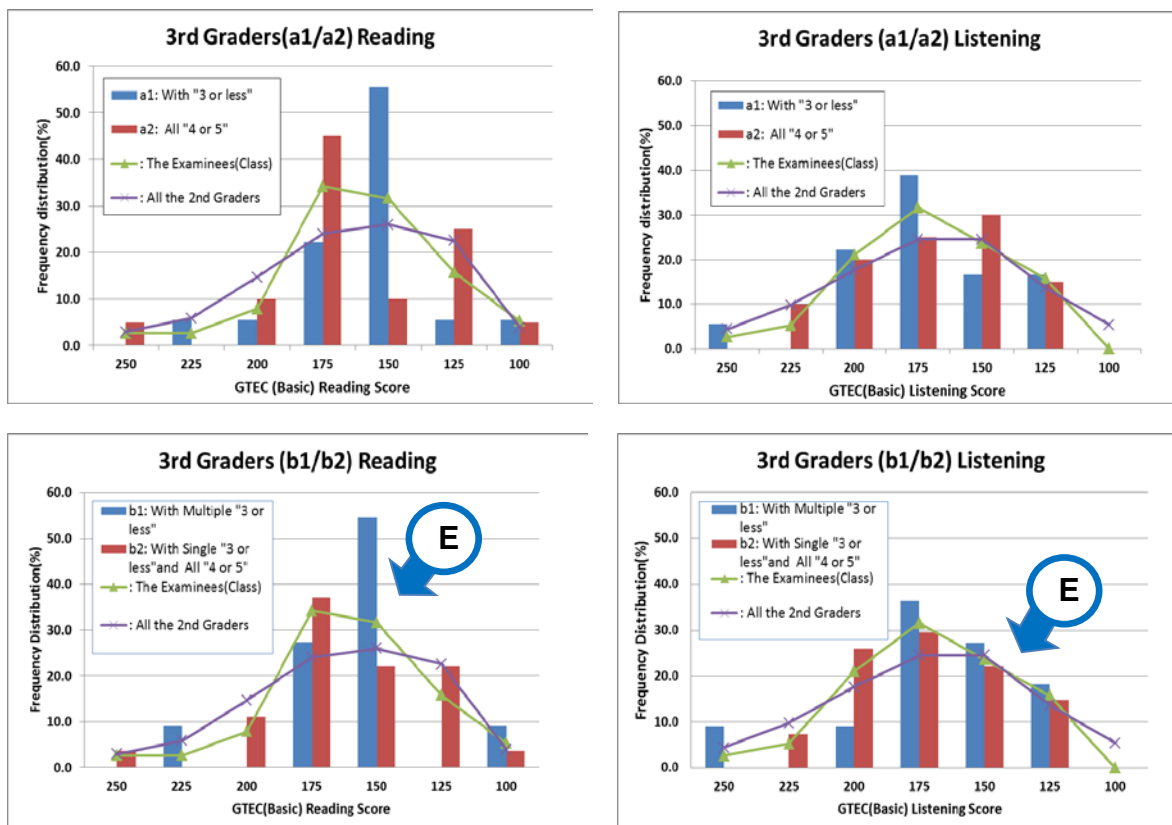Figure 3. Comparison of GTEC Scores Classified with RST Grades (First-Graders)

Figure 4. Comparison of GTEC Scores Classified with RST Grades (3rd Graders)

These results raise interesting implications concerning the mutual relation between RST Six Component Skills and Reading and Listening in English; slow learners might have trouble in some aspects of reading, and reading competency has a causal relationship with Listening scores. It is quite possible that reading competency significantly influences younger students' learning more than that of elder students, although we are unable to confirm this conclusion from our results, as the number of students and variations surveyed is relatively small in this study. It is also necessary to analyze each question connected with the component skills and compare the obtained results with other assessments or subjects. The next step would be to verify the results obtained from this study with scores from the TOEIC-IP test that the third-graders will take in February 2019.

CONCLUSION

The results of this study show that our investigations have a positive impact on mid-adolescent engineering students by cultivating their autonomy and reading competence in the early stage of their technical training and engineering education. Although non-curricular aspects are often ignored the subject instruction, this study is an important contribution because it may allow educators to encourage students to increase their self-esteem in various aspects of their school lives. Additional research is required to optimize the method to be a nexus between curricular and non-curricular approaches.

ACKNOWLEDGMENT

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How do Engineering Students Design Projects with Social Impact?

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ABSTRACT

In Colombia, poor management of the water resource creates water-related problems. These problematic situations require sustainable engineering solutions developed by professionals with the ability to recognize global needs, teamwork and the impact of their solutions on the future of humanity. In this sense, to reinforce the processes of quality in the training of engineers, a methodology has gradually been conceived that has given rise to a whole learning movement called Ingenieros sin Fronteras- Colombia. A team of professors, students and alumni of several programs of engineering have complemented the CDIO proposal with observation and participatory phases. Due to CDIO approaches have proven to be a powerful tool for developing professional skills by creating a formative identity through active learning, the training process in undergraduate and master courses has been enriched based on the oCDIO proposal. In this article, we present the learning methodology with which groups of students perform an engineering solution design with the ambition of impact on society. This methodology was implemented in the course of Industrial Engineering from 2012 to 2016. Results show that this methodology allows students to develop (1) professional skills related to communication and problem-solving, and (2) feasible engineering proposals that go beyond traditional approaches, and (3) the methodology promotes flexibility, autonomy, initiative, and active participation.

KEYWORDS

Participation, Observation, Sustainability, Standards: 1, 5.

INTRODUCTION

Engineers play a significant role in society, where their technical solutions have a high impact on the design of social and environmental systems. We are facing a crisis inside engineering practice, which emerges from applying technical knowledge that does not affect life, nor institutions, nor what happens in the daily life of the communities (Cech 2014). For example, the percentage of people in poverty in Colombia is 27.8% and the percentage of people living in extreme poverty is 7.9%. In addition, the increasing

inequality in this country plays a key role, reaching 0.535 on the Gini coefficient in 2015 (World Bank 2016). In this way, it is pertinent to investigate mechanisms or artifacts to teach/learn socially responsible engineering and that, through an adequate structure, achieve societal goals in the short and medium term.

Therefore, our world requires professionals with the capabilities to innovate, work together, understand complex situations and generate feasible solutions (Nussbaum 2005)(Nussbaum 2005)(Nussbaum 2005). Engineering students are increasingly interested in contributing to the design and development of these effective solutions for social problems (Beever and Brightman 2016). Understanding how engineering solutions can generate community change for the public good is important for professors (Leal Filho and Pace 2016, chap. 6), researchers (Lemons et al. 2014), professionals (Gómez Puente, van Eijck, and Jochems 2014), and students (Weber et al. 2014). The problem remains on that engineering programs, since their consolidation after the Second World War, have been taught in a deductive way (Goldberg 2012) This has privileged the sciences within engineering (Goldberg 2008), where professors approach first to the required theory, followed by typical problems of textbooks and finally, sometimes, real-world applications. As King (2012) points out, this structure needs profound changes that allow an engineering education focused on professional practice, autonomy, and deep and experiential learning. These changes can be summarized in three primary features. First, the knowledge and practice of engineering cannot be limited to a single field but allows the integration of other disciplines and pieces of knowledge (Sheppard et al. 2006). Second, engineers must recognize that their solutions are immersed in an intentional process that affects other systems that are complex by nature (Gallegos 2010). Finally, this integration allows to put on the table the social dimensions of the practice of engineering, hidden behind a technical façade for a long time (Eizenberg and Jabareen 2017). The challenge is, therefore, to connect engineering education and positive social change.

Therefore, the present article summarizes one possible approach to this challenge. In this experience, three main characteristics were evaluated. First, the use of methodologies which connect theory with practice by incorporating knowledge into real-life situations. Second, the importance of professional skills for the design of the technical solutions for the public good. Finally, the use of technologies during the experience to improve students learning experience. This methodology was applied in the EWB Engineer without borders Colombia course, where students designed solutions for different social problems. This paper is divided into four sections: a brief theoretical review that introduces the concepts of professional skills, CDIO learning, and engineering with social impact. Second, a presentation of the methodology used in the course and the assessment methods used. Third, the authors include a description of the qualitative and quantitative results of the experience. A final discussion presents several conclusions that generate relevant questions about the use of this kind of approaches to engineering education.

RESEARCH QUESTION

Given the background presented above, this study wants to explore the following research question: What is the impact of implementing socially oriented projects for engineering practice on the students?

THEORETICAL FRAMEWORK

CDIO context

As CDIO methodology recalls, an innovative approach for developing skills on problem-solving through projects. Specifically, the use of CDIO provides students with the necessary tools to deal innovatively and flexibly with complex problems within a society. The strengths of the CDIO approach are summarized in table 1.

Table 1. Strengths of the CDIO approach. Based on Edstrom and Kolmos (2014)

Characteristic	CDIO perspective
Definitions	The CDIO Standards: 12 standards ranging from design, implementation, and evaluation.
Curriculum	An integrated curriculum based on CDIO Standards.
Discipline	Discipline-led courses and an integrated learning experience.
Engineering Projects	Design-build experience.
Change Strategies	Recognition of deep understanding of disciplines and involvement of stakeholders outside academia.

In this case, EWB Colombia developed an approach to CDIO projects in five phases, the oCDIO methodology. The additional phase, observation, will be an opportunity for students to create strong relationships with the community, and interacting with them to understand their problematic situations (Arias, et al. 2016); meanwhile, the other phases (Conceive, Design, Implement and Operate) remain the same. Applying this methodology, students generate prototypes that are the result of a systematic analysis of the problematic situation, using technical knowledge, teamwork, and innovation. However, research on the effects that the application of CDIO on professional skills (Lewis and Bonollo 2002). and the use of socially-based approaches of CDIO is still inconclusive.

Social impact and participation action research (PAR)

Since the last decades of the 20th century, several research fields, particularly psychology, education, and engineering, have been having great changes that set significant differences in the ontological, epistemological, ethical, and methodological dimensions of how to approach community work (Langdon and Larweh 2015). Until the mid-twentieth century, social impact research was strictly framed into a quantitative focus, led by natural sciences or hard sciences (Lleras 1996), using positivist, coherent characteristics with the subject-object relation, experimentation, objectivity, proof, validity, and reliability as indispensable conditions(Fals-borda 1987). As an alternative for social approaches, using hard sciences stands the action research, specifically participatory action research. PAR allows projects and practitioner to achieve accurate feedback and adjustments for the proposals (Mackenzie et al. 2012). Furthermore, PAR eases institutions contribute to the community as part of their social responsibility, open to real problems and real solutions, and generate processes of teaching and research involving all stakeholders (Hernández, Ramírez Cajiao y Carvajal Díaz 2010).

STUDY CONTEXT

Course overview

Engineers without Borders (EWB) Colombia designed a learning space where engineering students' work becomes relevant by interacting directly with vulnerable communities. The projects are based on guidelines that students, professors, practitioners and volunteers on EWB Colombia must understand, develop and share. These guidelines or objectives point to important characteristics of socially responsible engineering and solution-based thinking. These objectives are:

- To recognize the contribution of engineering in improving the life quality of communities.
- To identify the specific problems of vulnerable communities and the opportunities for intervention from engineering.
- To apply science and technology knowledge in projects that address issues in vulnerable communities.
- To work in multidisciplinary teams for the conception, design, and implementation of innovative solutions to social problems.
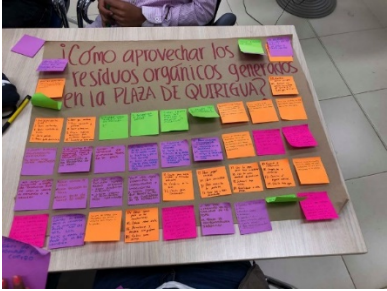
With these objectives in mind, the course mid-career EWB course. This course was integrated on the curriculum of the industrial engineering program as the course of engineering design and an alternative for implementation of their knowledge in the second half of the career. In this course, which is not mandatory, students work on groups of two or three students to solve a real challenge together with a community using explained in the next section. This course is offered to students of six to the seventh semester, and during around five months students work to implement a solution to the specific challenge. The final task includes a presentation to the community members and external experts, who evaluates the solutions not only in terms of the technical aspects but also on the level of involvement achieved. Several of these projects are developing in following semesters.

Design of the methodology and phases

In this regard, the theoretical proposals outlined above and the objectives of EWB Colombia have been integrated to provide a working methodology to work with vulnerable communities. The following table 2 provides a description of the methodology that was performed.

Table 2. oCDIO Context

Phase	Description	Some Examples
Observation	The student requires factual evidence (such as indicators, situations, and experiences) to improve their knowledge of the problem. This is a phase where the engineer is linked, as stated at the beginning of this phase, at an early stage that will allow you to delve into the collective design with the community.	

		To understand problematic situations WITH the community
To Conceive	The articulation with traditional engineering methodologies is when, after having evidence of variables and their relations, a process of initial conception of ideas starts. This phase must lead to the future co-construction of a solution.	 To conceive real solutions to real problems
To Design	Participatory spaces are designed, where ideas knowledge, interests and local resources translate into designs and innovative actions that provide creative solutions.	 To co-design (students + community)
To Implement	The students and the community developed activities that contribute to the solution and give an answer to the co-design	 The implement of 1) Transformation of fog in water in a rural context; 2)

		recollection and purification of rainwater in a rural context.
To Operate	Actions are monitored and justified to see both if the project contributed to changing the environment and quality of life of people. This phase requires ongoing monitoring where it is seen that not only the technical solution is taking effect, but also the co-participation in all phases has generated value added in the full process.	

The participatory component, drawn from PAR, is transversal to the oCDIO phases, meaning that each one of them should be developed together with the community. That is why it becomes important that learning is not given exclusively in college classrooms but directly in challenging contexts.

METHODS

Subjects

The participants of the study were 56 students who enrolled in the engineering courses of Universidad de los Andes (a large private university in Colombia) and Corporación Minuto de Dios (a large regional university in Colombia). In this course, students were involved in service learning, active learning activities and project-based learning to co-create with a community a solution to a water problematic situation. The posters of some of the courses of the last years are presented in Figure 1.
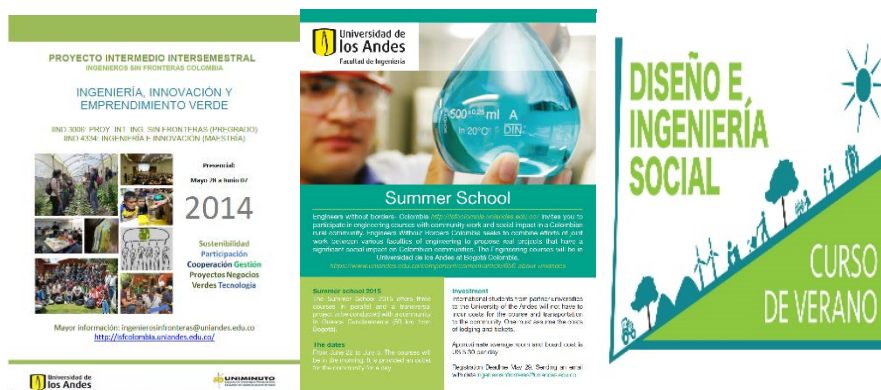

Figure 1. Images of examples of version of the courses from 2014 to 2016

To accomplish this purpose, the researchers design a survey where they can determine: Student's perceptions of the course methodology and how this course was useful for their academic or professional lives. Student's perceptions about the contribution of EWB Colombia courses to their professional skills. The chosen professional skills are based on Markes' (2006) research on the skills that employers value in engineering students, the assessments of Mohan, Merle, Jackson, Lannin, and Nair (Mohan et al. 2010) for professional skills within engineering curricula and the professional skills derived from ABET's evaluation of engineering programs (Reich et al. 2015). Therefore, fourteen professional skills were selected and evaluated using a Likert-scale perception

questionnaire[1]. Different socio-demographic characteristics of students participating in the study (gender, age, and occupation). In addition, the academic level of the students when they enrolled in the course (undergraduate or graduate) were considered. Furthermore, informed consent was provided at the beginning of the survey, where participants know about the objective of the survey and the possible risks of answering it. The survey had 46 questions, with three open questions. Finally, the survey was upload to Google Forms© to be available in an online format. The survey was sent by email to 360 students who took the courses between 2012 and 2016. The response rate was 15.5%, with a total amount of 56 responses[2].

Description of the process

During the observation phase, the students did the workshops in several high schools of Guavio Region, in Cundinamarca. Before the first visit to the community, they did a review of the town, as well as their economic and natural sources, so they were aware of the context. During the visits, the students worked with the students and the producers of the region. From these inputs, the students diagnosed that this region has good access to water, but there was a misconception of abundance that led to a huge misuse of the resource. Furthermore, some people in the town were open to embracing innovative solutions and most of them count with good connectivity to the internet.

On the conceiving and designing phases, the university students proposed several solutions based on the information collected and the engineering tools they had learned so far. After that, they went back to the school two times to develop workshops with the students, aiming to collect more information about the potential users of the solution, get feedback on their initial idea (or ideas) and keep on developing the idea together with the community, so it could fit both their needs and expectations.

Finally, the concept of La Liga del Agua was born: considering that students and the community, in general, want to learn how to use of their water resource, a gamified online environment was developed. This platform was designed as an interactive space where participants can learn about their consumption and good practices for water resource management. On the platform, the users should enter daily information on their consumption by giving the water consumption information of their water counter.

The game consisted of several levels that increase their difficulty and where they can according to their performance. To get from a level to another, the platform users should answer some questions related to the water (water cycle, consumption, saving techniques, pollution, global warming, etc.). The users could compete against their Facebook friends and other unknown people around the globe.

This platform was implemented in nine towns of the Guavio region for around three years, with outstanding results of 11% water saving on each household, on average, and more than 2000 participants.

Findings

From the 56 engineers and engineering students that answer the survey, 38.2% were female and 61.8% male (in concordance with the population of the courses). 81.8% of the respondents are between 21 and 26 years, while 5.4% are between 30 and 35 years and 1.8% are outliers with 19 and 49 years. 76.7% of the respondents stated that they are currently studying and/or working; from them, 23.3% are only studying, while 31.7% only work and the remaining 21.7% perform both activities. No significative differences

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[1] A translated version of the questionnaire is available in the following link: https://goo.gl/Uh2tcy.

[2] The data should be available by request.

between groups were found during the analysis. Regarding the perceptions of the different activities developed in the courses, it was found that 92.7% of the respondents perceived the EWB courses as important or very important for engineering students training. In addition, more than half of the participants agreed that the theoretical concepts on which the courses are based are useful for their professional practice. According to the course's curriculum, students should develop a project along the course, working in teams. 61.9% of them say that was relevant for their professional development. Overall, 92% of respondents said the EWB Colombia course in which they participated was interesting, 72.7% consider that the course is useful for the professional life and 83.6% added that courses like this should be included in the curriculum of the engineering programs. Some of the students consider the courses:

- "Me permitió observar y analizar otros tipos de negocios desde una perspectiva mucho más responsable" (It allowed me to observe and analyze other types of businesses from a much more responsible perspective)
- "Tuve un espacio de aplicación real de mis conocimientos, siento que fue mi primera experiencia profesional" (I had a real application space of my knowledge, I feel it was my first professional experience).
- "Entendimiento del poder de la ingeniería en las necesidades de los sectores en Colombia" (Understanding the power of the engineer in the needs of the sectors in Colombia)

Based on the perspective of the professional skills, three of them stands out as the most important skills developed on the course. First, 85% of the students consider that their negotiation skills were improved during the course. Second, 90% of the participants consider that they solve a problem creatively more frequently after being part of the course. Lastly, the communication skills (both oral and written) was improved in 100% of the responses. This result is interesting because is the first time these skills were assessed in a community engagement course, showing the power of the interaction with a real problem to build upon the professional skills of the students. According to the opinion of the students, the impact on professional skills was:

- "Principalmente ayudo a fortalecer mis habilidades de comunicación. Al ser un proyecto netamente práctico con personas dueñas de negocios de diferentes capacidades económicas y sociales te exige un mayor nivel de comunicación para lograr tus objetivos." (Mainly the course helped me to strengthen my communication skills. Being a clearly practical project with business owners of different economic and social capacities requires a higher level of communication to achieve your goals.)
- "Me ayudó a ver que como ingenieros tenemos que involucrar a las comunidades en las soluciones que estamos diseñando y no caer en la falacia del experto." (It helped me to see that as engineers we must involve communities in the solutions we are designing and not fall into the fallacy of the expert).
- "Brindo herramientas transversales a la ingeniería que de otra forma no se habrían dado." (Provide transversal tools to engineering that otherwise would not have occurred.)

CONCLUSIONS

The use of a social perspective in engineering education is not new (Al Lily 2013; Abaté 2011). This perspective of engineering teaching has been focused on the ethical implications of engineering practice and the inclusion of the social justice (Leydens and Lucena 2014; Baillie et al. 2011; Kabo and Baillie 2009). However, this approach and the use of oCDIO context courses and its relationship with service learning has a huge opportunity to learn about it. Most of the engineers and engineering students that participated in the survey stated that the courses were interesting and useful for their

professional development. Furthermore, a high proportion indicated that social-oriented oCDIO courses as the ones offered by EWB Colombia should be part of the engineering curriculum. It was probed that sharing experiences with the communities affect the way respondents evaluate the courses' contributions towards the development of professional skills. Engineers that are working or doing post-graduate studies, on the other hand, valued more positively the contribution of the courses to their professional skills, especially those related with work management, working on groups and creative problem-solving. Additionally, regardless of the context, most of the respondents pointed out the EWB Colombia courses foster their ability to solve engineering problems and the participants pointed out this professional skill development is a response to the oCDIO approach of the courses. This study reveals the need for further that links theory and practice in engineering education. Even when some empirical research has been developed in the last years, integrative and comprehensive approaches should be designed and implemented in engineering schools to achieve sustainable solutions with social impact. This methodological proposal is one of the infinite possibilities that allows the involvement of students and the community through engineering practice. This "hands-on" approach suggested by EWB Colombia allows engineering students to connect with the reality and the context under study, get first-hand information from the stakeholders and conceive solutions that are pertinent and adequate for the problem they are trying to tackle. Employers and academia must recognize the importance of these results to prepare engineers with the needed abilities to face the task that 21st century proposes. Finally, this study provides results that can be valuable in the design of the curricula in engineering programs, where major changes reside.

ACKNOWLEDGMENT

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CREATION OF AN ACTIVE LEARNING ENVIRONMENT AND OBJECTIVE EVALUATION OF GENERIC SKILLS AT NATIONAL INSTITUTE OF TECHNOLOGY, SENDAI COLLEGE

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ABSTRACT

National Institute of Technology (KOSEN), Sendai College (Sendai KOSEN) established the educational goal to foster students with global mindset, creativity and GENERIC SKILLs. In order to achieve this goal, we have developed a curriculum incorporating AL and PBL, reconstruction of the educational environment implementing AL and PBL, and ability development of teachers. As a result, the proportion of subjects that introduced AL reached 83.7% at the end of academic year 2017.

In order to evaluate the effectiveness of our reconstruction of educational method, we conducted PROG test to evaluate student's GENERIC SKILLs in an objective way. As for a GENERIC SKILLs growth characteristic of the students of Sendai KOSEN, it turned out that the literacy skills of students grew steadily every year regardless of the grade of the students. On the other hand, the competency skills were not developed apparently until the third grade, but the certain growth was observed after the fourth grade.

In this paper, we introduce the outline of educational environment refurbishing in Sendai KOSEN

KEYWORDS

Active learning, PBL, Refurbishing educational environment, Generic skills, PROG test, Standard 6, 8, 10, 11

BACKGROUND

National Institute of Technology (KOSEN), Sendai College has a history of more than half a century for producing many mid-level engineers following the strong demands from Japanese society at the time of its establishment. KOSEN students learn expertise and practical skills from the age of 15 and become an engineer at the age of 20. Such KOSEN education has been highly appreciated by Japanese industry.

However, with the rapid development of ICT, the diversity and complexity of society has increased, and the changing speed of social infrastructure has become faster. Under such circumstances, in addition to the expertise and technical skills acquired by young engineers , it is important to nurture students with generic skills (GENERIC SKILLs), consisting of fundamental competencies and literacy skills to make good use of these expertise and skills. These days, Kosen is required to provide education programs in which students learn generic skills such as communication skills, collaboration power skills, in addition to being trained in specialized knowledge and skills. The reformation program of educational environment at Sendai KOSEN [1] was adopted as an Acceleration Program for University Education

Rebuilding (AP) [2] in 2014, and it was a driving force for the whole college to tackle the refurbishing of the educational environment.

In this paper, we introduce the outline of educational environment refurbishing in Sendai KOSEN. Moreover, we mention the educational effect accompanying this reformation based on the evaluation of generic skills of our students measured in an objective manner.

REFURBISHING EDUCATINAL ENVIRONMENT

In these days, Japanese society and industry expect KOSEN graduates to be engineers with global mindset, creativity and GENERIC SKILLs in addition to technical skills as mid-level engineers. In order to cope with the new image of the human resources fostered at KOSEN, we have been focusing on an educational method to nurture students' GENERIC SKILLs. At the same time, we also have adopted the good parts of a traditional educational method, namely the lecture followed by related experiments / practices.

We developed a curriculum that is a mixture of traditional lectures, Active Leaning (AL) and Problem/Project-Based Learning (PBL). In particular, in order to bring out autonomous learning attitude of students and realize an education program that fosters GENERIC SKILLs, we introduced AL methodology and PBL in all grades, including introductory courses in the first grade and graduate studies conducted in the final grade (5th grade). In parallel with the curriculum development, we improved our educational environment to implement the curriculum. In particular, we carried out the following educational environment refurbishing:
   1) Educational Infrastructure Refurbishing
      1-1) Refurbishing a special classroom to implement AL,
      1-2) ICT conversion of general classrooms (Installing the whiteboard, projector,
         document camera and wireless LAN access point),
      1-3) student use of campus wireless LAN and adopting Bring Your Own Device (BYOD)
   2) Educational development
      2-1) teaching ability development to increase the number of teachers with educational certification (CompTIA CTT+ [3])
      2-2) FD by outside instructors and cafe style interactive FD

Figure 1 shows the status of infrastructure improvement, the status of teaching ability development of teachers, and the proportion of subjects incorporating AL at our college since 2014.
1) The maintenance process of each item about infrastructure environment is shown below.
   1-1)   We provided 3 AL dedicated classrooms in the academic year 2014, the infrastructure improvement starting year, and refurbished in total 14 classrooms with AL specification at the end of the academic year 2017. Finally, about 20% of all classrooms became AL special rooms.
   1-2)   We have converted all classrooms into ICT usable rooms. Along with the ICT conversion of general classrooms, it became much easier to introduce AL in all subjects.
   1-3)   We had developed student use of campus wireless LAN and BYOD in the whole campus by the end of the academic year 2016.
2) We show the implementation status and effectiveness of each item about the development of teaching ability below.
   2-1)   The number of CTT+ (Certified Technical Trainer+) trainers (including qualification holders and teachers who completed the same level of training) was 16 in the academic year 2014, 30 in the 2015, 38 in the 2016, and the 38 in the 2017. As a result, about 30% of teaching staff acquired practical skills on AL. In addition, these early qualification-acquired teaching staff contributed to an on-campus introduction of AL.

2-2) In the 2014 academic year, our FD was limited only to AL methods and mostly explained of implement about AL by the external lecturers, and how to use various tools. From the 2015 academic year, we introduced FD for the purpose of promoting AL in actual classrooms, and also World Cafe Style interactive FD (Fig. 2), where teaching staffs share their activities (including failures) actually conducted in classes. The interactive FD contributed to solve various questions of teaching staffs who were considering introducing AL. Moreover, many AL practice cases were reported in the interactive FD, and it became easier to find solutions for each teaching staff.

With these refurbishment of infrastructure and FD the ratio of AL introduction in classes achieved 83.7% at the end of the academic year 2017. In particular, the introduction rate was 37.8% at the end of the 2014, and then it was increased to 73.0% at the end of the 2015. In the 2015, we have completed ICT conversion of general classrooms and the number of CTT+ holders became doubled. These two factors would be the key contributing factors to the increase of the AL introduction rate.
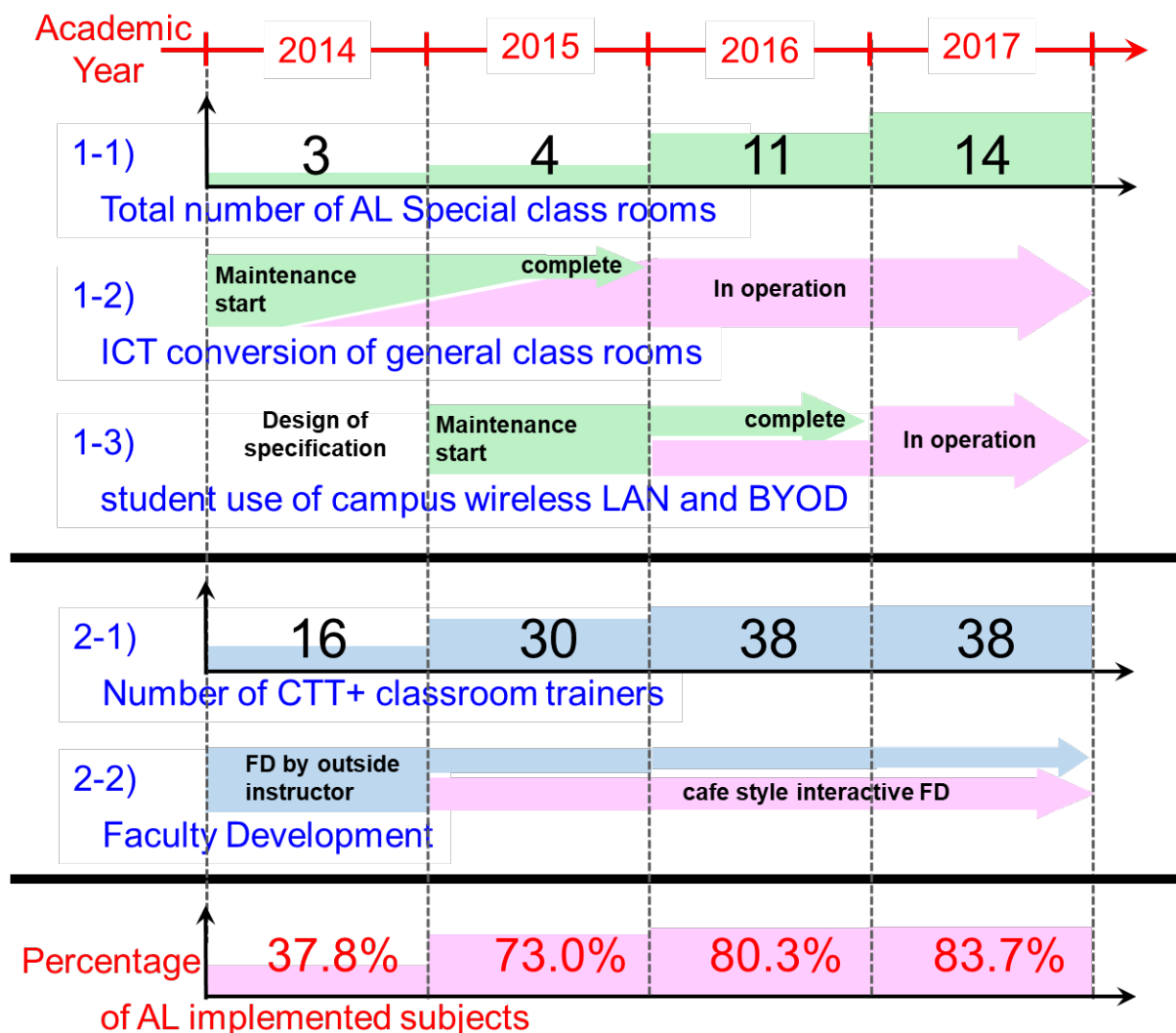

Figure 1. Yearly change in the status of refurbishment of infrastructure, teaching ability development, and the percentage of AL implemented subjects

Figure 2. Cafe Style Interactive FD

EVALUATION OF THE EDUCATIONAL EFFECTS

We evaluate GENERIC SKILLs of our students using the Progress Report on Generic Skills (PROG) test [4] to analyze the educational effect after refurbishing the educational environment. We show our detailed results of the PROG test in [5] [6]. Thus, in this paper, we only show the outline of the PROG test and the yearly change in the total score of the students' literacy and competency.

The PROG test was developed at Kawai-juku [7], which is one of Japan's biggest learning cram school. PROG test consists of two parts, the literacy part that evaluates the practical ability to solve problems by utilizing their own knowledge and the competency part that evaluates the ability to build good relationships with other people and their surroundings. The evaluation items of the PROG test are selected by referring to the key competency determined in OECD's DeSeCo project [8] and by examining the adoption selection criteria in Japanese companies. There are 6 major items in the literacy part and 3 major items in the competency part. Regarding competency, we categorize three major items into 9 middle items. Moreover, these 9 middle items are categorized into 33 small items. The questions in the literacy part are similar to those of SPI [9], while large part of the competency test contains questionnaire style asking the characteristics of people's behavior. Each competency part element is evaluated based on a comparison of statistically processed exemplary answers from highly rated Japanese business persons and answers of examinees. The score of the PROG test is evaluated with values from 1 to 7 (some elements up to 5) for both literacy and competency, and a larger number represents a better result.

We explain our result of the PROG test. Sendai KOSEN consists of five years of associate undergraduate course (Associate Degree Course) consisting of seven departments and two years of advanced course (Bachelor's Course) consisting of two course. We have conducted PROG tests every year for our students to evaluate their GENERIC SKILLs quantitatively since the 2014. Table 1 shows the grade of students who took the PROG test. As for the result of the 2018, some of test results are not available at the moment yet and we decided to omit it from our analysis in this paper.

Table 1. The Grades of Students who took the PROG Test in each year

Grade	Year			
	2014	2015	2016	2017
Regular 1	○	○	○	○
Regular 2	○	○	○	○
Regular 3	○	△	○	○
Regular 4	○	○	○	○
Regular 5	○	△	○	✕
Advance 1	△	△	○	○
Advance 2	△	△	○	○

○: Students of every department and major took the PROG test
△: Only students of some departments and a major took the PROG test
✕: Students did not take the PROG test
*In the analysis in this paper, the data of △ are not included
  because the numbers of samples are very different.

We show the PROG results of our students from the 2014 to the 2017 in Figure 3. Figure 3 (a) shows that in the literacy part the students' ability is steadily growing every year regardless of the grade. From the figure 3-(a), the significant growth was observed in all grades from the 2015 (blue bar) to the 2016 (green bar). Year 2015 was the year that ICT conversion of general classrooms was completed, and interactive FD was started. The question of whether these two factors contributes to the improvement of literacy ability requires further analysis.

We show the yearly changes in the competency of our students from the 2014 to the 2017 in Figure 3 (b). In the competency part, noticeable growth was not observed until the third grade, but obvious growth was observed in and after the fourth grade. In part, the growth of competency part in upper grades has been observed. The differences between the upper grade curriculum and others are the internship and large-scale PBL (one-day), thus these might be contributing factors.

Many universities conduct PROG to evaluate generic skills of their students. Thus, we show a brief comparison of the PROG scores of our students and university students who study science and engineering below. In the literacy part, the average score of the university first grader studying in the science and engineering departments in the 2017 is 4.80, and then the score of 2nd grade students of our regular courses (corresponding to the 2nd year high school student) is higher than 4.80. In the competency part, the average score of the university first grader studying in science and engineering departments is 3.07. Therefore, the scores for the 1st to 3rd year students of regular courses is the same as the average score of the university first grader. Also, the score of students in the 4th year of regular courses, whose ages are the same as those of first grader in universities, is much higher than the average score of the first grade of the university students.
Based on the above results, our educational improvement and educational environment reconstruction implemented in this project may increase the potential for great improvement of students' GENERIC SKILLs.
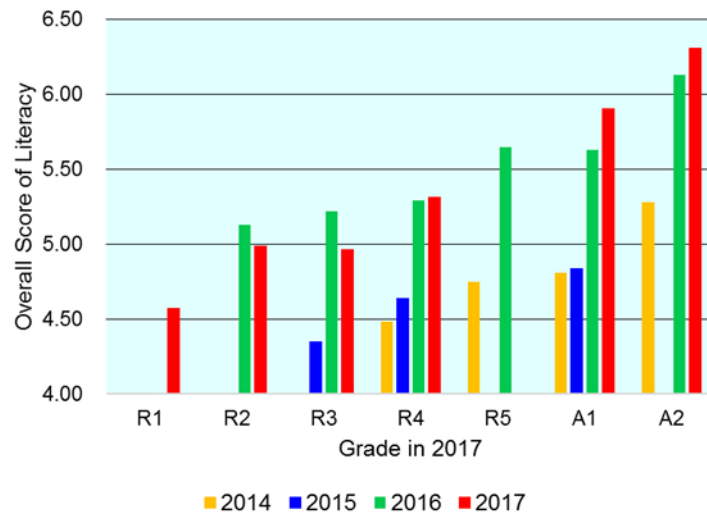
(a) Yearly changes of the overall scores of the Literacy part
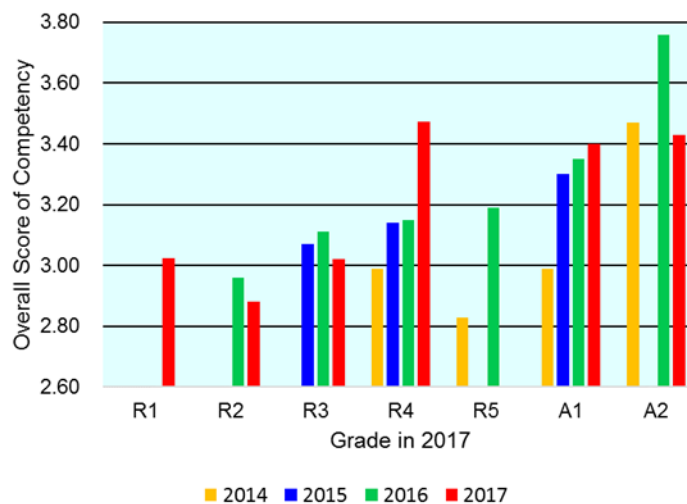
(b) Yearly changes of the overall scores of the Competency part

Figure 3. PROG results for four years from the 2014 to the 2017.

SUMMARY

Along with changes in society, the requirements by companies for Sendai KOSEN graduates have changed. In order to meet to such requirements, Sendai KOSEN reestablished the educational goal to nurture students with global mindset, creativity and GENERIC SKILLs. In order to achieve this goal, we have conducted 1) development of a curriculum incorporating AL and PBL in a well-balanced manner, 2) reconstruction of the educational environment implementing AL and PBL, and 3) ability development of teachers (including acquisition of implementation methods of AL) since the 2014. As a result, the proportion of subjects that introduced AL was 83.7% at the end of academic year 2017. In particular, there was a remarkable increase of the rate at the end of the 2015. In the 2015, we have completed ICT conversion of general classrooms and the number of CTT+ holders became doubled. These two factors would be the key contributing factors to the increase in the AL introduction rate.

In order to evaluate the effectiveness of our reconstruction of educational method, we conducted PROG test to evaluate students' GENERIC SKILLs in an objective way. As for a

GENERIC SKILLs growth characteristic of the students of Sendai KOSEN, it turned out that the literacy skills of students grew steadily every year regardless of the grade of students. On the other hand, the competency skills were not developed apparently until the third grade, but the certain growth was observed in and after the fourth grade. A part of the large increase of literacy score for all grades in the 2015 can be the result from our efforts but it is necessary to keep tracing future results to make any conclusion. On the other hand, internship and PBL programs seem to be quite effective to improve the competency of students and we must analyze the detail of these programs for further improvement.

Furthermore, in comparison with the PROG result of university students and those of our students, the average score of literacy and competency of Sendai KOSEN students are not inferior compared to the average score of university students.

Our future works are 1) analysis of details of contributing factors of rising competencies in upper grades, and 2) improvement of education methods in lower grades based on analysis results. Analyzing the difference between the upper grade curriculum and the lower grade curriculum, will give us hints of rising competencies. Then, we will clarify the causal relationship by improving the education method of the lower grade based on this consideration.

ACKNOWLEDGMENTS

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[3] About CompTIA CTT+: https://certification.comptia.org/certifications/ctt (URL)
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[8] About DeSeCo Project at OECD: http://www.oecd.org/education/skills-beyond-school/ definitionandselectionofcompetenciesdeseco.htm (URL)
[9] About Synthetic Personality Inventory (SPI): https://www.spi.recruit.co.jp/
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COMPARISON BETWEEN NIT KOSEN CURRICULUM AND CDIO STANDARDS AND SYLLABUS

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ABSTRACT

Japanese College of Technology (known as "KOSEN") for engineering education, starting at the age of 15, is a Japan's original tertiary education school established during rapid economic growth in the 1960s. At present, there are 51 national KOSEN colleges operated under the National Institute of Technology (NIT), 3 prefectural/municipal colleges, and 3 private colleges. The KOSEN's consistent 5-year college engineering education and additional 2-year advanced course education (5+2 = 7 years) including academic research work enables the students to be practical engineers, effectively. Although KOSEN's curricula have provided sufficient learning opportunity for the students to study theoretical knowledge and to conduct scientific/engineering experiments and workshop training as well as research work to foster practical manufacturing skills of students, KOSEN education also faces various challenges in the globalized world. In order to improve the preparation of KOSEN students to meet high demands in a rapidly changing world, NIT has to improve the curriculum as well as educational approaches. Since AY2018, NIT has implemented an innovative curriculum called "Model Core Curriculum (MCC)" that provides a framework for teaching, learning contents and outcomes levels in major engineering fields as a minimum standard for NIT's KOSEN. In addition to professional skills, generic skills are also defined as one of the most important outcomes of teaching and learning through the MCC.

In this research, NIT's MCC is compared to the CDIO standard and syllabus to clarify the similarity and difference between NIT's KOSEN education and the CDIO initiative. It is shown that the MCC well covers and matches with most of the items in CDIO standard and syllabus. This is due to that KOSEN education focuses on "Monodzukuri" and research work that require engineering design approach and C-D-I-O process. The details of the comparison between NIT's KOSEN MCC and CDIO, including mapping of criteria and subjects according to educational outcomes and standards and how the MCC works in NIT's KOSEN education are presented.

KEYWORDS

Active Learning, Assessment, Continuous Improvement of Education, Curriculum Design, Model Core Curriculum, Quality Assurance, CDIO Standards, CDIO Syllabus, CDIO Standards: 2, 3, 5

INTRODUCTION OF KOSEN EDUCATION

KOSEN Education

In Japan, about 1 percent of the upper secondary school graduates enter the College of Technology. College of Technology, Koto-senmon-gakko in Japanese, is also known as its abbreviated name "KOSEN". KOSEN is Japan's original tertiary engineering education school starting at the age of 15. KOSEN was first founded to meet the strong demand from industry for practical engineers in 1962 during rapid economic growth in Japan. At present, there are 57 KOSEN in Japan: 51 national KOSEN run by the National Institute of Technology (NIT), 3 prefectural/municipal KOSENs and 3 private KOSENs. Most of the KOSENs provide engineering education programs for associate degrees including Mechanical Engineering, Electrical and Electronics Engineering, Architecture, Civil and Environmental Engineering, Control and System Engineering, Information and Telecommunication Engineering, Chemistry and Biochemistry, Material Science, and Shipping Technology. Students who graduated lower secondary school can apply to KOSEN.

As lower secondary graduates enter KOSEN and KOSEN education is a 5-year college school (five and a half years at colleges of maritime technology), the curriculum is often misunderstood as a combination of upper secondary education with junior college one. However, five-year consistent engineering education including project-based learning/academic research works enables the students to be practical and innovative engineers, effectively. The KOSEN Curricula are designed to provide scientific knowledge, experiments, workshop training to foster practical manufacturing skills of students. KOSEN education has been highly evaluated by the public, by industries, and by other institutions. The following comment by an OECD director is a good example describing KOSEN education: "What makes the KOSEN schools different is their unique blend of classroom-based and hands-on, project-based learning." Figure 1 shows the basic curriculum structure of the 5-year regular course of KOSEN. KOSEN provides the students with a well-balanced General Education subjects (Liberal arts) and Major Engineering subjects in accordance with students' development.
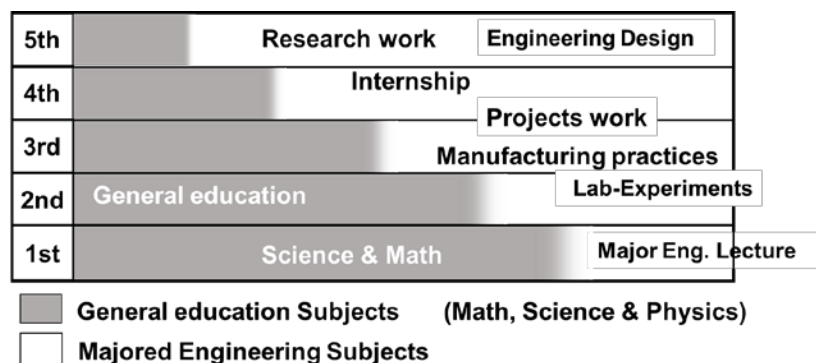
Figure 1. Curriculum structure of the 5-year regular course of KOSEN

As mentioned above, the outstanding characteristic of KOSEN education is its 5 years (regular course as college part) of consistent early engineering education starting from age of 15 years of which the students are usually in the middle of secondary education. With the additional 2-year advanced course education within KOSEN, up to 7 years of consistent engineering education can be conducted through various methods. At present, there are 51 NIT KOSEN (55 campuses), and approximately 50,000 students from age of 15 to 22 years are enrolled. As KOSENs were established to respond to a strong need for well-trained manpower in the rapidly growing industrial/manufacturing sectors, each KOSEN locates basically in industrial city/zone in Japan. About 60 percent of students obtain employment upon their graduation,

about 25 percent of the KOSEN graduates proceed to universities and 15 percent of KOSEN students continue their studies and research at two years of advanced courses within KOSEN to obtain a Bachelor's degree. KOSEN education has been playing very important roles in human resource development for industries/manufacturing sectors. In fact, the number of students who graduate from both regular and advanced courses of KOSEN is about 10 % of the total number of new graduates of engineering departments including junior colleges, universities, and graduate schools in Japan. Table 1 shows a summary of NIT KOSEN.

Table 1 Summary of NIT KOSEN

	Description	remarks
Number of NIT KOSEN	51 Colleges (55 Campuses)	
Admission requirement	Completion of lower secondary education	*
Transferred student	Upper secondary school graduates to the 4th year grade	
Degree to be obtained	5-year regular course: Associate degree	
	2-year advanced course: Bachelor degree	
Number of Students	48,640 (5-year regular course), 2,946 (Advanced course)	As of 2017

* 99.8 percent of those who enter KOSEN Colleges is new graduates from lower secondary schools. In general, mature-aged and post-school entry is not popular in Japan.

Model Core Curriculum

Over fifty years have passed since the first KOSENS were established and the social demands for KOSEN education as well as engineers have changed. As mentioned in the CDIO syllabus, modern engineering education programs need to foster the students' broad base of knowledge, skills, and attitudes necessary to become successful and innovative engineers. In order to improve the preparation of KOSEN students to meet these high demands in a rapidly changing world and technology, NIT has designed "Model Core Curriculum (MCC)." MCC was designed in reference to international standards, such as the criteria of Accreditation Board for Engineering and Technology (ABET), Standards for the Accreditation of Engineer Education by JABEE (Japan Accreditation Board for Engineering Education), UK Quality Assurance Agency for Higher Education (QAA) as well as the CDIO syllabus. MCC provides a framework for learning contents and outcome levels as a minimum standard for NIT KOSEN. Table 2 shows the contents of MCC.

Table 2. The Contents of Model Core Curriculum

Chapter	Contents
1	Educational Modalities Based on Model Core Curriculum
2	Attainment Targets for Basic Competency Requirements for Engineers
3	Attainment Targets for Knowledge, Expertise and Competency Requirements for Engineers
4	Attainment Targets for Interdisciplinary Competency Requirements for Engineers
5	Quality Assurance Functions of the Model Core Curriculum
5.1	Curriculum Design and Syllabus Based on MCC
5.2	Efficient and Effective Evaluation Method for Students' Attainment Levels
5.3	Collaboration among teachers on educational contents and teaching methods

5.4	Systematic Implementation of FD/SD
5.5	Mechanisms for Students' Self-Oriented Learning with reflecting their achievements
5.6	Developing the mechanisms for evaluation and continuous improvement of the Model Core Curriculum

Chapter 1 gives an introduction and rationale of MCC. From Chapter 2 to 4, various competency and desired attainment levels for engineers are described. Chapter 5 covers Quality Assurance. Although all chapters contain sub-chapters, only those of Chapter 5 is listed for the comparison between MCC and CDIO standards shown afterwards. The general education including STEM covered by MCC is listed in Table 3. In the MCC, competencies required as engineers are broadly divided into three categories as described in Table 3 to Table 5 according to major engineering fields and students' career paths. These three categories, namely "Basic Competency requirements engineers (I to IV)" in all areas, "Knowledge, Expertise and Competency requirements for engineers (V to VI)" and "Interdisciplinary Competency requirements for engineers (VII to IX)."

Table 3. Basic Competency requirements engineers: General education including STEM

I. Mathematics		
II. Natural Science	II-A	Physics
	II-B	Physics Laboratory
	II-C	Chemistry
	II-D	Chemistry Laboratory
	II-E	Life Science and Earth Science
III. Humanities and Social Sciences	III-A	Japanese
	III-B	English
	III-C	Social Studies
IV. Basic Engineering	IV-A	Engineering experiment techniques (measuring methods, data processing methods and analytical approaches)
	IV-B	Ethics for engineers (including intellectual property, legal compliance and sustainability) and Engineering History
	IV-C	Information Literacy
	IV-D	Globalization and Multicultural Studies

Table 4. Knowledge, Expertise and Competency requirements for engineers: Major fields

V. Knowledge and Expertise for each Engineering	V-A	Mechanical Engineering
	V-B	Material Engineering
	V-C	Electrical & Electronic Engineering
	V-D	Information Technology
	V-E	Biological & Chemical Engineering
	V-F	Civil Engineering
	V-G	Architecture
	V-H	Maritime Engineering (Navigation)
	V-I	Maritime Engineering (Ship Engineering)
VI Engineering Experiments and Practice Competencies	VI-A	Mechanical Engineering
	VI-B	Material Engineering
	VI-C	Electrical & Electronic Engineering
	VI-D	Information Technology
	VI-E	Biological & Chemical Engineering

	VI-F	Civil Engineering
	VI-G	Architecture
	VI-H	Maritime Engineering (Navigation)
	VI-I	Maritime Engineering (Ship Engineering)

Table 5. Interdisciplinary Competency requirements for engineers

VII General Skills	VII-A Communication Skills
	VII-B Consensus-building Skills
	VII-C Skills to gather, effectively use & communicate information
	VII-D Identifying Problems
	VII-E Logical Thinking
VIII Mindset and Direction (Personality)	VIII-A Sense of Self-ownership
	VIII-B Self-management Ability
	VIII-C Sense of Responsibility
	VIII-D Teamwork Skills
	VIII-E Leadership
	VIII-F Sense of ethics for engineers (respect for creativity and public morality)
	VIII-G Future-oriented vision and career designing ability
	VIII-H Comprehension of corporate activities
	VIII-I Comprehension of relationship between study and corporate activities
IX Integrated Learning Experience and Creative Thinking	IX-A Creative Innovation Ability
	IX-B Engineering Design Ability

In the MCC, the attainment targets of each subject are determined based on 6-level Bloom's Taxonomy. Table 6 shows the relationship between the attainment target levels and the corresponding education programs (fields).

Table 6. Attainment levels of KOSEN 5-year regular curse and 2-year advanced course.

Competency Requirements	Attainment Levels					
	1 Know/Re-member	2 Understand	3 Apply	4 Analyse	5 Evaluate	6 Create
Basic Competency Requirements for Engineers						
I. Mathematics	K	K	K	A	S	S
II. Natural Science	K	K	K	A	S	S
III. Social Sciences	K	K	K	A	S	S
IV. Basic Engineering	K	K	K	A	S	S
Knowledge, Expertise and Competency requirements for engineers						
V. Knowledge and Expertise for each Engineering	K	K	K	K	A	S
VI. Engineering Experiments and Practice Competencies	K	K	K	K	A	S
Interdisciplinary Competency requirements for engineers						
VII. General Skills	K	K	K	A	S	S
VIII. Mindset and Personality	K	K	K	A	S	S
IX. Integrated Learning Experience and Creative Thinking	K	K	K	A	S	S

Note: K: KOSEN regular (College) course, A: Advanced course, and S: Higher-level qualification such as professional engineer

These listed learning contents and competency with attainment targets as well as 5-year long plan for students' educational achievement ensure the quality of engineering education at NIT KOSEN.

Since the academic year 2018, all NIT KOSENs' syllabus based on MCC is listed and shared on the KOSEN website (https://syllabus.kosen-k.go.jp/Pages/PublicSchools, in Japanese). All subjects at NIT KOSENs will be correlated to MCC and be managed to accomplish all educational goals in MCC. Figure 2 shows the implementation status of MCC for subjects provided in AY2018. Although some NIT KOSENs have reported lower implementation of MCC correlated subject (>50%) due to characteristics of department/program or ongoing programs, it is shown that about 43 % of NIT KOSENs have fully adopted MCC (100%) and 90 % adoption for another 43 % of NIT KOSENs, respectively.
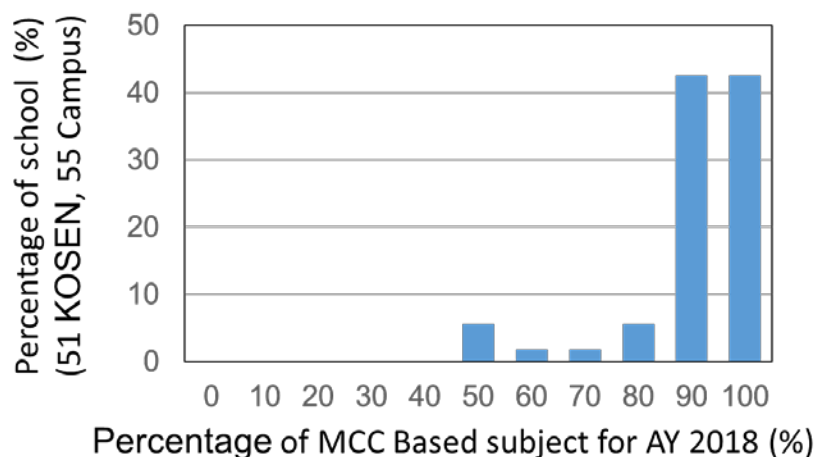

Figure 2.   Implementation status of MCC for subjects provided in AY2018

It should be noted that each NIT KOSEN has been planning and implementing its own distinctive education in addition to MCC, since MCC covers only the core part of curriculum contents (60-70%). Original educational programs reflecting regional characteristics as well as educational assets provide the students with contextualized learning opportunities. NIT's "KOSEN 4.0 Initiative" is an educational project to promote distinctive educational programs at each KOSEN, especially for "Human resource development for new industries", "Contribution to regional development," and "Globalization" of NIT KOSEN education. For the last two years, 71 unique programs have been adopted and implemented. (https://www.kosen-k.go.jp/about/profile/main_super_kosen_4.0list.html, in Japanese)

COMPARISON BETWEEN NIT MCC AND CDIO

MCC and CDIO syllabus
In the MCC, education programs with learning contents and goals are described in Chapter 2 to 4 which is corresponding Table 3 to 5 in this paper: "Basic Competency requirements engineers (I to IV)", "Knowledge, Expertise and Competency requirements for engineers (V to VI)" and "Interdisciplinary Competency requirements for engineers (VII to IX)." Table 7 shows the correlation mapping between these items (I to IX) to the CDIO syllabus (Malmqvist 2009), (Cloutier, Hugo & Sellens 2010). It is shown that MCC items are strongly correlated to CDIO syllabus items, except 4.2, because entrepreneurship that is also described in the extended CDIO syllabus is not covered by MCC.

The uniqueness of the KOSEN curriculum is a blend of classroom-based, hands-on, project-based learning, as well as "Research Work". The number of credits for research work is typically about 10 credits at the 5th year grade as a culmination of study in KOSEN. As a culture of KOSEN education, the topics of their research have tended to be academic ones and the results have been reported at academic societies and conferences. Thus, KOSEN education has mostly focused on scientific and technological interest as "Monozukuri", but less interest in business and operation of a business. However, entrepreneur education has been adopted in NIT KOSEN education as extra-curricular activities (e.g. Startup contest, Hackathon, etc.). Therefore, the part of entrepreneurship belongs to each KOSEN's education program.

Regarding the concept of "Conceive", "Design", "Implement", and "Operate," NIT KOSENs provide the students with subjects/programs such as Research work, Project Based Learning, etc. based on "Engineering Design" concept that is also adopted by JABEE. Especially, the research work at the 5th grade that requires the engineering design approach and C-D-I-O process is the uniqueness of KOSEN education and plays a very important role in the program. With regard to JABEE, 95 % of NIT KOSENs have been accredited by JABEE and 41 NIT KOSEN programs are JABEE accredited at present. Although some NIT KOSENs have voluntarily withdrawn from JABEE to seek their own characteristic educational programs, most of NIT KOSEN's engineering education programs are found to match with JABEE's criteria. As JABEE criteria are reported to correlate well with the CDIO syllabus (Rynearson 2011), it seems that NIT KOSEN's engineering education is highly consistent with CDIO standards.

Table 7. Correlation of NIT KOSEN MCC to CDIO Syllabus

CDIO Syllabus	NIT KOSEN Model Core Curriculum								
	I	II	III	IV	V	VI	VII	VIII	IX

1	1.1	●	●							
	1.2				●					
	1.3					●	●			
2	2.1							●		●
	2.2						●	●		●
	2.3						○	●		●
	2.4								●	
	2.5							●	●	
3	3.1							●	●	
	3.2							●		
	3.3			●	●					
4	4.1			●	●					●
	4.2			○					○	
	4.3						○			●
	4.4						○			●
	4.5						○			●
	4.6						○			●

○：Weak correlation　●：Strong correlation

MCC and CDIO standards

All MCC contents, Chapters 1 to 5, are compared with CDIO standards as shown in Table 8. Since MCC encompasses learning contents for each engineering field with specific attainment target levels, students' professional and generic competencies, curriculum design, educational approaches, quality assurance measures, etc., it correlates well with CDIO Standards. Especially for "9. Enhancement of Faculty Competence", NIT HQ has planned and conducted various workshops and training for KOSEN faculties based on MCC in addition to each KOSEN's faculty training. From these results, it is shown that NIT KOSEN's education programs based on MCC highly match with both the CDIO syllabus and standards.

Table 8. Correlation of NIT KOSEN MCC to CDIO Standards

CDIO Standards	Model Core Curriculum				
	C. 1	C. 2	C. 3	C. 4	C. 5
1: The Context	○	○	○	○	●
2: Learning Outcomes		●	●	●	
3: Integrated Curriculum			●	●	●
4: Introduction to Engineering		●			
5: Design-Implement Experiences			●	●	
6: Engineering Workspace			●		

7: Integrated Learning Experiences		○	○	●	
8: Active Learning				●	●
9: Enhancement of Faculty Competence					●
10: Enhancement of Faculty Teaching Competence					●
11: Learning Assessment*		○	○	○	●
12: Program Evaluation					●

○：Weak correlation ●: Strong correlation

CONCLUSION

This paper provides a comparison between the NIT KOSEN Model Core Curriculum (MCC) and CDIO Standards and Syllabus. As the MCC covers learning contents for each engineering field with specific attainment target levels, students' professional and generic competencies, curriculum design, educational approaches, quality assurance measures, etc., it correlates well with the CDIO Standards and Syllabus, except entrepreneurship part (i.e., Syllabus 4.2).

Regarding the concept of C-D-I-O, NIT KOSENs provide the students with programs (e.g. Research work, Project Based Learning) based on "Engineering Design" concept which is also consistent with the CDIO concept. From these results, it is revealed that NIT KOSENs share the same educational views with the CDIO initiative. In fact, 5 NIT KOSENs have joined the CDIO initiative so far (last 3 years). Nowadays, it is important for all engineering education institutes to develop students' broad base of knowledge, skills, attitudes and competencies across the curriculum/program for their future success as engineers. Therefore, it is expected that joining of NIT KOSEN's joining to CDIO initiative will promote sharing NIT KOSEN's educational experience and practice with CDIO initiative and member institutes as well as further development of engineering education program.

ACKNOWLEDGMENTS

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CDIO FACULTY DEVELOPMENT COURSE – BUILT-IN IMPLEMENTATION

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ABSTRACT

To successfully implement the CDIO approach in engineering programs, a holistic approach is required, connecting the philosophy of the program with teaching and learning activities in the courses. One influential component in this interaction is faculty members and their competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning (CDIO Standard 10). As an effort to support such faculty development, a group of universities has been conducting activities directly aiming to enable and drive CDIO implementation in the participating universities (mainly within the EIT Raw Materials programme). In this paper, we will continue reporting and critically reflecting on these CDIO-based faculty development endeavours. Initially, a faculty development course was launched in 2016 at Chalmers University of Technology and offered to participants from other universities (Bhadani et al., 2017). The paper starts by outlining the adaptation of the course into its second version, followed by investigating the experiences from the first group in 2018. The course was designed to suit both experienced and novice faculty. It offered a staged introduction to CDIO implementation alternated with sessions in which participants worked on their own course development. The rationale for this design was to increase the direct usefulness for the participants, in that they should feel engaged and involved during learning and be able to immediately apply their learning to their own course. To estimate the impact of the course on participants' actual course design and implementation, participants' final presentations and feedback were analysed. Interviews were also conducted to gather information about the changes made in the participants' own teaching, as well as the perceived influence of the CDIO course on those changes. The paper could be used to support organizers of faculty development courses in other universities, by documenting a model that can be implemented as a standard faculty training course.

KEYWORDS

Faculty Development, Raw Materials, Course Development, Standards: 9, 10.

INTRODUCTION

Changes to a business organization are inevitable as they can be driven by many internal and external factors which can come in many forms, shapes, and sizes (Todnem By, 2005). Those inevitable changes are not only restricted to business organizations but also apply to academic organizations such as higher education universities, which aim to modernize engineering education. Considering the wide range of stakeholders involved in today's education system such as society, students, teachers, institutions, employers, governments, industries and so on, it is not sufficient that one person can act as a leader and bring changes, but rather a collaborative effort is needed (Walkington, 2002). Further, Walkington (2002) took inspiration from Fullan (1993) regarding the importance of every unit in a change process and proposed that both top-down (programme to course) and bottom-up approaches (course to programme) are needed to bring improvements towards education development.

Within the CDIO Initiative, the training of faculty members has been identified as one of the critical aspects of the effort to reform and enhance engineering education (Crawley et al., 2014). Malmqvist et al. (2015) conducted an extensive survey on forty-seven CDIO universities to evaluate outcomes and barriers for CDIO implementation. The survey results highlighted that the CDIO Standards 9 and 10, which focus on the enhancement of faculty competence, have shown modest improvements compared to the other ten standards which revealed substantial progress (Malmqvist et al., 2015). It seems that faculty development is a rather slow procedure, which requires continuous effort and sharing of knowledge and experience to build progress. Learning from experience is a useful and necessary approach, but it can be accelerated by also learning from the experiences of others.

Faculty development is addressed in many universities through courses related to teaching and learning, mentorship etc. One method for enhancing faculty competence is to introduce and apply CDIO in faculty development courses. This has been applied in the project *CDIO within EIT Raw Materials Knowledge and Innovation Community* (Edelbro et al., 2017). In 2016, a faculty development course was launched at Chalmers University of Technology introducing CDIO to faculty within the Raw Material sector (Bhadani et al., 2017). In 2018, a second version of the course took place, again at Chalmers, now under the umbrella of CDIO2 project which is a continuation of the previous efforts. Here, the focus shifted mainly to the implementation of the CDIO approach (Clausen et al., 2018).

This second version of the faculty development course incorporated previous participants' feedback, which highlighted the need to utilize the time during the CDIO course to make improvements to their own courses or programme (Bhadani et al., 2017). Another adjustment from the previous course was the documentation of the results from the course's outcomes. The second version of the course was organized in a workshop format to increase active involvement and produce direct usefulness of the course for the participants. The course was also designed to target both experienced and novice faculty members. The continuous improvement of this CDIO course is aimed to produce a standard course with appropriate guidelines for continuous education of faculty members. To develop and improve this course further, we posed our research questions:

1. Which CDIO components from the faculty development course are perceived as useful from faculty to develop their own course?
2. How do faculty make use of the information they receive during the course?

The research questions support the development of elements that can be implemented in a standard faculty development course. The paper is organized in the following sections: We begin by reviewing the literature on faculty development and proceed by describing our current course. Then the KJ method and semi-structured interviews are used to investigate

the results of the current course. The aim is to evaluate the critical aspects of the course and present guidelines for developing and conducting a standard CDIO course for future reference.

LITERATURE REVIEW

Högfeldt et al. (2013) interviewed programme leaders of eight different master programmes within engineering fields from Nordic countries and found that a substantial amount of negotiation and collaboration is needed to run a master programme. They also added that a collaborative effort of sharing ideas and experiences is needed both from programme leaders and faculty members to successfully run a programme (Högfeldt et al., 2013). An investigation by Malmqvist et al. (2008) regarding the development of faculty competence within three Nordic universities highlighted two typical categories of skills required for implementing change in academia: pedagogical competence and management competence. The pedagogical skills could typically help a faculty member understand what to change in a course or programme, and the management skills could assist them in implementing the changes. Both skills along with appropriate individual motivation and encouragement by the institution are needed to bring about change in various contexts in academia (Malmqvist et al., 2008).

Farmer (2004) reported that there is a need to measure the outcome of the faculty development courses on faculty themselves. This is related to following-up with the development work of the faculty as their expertise varies widely. Finding objective evidence with such development is often regarded as challenging (Farmer, 2004). Dolmans et al. (2002) reported a trend in faculty training for problem-based learning that content experts tend to use subject-matter for discussions while non-subject experts emphasized the process expertise for facilitating discussions. This distinction needs to be considered while evaluating the results of a faculty development course as results presented by the participants can be either process-oriented or content-oriented. To further longitudinal knowledge transfer, Loyer and Maureira (2014) proposed a mentoring approach for training new faculty to motivate the use of active learning and implementation of gradual changes in a course. This resulted in knowledge transfer between an experienced faculty member and a novice faculty member in a longitudinal framework, although the aspect of resource allocation was questioned (Loyer & Maureira, 2014). Chuchalin et al. (2015) also recommended follow-up with the faculty member development at specific intervals to discuss the successes and failures of their implementations. Their results also highlighted that in order to implement changes, a faculty member needs to be aware of their roles and responsibilities for the entire programme outcomes and this is especially challenging (Chuchalin et al., 2015).

From literature, it is noticed that the active engagement of faculty during the training activity is a critical step to get them started with the thinking process. Further, an active follow-up can support the implementation of new ideas and evaluate their development. This is also useful for understanding the learning process of a faculty member. The change process is related to the personal motivation of a faculty member, together with the new pedagogic and managerial skills. Further, it can be suggested that any formal training activity should at least show the role of a course in an engineering programme, and how the programme matters to stakeholders, so that the participants can appreciate that their contribution as educators is for a greater cause.

DEVELOPMENT OF THE CDIO FACULTY DEVELOPMENT COURSE

The development of the CDIO faculty course was itself based on the CDIO principles. We aimed to create a coherent course with elements of active learning where the implementation of the CDIO mind-set to participants' own courses was in focus. The targeted audience were course examiners, teachers and teaching assistants who wanted to rethink their course in a structured way with the assistance of CDIO experts and peers. The course was given at Chalmers in two days, and there were 15 participants both from raw materials universities and from universities active in the CDIO community.

Course Organization

The course was designed based on the principles of constructive alignment where learning and assessment activities map to the learning objectives of the course (Biggs, 2014). The intended learning objectives were based on the first version of the course (Bhadani et al., 2017) but were focused on a course level:

L1. Explain how the CDIO approach can be implemented in engineering education.
L2. Apply the CDIO Methodology to course development, including
    a. Formulating learning outcomes on the course level
    b. Developing appropriate learning activities for discipline-led learning and a problem-based/project organized learning
    c. Developing appropriate assessment methods aligned with the intended learning outcomes

Our target was to create a learning community of educators, here in the role of students, who would engage and interact with each other and develop their own courses (Zhao & Kuh, 2004). The structure consisted of pre-preparation activities, seminar sessions, case studies, and group work. The course activities are presented in Table 1 with their rationale. Each activity was conducted for one hour with breaks in-between.

A key aspect of the revision of the faculty development course is to increase the engagement of the participants and support the actual implementation of the presented material to their own courses. The course preparation and the submitted presentations helped the course instructors get an overview of the participants' background, issues, and expectations, and it also helped the participants reflect on and summarize what they want to improve in their course before attending. Case studies were used to inspire the participants and showcase examples of appropriate implementation of the CDIO approach. The multiple sessions provided the context and the information for the participants to work and discuss during the group work. The group sessions aimed to help the participants reflect on the information they received in the previous sessions and translate them to their own teaching. Sharing of experience with the other participants was a key in this activity. The participants also received individual feedback and comments from the instructors during the group sessions. The final presentation acted as an incentive for the participants to keep working in their course during the two days. Additionally, it was an opportunity to concretize the information they received and receive feedback from the instructors and the other participants.

EVALUATION OF THE CDIO FACULTY DEVELOPMENT COURSE

The overall assessment of the result of the CDIO faculty course was based on an analysis of the participants' final presentations, short interviews with three of the participants to receive feedback and instructors' own critical reflection. The analysis was conducted to evaluate the changes participant intended to include in their courses after attending this course. This can

potentially reflect on the research question about what component of the faculty development course was found to be useful and applicable to the participants' courses. The semi-structured interview was conducted to receive feedback for the participants' motivation, the course content, and organization as well as the utilization of the information they received.

Table 1: CDIO faculty development course organization and its content.

Activity	Topic	Content and Rationale
Course Pre-preparation	Participants' own preparation	To prepare 3-slide presentation including the learning objectives, learning activities and assessment techniques of their own course.
Day 1		
Session 1	Introduction and Participants Presentation	To help participants get to know each other and their expectations, especially since the audience was international and from different disciplines.
Case Study 1	Mechanical Engineering - Sustainable Development and Mathematics	To inspire the participants and showcase examples of appropriate implementation of the CDIO approach.
Session 2 (Parallel)	a. Introduction to CDIO b. Lab Tour	To introduce CDIO fundamentals to novice faculty members, and address implementation aspects to faculty experienced in the CDIO approach.
Session 3	Formulating learning outcomes (presentation)	To introduce systematic methods to connect courses with programs through the intended learning outcomes.
Group Work 1	Design learning outcomes	To design and develop appropriate learning outcomes of a course with respect to making deliberate contributions to a program.
Session 4	Effective course design (presentation)	To introduce the constructive alignment between the course activities and the outcomes of the courses, and inspire the design of innovative learning activities.
Group Work 2	Design learning activities	To design or revise existing learning activities of the participant's own course.
Day 2		
Case Study 2	Assessment in product design course	To showcase an example of assessment technique from a large project-based course.
Session 5	Assessment development (presentation)	To provide theoretical insights and techniques for the development of assessment.
Group Work 3	Re-design of assessment	To apply modern assessment techniques to re-design participants' own course.
Group Work 4	Popular presentation preparation	To summarize the ideas that participants have developed, applicable to their own course.
Session 6	Final Presentation and Feedback	To present and discuss participants' planned developments of their own course.

KJ Analysis

KJ analysis is a method for understanding and developing a thematic relationship from an abstract data set (Plain, 2007). The analysis was performed by two members (the two first authors). First, they individually reflected on the themes featured in participants' final presentations and produced a set of post-it notes on a whiteboard. Then they silently re-arranged the notes into groups. After this, the members discussed and developed thematic names for each group. Finally, the groups were re-arranged to form larger sets. Figure 1 depicts the final themes that emerged from the analysis.

Based on the analysis, the three main themes that emerged were in accordance with the sections in the course, learning objectives, teaching and learning activities, and assessment. For the *learning objectives*, the main changes that the participants will make are to include clear general and specific learning objectives, clear formulation of the learning objectives within the course and clear connection between the program's and the courses' learning objectives. Regarding the *teaching and learning activities,* the main additions or changes to participants' courses will be the non-traditional content delivery, the intention to increase student motivation

Learning Objectives
- Clear general and specific LOs
- Clear formulation of LOs within a course
- Clear connection between program LOs and course LOs

Teaching and Learning Activities
- Non-traditional content delivery
- Project-based learning
- Team formation
- Mentoring techniques
- Student-centred learning

Teaching and Learning Assessment
- Increase student motivation through attractive learning activities
- Assessment based on LOs
- Clear connection between assessment and activities in the course
- Effective assessment for validity and reliability
- Individual assessment in team environment
- Use of real-world examples and problem for assessment
- Time-efficient assessment
- Continuous assessment during course
- Meaningful assessment
- Understanding between formative and summative assessment

Figure 1: Result of the analysis performed on the participants' final presentation.

through engaging learning activities, the focus on student-centred learning, the use of project-based learning and the use of real-world examples and problems. Some of the participants will also try mentoring technique during teaching and will adjust the way the teams are formulated. Regarding the *assessment* theme, which was found to be most reflected, the main concepts that appeared are the use of meaningful and time-efficient assessment techniques based on learning objectives, the understanding between formative and summative assessment, the ways of individual assessment in team environment, the continuous assessment during course and the effective assessment assuring both validity and reliability.

Results from Interviews

Three course participants were interviewed. They were asked to give feedback on the course content and organization as well as on how they had utilized the information they received. All three were relatively new to the CDIO approach, and in the second session in the schedule, they chose the introductory course instead of the lab tour (see Table 1). Two of them were post-docs (A and B), and one was an associate professor (C). The courses under

consideration by different interviewee were: A - Communication Network Analysis, B - Supply Chain Management, C - Signal Processing Measurement and Applied Control for Automotive System. The topics covered during the interview were their motivation for participating, the most useful information for them in the course and what they plan to change in their own course, and finally, their opinion about the course format and suggestions for improvement.

Motivation for participation: The motivation for participation in the course varied between the interviewees. The first postdoc (A) wanted to improve the quality of her teaching and change the teaching methods of her theoretical course to be more motivating and engaging for the students. The second postdoc (B) was interested in understanding how the teaching is conducted in an engineering environment and how he could merge his own business background with the skills they want their students to learn. The associate professor (C) wanted to create a new course on the Master and Ph.D. level, and she participated in the CDIO course to develop her course based on the CDIO philosophy.

Reflection of the course content: Regarding the content, all three enjoyed the faculty course and found it overall useful as it was complementary to their formal pedagogical education at their home university. For A, the parts of the course that were the most useful were the examples in the mechanical engineer program study case, e.g. how to use MATLAB coding, and the guides of how different teaching or assessment methods work in practice, e.g. how to use specific examples to explain more theoretical and advanced concepts, and what were their results. Changes that A is going to implement are the introduction of short problems at the beginning of each course to make students think and not until after they have tried, to give them the theoretical parts and oral assessment when feasible. B found the case studies to be the most useful element. He does not currently have his own course, but he took the opportunity to reflect on the information, take a step back and look at his role in the classroom and not only the students' role. He reflected that there are things they take for granted and they need to reflect upon. His changes in the course he is involved would be to include continuous assessment and more seminars and assignments instead of lectures to activate students' independent learning. C appreciated the holistic approach of CDIO concept. For her, the most exciting and relevant part was the continuous learning approach where one concept evolves throughout the years in different courses and levels and when students graduate they build up the knowledge without perhaps realizing it. C similarly to A appreciated the detailed examples especially on how to make grading easier. She also liked the comparison between formative and summative assessment and how to connect it with the learning objectives.

Format of the course: For all of them it was the first time they attended a faculty course with such condensed format and volume of information. They preferred this format compared to spread ones where the activities are carried during a longer period. They mentioned that the activities complemented well the things they were taught and there was a good mixture of presentations where they were introduced to the idea, a time to work on their own and discuss and then present their ideas and get feedback from the audience which was very relevant. All of them found the interactions with the other participants during the group work and presentations useful. They thought that it was beneficial to have the possibility to discuss with others and get their experiences, how they are working, what they are doing, whether they are applying those ideas, or they are new to it. C also mentioned that it was very nice that the group leaders came to the rooms and made the discussions vivid. Regarding the final presentations, A mentioned that although they were useful, the time-schedule should be stricter. B also thought that they were useful since they formalized the things that they learned in a structured way. They also stayed alert throughout the course since they needed to create an outcome of the discussions and present it. B also liked that it was more interactive than just listening.

Improvements for the next course: Regarding their suggestions for improvement they generally thought that the content was sufficient. A mentioned that she would like more examples, especially on how to maintain students' attention. B would like a continuation of the course for the next period. Additionally, he thought it would be useful if credits were given, but that was not his main priority. He would also prefer some additional pre-preparation for the course, for instance, some relevant scientific articles or papers from the CDIO conference, to start thinking about his own input to the course in advance. C suggested to include more details about how a project-based course worked during the case study. She would also like an infographic of the CDIO method as a quick reference. She thinks we should follow up after a period and ask participants what they have implemented from the course and how it worked and provide that information in an upcoming faculty course.

In general, all of them felt engaged. A liked that the speakers were experienced in their area, and energetic. She mentions "*it is nice to see people who are trying to increase the quality of the education and are enthusiastic because you do not feel alone. It was also nice that I could get help from them*" and she continued that in the past she wanted to improve things, but she did not get support. C mentioned that after the workshop she shared the material with her research group and they were interested and asked her to present the ideas. Additionally, they liked the refined version of her course with its connection to their courses, and she will present it to her colleagues in department level.

DISCUSSION

Based on the feedback from the first round of the faculty development course (Bhadani et al., 2017), the second version of the course was given in a more active workshop format, including the dedicated time after each theoretical session for discussions with peers and own course development. Although the motivation for participation in the course varied between the three individuals, the new course design was very well received as can be noticed by the interviews. Based on the results, it can be argued that creating an interactive environment together with purposefully aligned sessions is a useful ingredient in such course organization. Furthermore, creating active engagement by the instructors, providing content-specific feedback is found to be appreciated, which is in line with the finding from Dolmans et al. (2002).

As it can be observed by the KJ analysis, the main themes covered all the topics, the learning objectives, teaching and learning activities, and assessment techniques. The topics which were found to be most useful varied widely among the participants as it depends on their personal experiences, their course responsibilities (e.g., postdoc, associate professors), and the strengths and the weaknesses of their own course. Therefore, we believe that it is necessary to have a holistic approach to the choice of topics to assure a uniform level across participants.

In particular, the participants found the topics related to the development of learning assessment within a course to be most used as it can be reflected from KJ analysis. The interviews' results also indicate that there are usefulness and demand in the development of continuous assessment activities within a course. This could indicate that there exists a knowledge gap, or a particular need, to develop time-efficient and effective assessment activities.

The participants used the information received during the course in three main ways: to spread the knowledge and inform their colleagues about the methods and tips they learned, to make improvements in their existing courses, or to refine and promote their new course proposal. The future work is to contact the participants of the course after one year and

evaluate if and to what extent they have implemented the changes in their courses and how satisfied they are with the results, what worked and what did not. Another aspect to be investigated is how this faculty development course could be integrated with existing pedagogical courses for faculty to assure its continuous and sustainable implementation.

CONCLUSION

The second version of the faculty development course at Chalmers University of Technology was focused on the implementation of the CDIO approach in the participants' own courses. The structure of the course in the workshop format was highly appreciated by the participants who felt engaged. The course was designed to suit both experienced and novice faculty. The course offers sessions alternating theory and practice, which seems to have increased the direct usefulness and impact on the participants compared to a previous version of the course. A holistic approach to teaching CDIO with appropriate case studies, mentorship and active engagement, with direct usefulness of the course, is recommended for future execution of such course. Further, follow up with the course participants is needed to ask a question regarding the actual implementation carried on and their insights from it. Future work will be directed towards further improving and expanding the course for larger audience.

ACKNOWLEDGMENTS

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IMPROVING STUDENTS´ PROJECT MANAGEMENT SKILLS IN BIOMEDICAL ENGINEERING PROJECTS

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ABSTRACT

Earlier studies suggested the Project Management (PM) skills are core to the leadership attributes of engineers. Some interrelated research streams are available for an understanding of the challenges in teaching and learning both engineering and PM education. The need to teach and learn PM in engineering schools has been advanced by employers. Today, organizations expect engineers to excel in many soft skills, including teamwork and communication. They are keen to tap into these vital soft skills that they obtained during their studies and periods of work experience, rather than just degree-specific knowledge. In this study, an integrative Project-Based Learning (PBL) approach is presented. It is used in two courses devoted to the biomedical engineering field, namely "Bioengineering Design" and "MedTech", included in the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management, respectively, both at the ETSI Industriales from Universidad Politécnica de Madrid. These courses follow a framework completely aligned with the spirit of the International CDIO Initiative. Students from both courses collaborate in teams and live through the complete project life cycle of innovative medical devices. The PBL approach applied is aimed to allow students to learn basic PM skills such as technical, business, and human ones. From the beginning of the courses, students are provided with specific knowledge, tools, and exercises to improve their capabilities for building strong teams and achieving their project goals. By integrating PM deliverables (scope, time, cost, risk, quality and communication management) with team development strategies (team agreement, personality identification, competencies assessment, teambuilding, roles definition, and personal interviews) and specific soft skills workshops it has been possible to provide an effective learning experience for improving students PM skills. Main results, difficulties, benefits, and conclusions of the experience are presented in this work as well as lessons learned for the continuous improvement for the next courses.

KEYWORDS

CDIO as Context, Project Based Learning, Project Management, Skills, Biomedical Engineering, Standards: 2,3,4,7, 8.

INTRODUCTION

In this study, a PBL approach following CDIO principles is applied to allow students to learn basic Project Management (PM) skills. These students belong to two courses devoted to the biomedical engineering field, namely "Bioengineering Design" and "MedTech", included in the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management.

From the beginning of the courses, students are provided with specific knowledge, tools and exercises to improve their capabilities for building strong teams and achieving their project goals. By integrating PM deliverables (scope, time, cost, risk, quality and communication management) with team development strategies (team agreement, personality identification, competencies assessment, teambuilding, roles definition, and personal interviews) and specific soft skills workshops, it has been possible to provide an effective learning experience for improving students PM skills.

Main literature review, learning approach, results, difficulties, lessons learned and conclusions of this experience during the 2018-2019 course are presented in this paper.

IMPROVING ENGINEERS´ PROJECT MANAGEMENT COMPETENCIES

Earlier studies suggested the project management skills are core to the leadership attributes of engineers (Hamilton, 2006; Wearne, 2004). Some interrelated research streams are available for an understanding of the challenges in teaching and learning both engineering (Zhou, 2012) and project management education (Ashleich et al., 2012; Louw & Rwelamila, 2012). Students' experiences have remained a major theme of interest to scholars, especially in the engineering and project management areas (Dietrich & Urban, 1998; Heer et al., 2003).

The notion of students' experience in studying project management remains a core element of the wider teaching and learning discourse (Chipulu et al., 2011), especially in light of emerging ideas concerning the creation of reflective and creative practitioners (Berggren et al., 2008; Crawford et al., 2008). This need to teach and learn project management in engineering schools has been advanced by employers.

Project Management Competencies at a glance

The project management function is relevant and requires a wide vision of different areas to coordinate, along with a wide range of personal skills (Ahsan & Ho, 2013; Kerzner and Kerzner, 2017; PMI, 2017). To successfully manage projects, different skills are required, including interpersonal ability, technical competencies, and cognitive aptitude, along with the ability to understand the situation and people, and to dynamically integrate appropriate leadership behaviors (Pant and Baroudi, 2008).

Competencies for project management can be defined as a cluster of knowledge, aptitudes, attitudes, and behaviors that are needed to accomplish a piece of work (Boyatzis, 1982). Along these lines, Parry (1998) defines competences as a set of related knowledge, skills and personal characteristics that have an influence on individual and group work in an organization, are related to job-performance and can be improved by training and professional development.

The importance that is attributed to the strategic role of project management in organizations has led in recent decades to the growing development of frameworks of international competencies and professional standards. Some of the main competency frameworks are Project Manager Professional (PMP) certification by the Project Management Institute (PMI, 2017), the International Project Management Association certification (IPMA, 2015), the competency framework of the Association for Project Management (APM, 2008) and the professional standards that have been defined by the Australian Institute of Project Management (AIPM, 2008).

Based on previous frameworks of project management competencies, as well as other relevant researches, Takey and Carvalho (2015) propose a set of competencies categories in the project management field. These competences are presented in Table 1 along with correspondent CDIO Syllabus version 2.0. (Crawley et al., 2011).

Table 1. Project management competencies categories.
Source: Adapted from Takey and Carvalho (2015)

Category	Competencies	CDIO Syllabus v2.0
Project management processes	Integration management; scope management; time management; costs management; quality management; human resource management; communication management; risk management; contract management; environmental management; safety and health management.	2.4; 4.3; 4.4; 4.5; 4.6; 4.7
Personal	Leadership; communication; opening; relationships; teambuilding; teamwork; development of others; conflict resolution; holistic view; systemic view; assertiveness; problem-solving; ethics and integrity; commitment; self-control/work under pressure; relaxation; uncertainty; creativity; negotiation; emotional intelligence; commitment to the organization; reliability; attention to detail; delegation; search for information; analytical thinking; conceptual thinking; flexibility.	2.3; 2.4; 2.5; 3.1; 3.2; 3.3; 4.7
Technical	General technical overview; technical vocabulary; technical challenges; search for innovative technical solutions; technical solution assessment; technical risk assessment; technical trade-off decisions; relationship between technologies; design (project); technical drawing	1.1; 1.2; 1.3; 2.1; 2.2; 2.3; 4.3; 4.4; 4.5; 4.6
Context and business	Organization's profitability; strategic alignment; customer relationships; customer satisfaction; forces of industry (organization, customer and suppliers); legislation; finance; continuous management improvement	4.1; 4.2; 4.8

Project-Based learning approach

Project-Based learning approach is an appropriate mean of improving engineers´ project management competencies. Project-Based learning (PBL) is a model in which learning opportunities are organized around projects. Projects are complex tasks that are based on challenging questions or subjects that involve the students in design, problem-solving, decision making, or investigative activities. In regard to students and Higher Education (HE), dealing with projects gives the former an opportunity to work relatively autonomously over extended periods of time. This culminates in the creation of realistic products or presentations (Thomas et al., 1999; Turner et al., 2002; van Rooij, 2009). In PBL, the project is the central teaching strategy. Students encounter and learn the central concepts of the discipline by means of the project.

Some studies have shown that students retain minimal information in the traditional, didactic, teaching environment and frequently have trouble in transferring the acquired knowledge to new experiences (Schmidt, 1987). In contrast, PBL has proved to be an excellent method for developing new forms of competencies (Graaff & Kolmos, 2003; Kolmos & Kofoed, 2002). A PBL environment enables students to draw upon their prior knowledge and skills, brings a real-world context to the classroom, and reinforces the knowledge that they acquired by both independent and cooperative group work (Schmidt, 1993). In order to be considered an example of PBL, a project should have centrality, a driving question, constructive investigation, autonomy and realism (Thomas and Mergendoller, 2000). Projects should have characteristics that provide a feeling of authenticity to students. These characteristics can involve the topic, tasks, the roles that students play, context within which the work of the project is carried out, collaborators who work with students on the project, products that are produced, an audience for the project's products- or criteria by which the performance or products are judged.

DESIGN OF THE LEARNING EXPERIENCE

Industriales Ingenia is a compulsory subject (12 ECTS) of the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management. There are 12 Industriales Ingenia different initiatives designed to cover most of the profiles of the Master's Degree in Industrial Engineering composed of approximately 300 students. 60 of these students selected in their first choice "Bioengineering Design," which is the most demanding option. The students of the Master's Degree in Engineering Management are 41 and they could choose between three different tracks for studying Industriales Ingenia. "MedTech" was the first option for 12 of them, who were all accepted. Therefore, a total number of 53 students are participating in these two subjects, working together in seven teams. These teams were formed with an average of 6 people from "Bioengineering Design" (technical profile) and 2 persons from "MedTech" (business and management profile). Although one project manager was required at the beginning of the course for every team, all the teams decided to work with a shared leadership for managing the project, giving an opportunity to horizontal organizations. These organizations maintain a decentralized power structure and place emphasis on teamwork and collaboration to achieve a collective goal. The group of professors agreed with this decision of working with shared leadership. Table 2 shows the characteristics of engineering students and their projects.

Table 2. Teams and projects participating in the experience.

Team members	Projects
1 MT* + 6 BD	Visual display for veins
1 MT + 7 BD	Standing frame

2 MT + 6 BD	Thumb prostheses
2 MT + 6 BD	Eyelid cleanser
2 MT + 6 BD	A smart insole for detecting blows to the diabetic foot
2 MT + 4 BD	Legs' massager for varicose veins
2 MT + 6 BD	Pump for liver transplants

*MT = MedTech; BD = Bioengineering Design

These seven multi-disciplinary teams work with the PBL approach under the supervision of the nine professors involved in these subjects, through lecture sessions and practical sessions, combined to reinforce the learning process. The PBL approach allows the members of each team to learn the four categories of PM skills.

Lecture sessions, together with some specific conferences led by professionals of the Bioengineering arena, allow the teams to improve their capabilities and achieve their project goals. Furthermore, for three sessions teams were divided to deal in depth with prototype design on the one hand, and into the marketing and entrepreneurship on the other hand. The rest of the sessions were shared and dealt with teamwork, project management and sustainability. Based on the PM style, some deliverables are required to the teams along the course. Table 3 shows the PBL methodology and techniques used for reinforcing the PM skills.

Table 3. The methodology used during the course.

Techniques	Description
Roles definition	Clients (professors), project managers* and team members
Teamwork and team development	Multidisciplinary teams; Team agreements; Personality assessment; Interviews; Organization charts; Competency assessment; Teambuilding activities; Conflict resolution activities.
Deliverables	A set of deliverables is scheduled with deadlines. They are linked with the four project management competencies categories. Some examples are: CAD designs; Simulations; Prototyping; Usability; Business Plan; Team performance; Project Management Plan.
Oral presentations	An interim presentation for assessing the progress and a final presentation is scheduled. They include technical, management, business, and sustainable aspects.
Meetings and interviews	With stakeholders (round tables with practitioners, hospitals, clients, doctors, regulators, etc.); and Professors (Mentoring);
Complementary workshops	Arduino-Matlab; Simulations; Sustainability; Biomechanics; Electronic design; Biomaterials; Leadership and communication skills; Entrepreneurship.

*The role of the project manager was distributed between the team members looking for a horizontal hierarchy.

LESSONS LEARNED DURING THE PROJECT PERFORMANCE

The six projects chosen by the students are shown in Figure 1. The first lesson learned is to afford the students to choose their own project. It allows students to become more involved in their designs. In addition, it allowed them to choose a project that responds to a close need, often lived by a family member or a friend. Then, the ability to obtain first-hand information also

increases and it is easier to align their entrepreneurship strategies with the client's needs. Thus, the skills related to the business are developed at the same time as the technical skills.
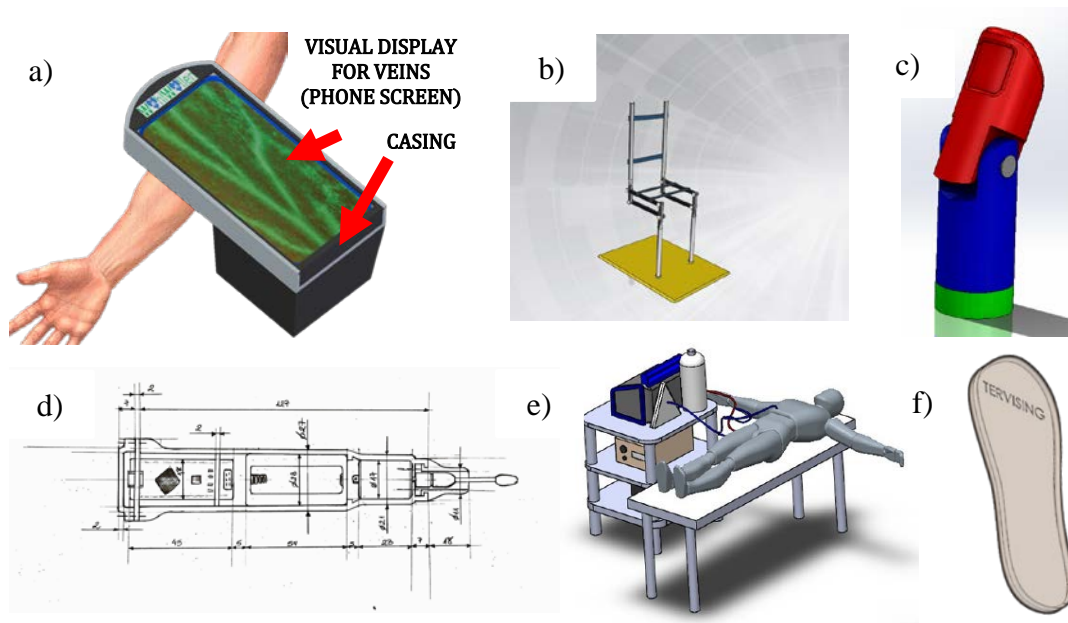

Figure 1. Selected conceptual design examples from different projects.
a) Visual display for veins. b) Standing frame. c) Thumb prostheses. d) Eyelid cleanser.
e) Pump for liver transplants f) A smart insole for detecting blows to the diabetic foot.

A second interesting finding is that the millennials generation prefers to work in horizontal teams, where the hierarchies are not very marked, in the style of teal organizations (Laloux, 2014).

Third learning is that working with some project management tools (See Figure 2) allows the students to manage their time better and to share the tasks properly. With the Work Breakdown Structure and the Gantt chart, the tasks are well identified and programmed, and team members know in which tasks are delayed. Other tools used for helping the team to achieve their objectives were roles definition and personality classification. By defining a set of responsibilities and functions of each person, based on their own strengths, training and experience, it is easier for them to better carry on their work with high commitment and performance. Personality classification, based on a simple game of 4 colors (red, blue, yellow and green), depending on the combination of Introversion-Extraversion and Rational-Emotional dimensions gives students the opportunity to improve self-awareness and communication with other team members. The process competences for the project manager are implemented for the first time for most of the students. It brings them a little closer to the future work that awaits them once they finish their masters.

The fourth but not last lesson learned is that when an appropriate follow-up to the teams is done, the team-work improves significantly. The monitorization of the teamwork was reinforced through some workshops for discovering the different personalities of the team members or the requirement of presenting their team buildings activities. This increases their personal competences for being future project managers.
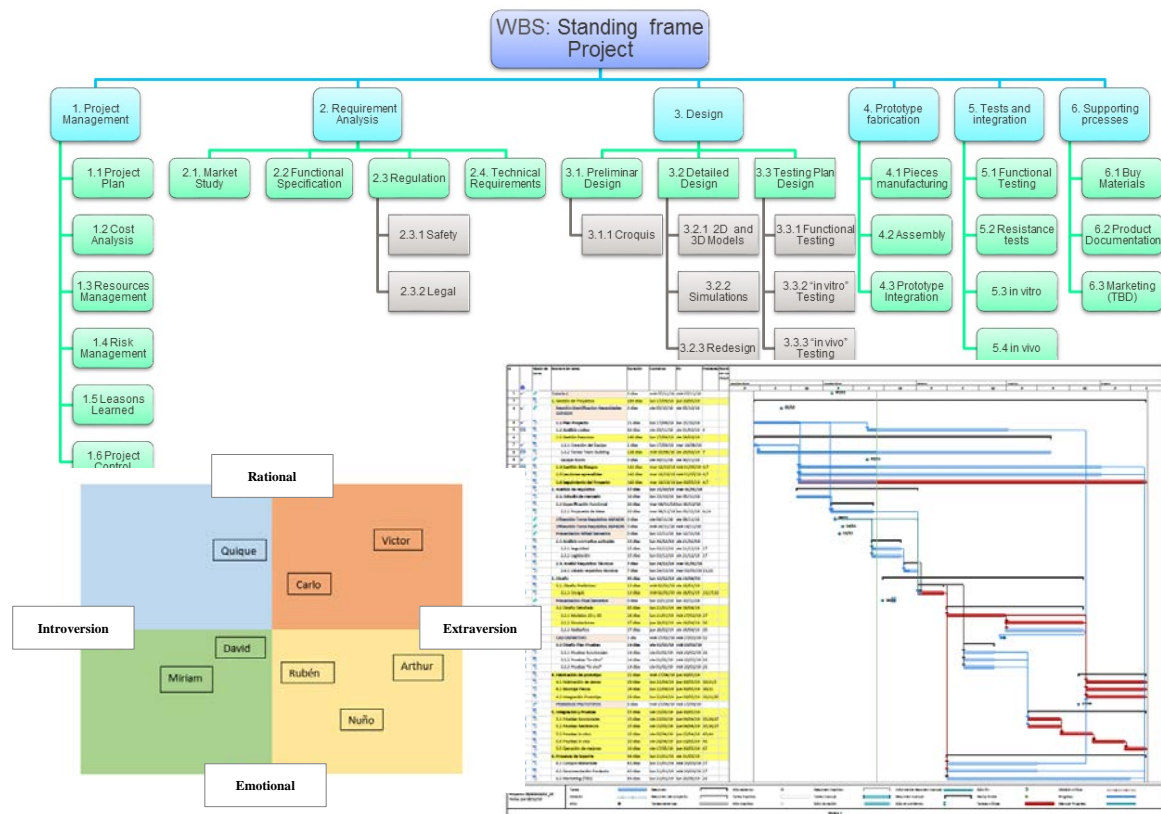
Figure 2. Several examples of project management tools used by students.

Concerning quantitative verification of the course, an interpersonal competencies survey was planned to be implemented by the students before and after the learning experience, in order to assess whether the course has an impact on their performance. The survey was built based on 37 performance indicators grouped along 8 competencies units: 1) Emotional management (5 items); 2) Self-confidence (4 items); 3) Commitment (4 items); 4) Effective communication (5 items); 5) Conflict management (4 items); 6) Effectiveness (5 items); 7) Team leadership (5 items); and 8) Professionalism (5 items). To measure the competencies, each item was defined by an extended Likert scale (from 1 to 7), which was used to assess the frequency (level) of each performance criteria.

Results for competencies measurement (n=40) at the beginning of the experience are shown in Table 4 and Figure 3. As seen, students have lower performance in *Effectiveness* (time management), *Conflict management* and *Communication*. On the other hand, they have really high means for *Professionalism* and *Commitment.* At the end of the course, the same survey is going to be implemented again by the same students so as to analyze differences and therefore the impact of this approach on students' performance, allowing to propose improvements actions for the next courses.

Table 4. Personal competencies self-assessment at the beginning of the course.

COMPETENCE UNIT	MEAN (N=40)	S.D.	MAX	MIN

1. Emotional management	5,14	1,30	7	1
2. Self-confidence	5,23	1,41	7	1
3. Commitment	5,64	1,05	7	2
4. Effective communication	4,80	1,39	7	1
5. Conflict management	4,88	1,23	7	2
6. Effectiveness	4,85	1,26	7	1
7. Team leadership	5,07	1,34	7	1
8. Professionalism	5,82	1,24	7	3
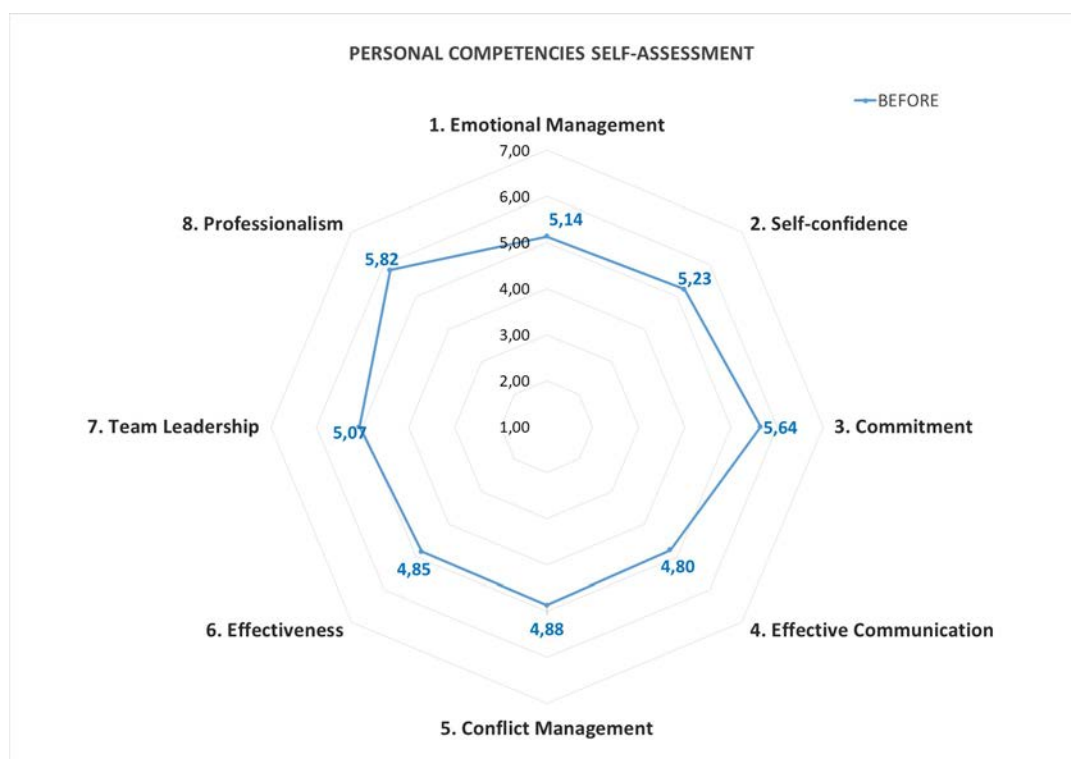
Figure 3. Personal competences self-assessment chart at the beginning of the course.

The main difficulties that raised during the experience were in the first place the effort needed by professors to be well coordinated, taking into account the ambitious objectives of the approach and the combination of two different master students in one project. As well, some difficulties have to do with the limitation in time and experience of the students, since they have several subjects with additional work and different agendas that make difficult to for them to work always together as a team.

CONCLUSIONS

The learning experience following the PBL approach and CDIO principles is showing to be really effective for future engineers and professionals. They have learned by doing, covering a wide range of competences related to project management. This experience is being

considered by both students and professors as really innovative and successful, bringing the possibility for other subjects to reproduce the methodology as an effective model.

This model gives the opportunity to students to have an experience very close to a professional one but maintaining the spirit of the university, focusing on continuous learning and using all skills necessary to be a competent engineer. Indeed, working in real projects allows them to deal with project management skills, highly required for employers nowadays.

A new way of teaching future engineers is emerging, which have some challenges both for students and professors. Students more and more have to be able to deal with a goal orientation mind combined with team building, commitment, conflict resolution, and emotional management issues. On the other hand, professors must be capable of accompanying students from a technical and human perspective, bringing them the opportunity to deploy all their potential.

ACKNOWLEDGMENT

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DEVELOPMENT OF INNOVATIVE LABS FOR EDUCATION IN MINING ENGINEERING PROGRAMS

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ABSTRACT

The School of Mines and Energy of the Technical University of Madrid is working on the transformation of an educational laboratory on Mining Technology to develop an Innovative Lab in this field. As part of a project developed by several European partners and supported by EIT Raw Materials, this is one of the first experiences oriented to educate and train undergraduate and MSc students, by creating a space devoted to the development of their technical and entrepreneurial skills. Moreover, in these spaces, the use and integration of new tools and technologies will help to educate the future professionals who will develop their activity within the 4th industrial revolution, in which the mining industry is called to evolve giving place to "smart mining factories" with cyber-physical mining systems. This will be translated in a completely new way to interact among computers, automatic systems, robotics, and humans. This paper describes how this education project is being developed.

KEYWORDS

INTRODUCTION

Innovation is at the heart of mining, but as technology continues to evolve at a rapid rate, mining companies need to look for new ways to leverage new tech to remain innovative and agile in a changing market. Like other industries, the mining sector is beginning to look at ways to leverage and learn from new entrants in this field, to become more competitive and cost-effective (Mining Global, 2018). To meet the challenges, the global mining industry is currently facing more competitive economic settings and increasing requirements and responsibilities for health, safety and environment (E. Clausen, J. Herrera Herbert, et al., 2017). The terms "Industry 4.0" (Marr, B. 2018), "Mining 4.0" (Bartnitzki, T. 2017) or "Mine of the Future" (Rio Tinto, 2008) are being widely discussed. The arising of technical priorities and objectives are critical in an energy-efficient, economically feasible and high-performance production of raw materials; increase in automation and autonomous systems for production, transportation, and processing while minimizing the impact on humans and the environment and maximizing the social license to operate (Marr, B. 2018) are aspects that need new generations of engineers.

Technological innovation is the key to future sustainability for the mining sector. However, technological developments based on the successful integration and implementation of sensor systems, modern information and communication systems as well as artificial intelligence, robotics, system automation, etc., will only lead to real breakthrough innovations if non-technical requirements related to social acceptance, environmental and social impact as well as regulatory constraints are additionally fulfilled. "Engineering shall no longer be the center of the society, but society shall become the center of engineering" (Kamp, A., 2017). The position of engineering in society is changing. Future mining engineers need to have a deep disciplinary knowledge while at the same time being strong in personal and interpersonal skills, leadership, innovation, entrepreneurship, and collaboration. Therefore, the mining engineer of the future needs to become an integrator of diverse skill sets and best practices together with being a coordinator of an increasingly interdisciplinary team.

The prime role of engineers is about innovation and designing systems (…), systems that actually design society as we know it (Kamp, A., 2017). Engineers focus on new ideas, on developing the best product. It is important that they have strong research, design and development skills. The main focus of the operational excellence role is process efficiency and finding ways to achieve the best total cost. These engineers oversee and standardize processes and have an eye for analyzing and solving problems. At last, the customer intimacy role has as a goal to provide customers with the best total solution and to respond to customers' specific technological needs. Professionalism, communication, and ethical responsibility are important features for those engineers (Langie, G. & De Norre, J., 2016).

Education of the new generations of Mining Engineers has evolved the same way as has happened in other engineering disciplines. Developments introduced in other industrial engineering disciplines can be adapted and applied to mining disciplines. And at the same time, new actors have appeared to shift changes. One of these actors is EIT Raw Materials.

EIT Raw Materials is one of the eight Knowledge and Innovation Communities created to boost innovation and entrepreneurship across Europe with the support of the European Institute of Innovation and Technology (EIT). Created in 2015 and participated by more than 120 European partners from leading industries, universities and research institutions from more than 20 EU countries (EIT, 2018), EIT Raw Materials is the largest consortium in the raw materials sector worldwide. Its partners are active across the entire raw materials value chain, from sustainable exploration, efficient mining and mineral processing to substitution, recycling, and circular economy. It has the vision of developing raw materials into a major strength for Europe by finding new, innovative solutions to secure supply and improve the raw materials sector in Europe and the mission of contributing to boosting competitiveness, growth, and attractiveness of the European raw materials sector via radical innovation, new educational approaches and guided entrepreneurship (EIT, 2018).

The Raw Materials Academy is the overarching brand of all the educational activities of the EIT Raw Materials. Activities across the entire ecosystem of learners (Ph.D. students, masters' students, industrial partners, professionals within the raw materials sector, and wider society) foster new ways of learning and teaching by connecting academia, industry and research organizations. EIT Raw Materials will educate people that will have an intra- and entrepreneurial mindset and will be able to develop their functions in new working environments, fostering the entrepreneurial and innovation skills, knowledge and attitudes needed for the entre- and intrapreneurs of tomorrow.

Before 2017, in Europe, there were no academic institutes applying CDIO for primary resource related university programs (Exploration, Mining, Mineral Processing, and Metallurgy). Supported by the EIT Raw Materials through the Raw Materials Academy, the first international education projects are being developed to contribute to the implementation of the CDIO methodology in primary resources linked programs (Herrera Herbert, J. et al, 2017). Based on a previous preliminary project, a second new project started in 2018 focusing, among other objectives, in the development of innovative labs for education in mining engineering and related disciplines. This experience will be extended later to create similar facilities in education programs in the rest of the mineral raw materials value chain.
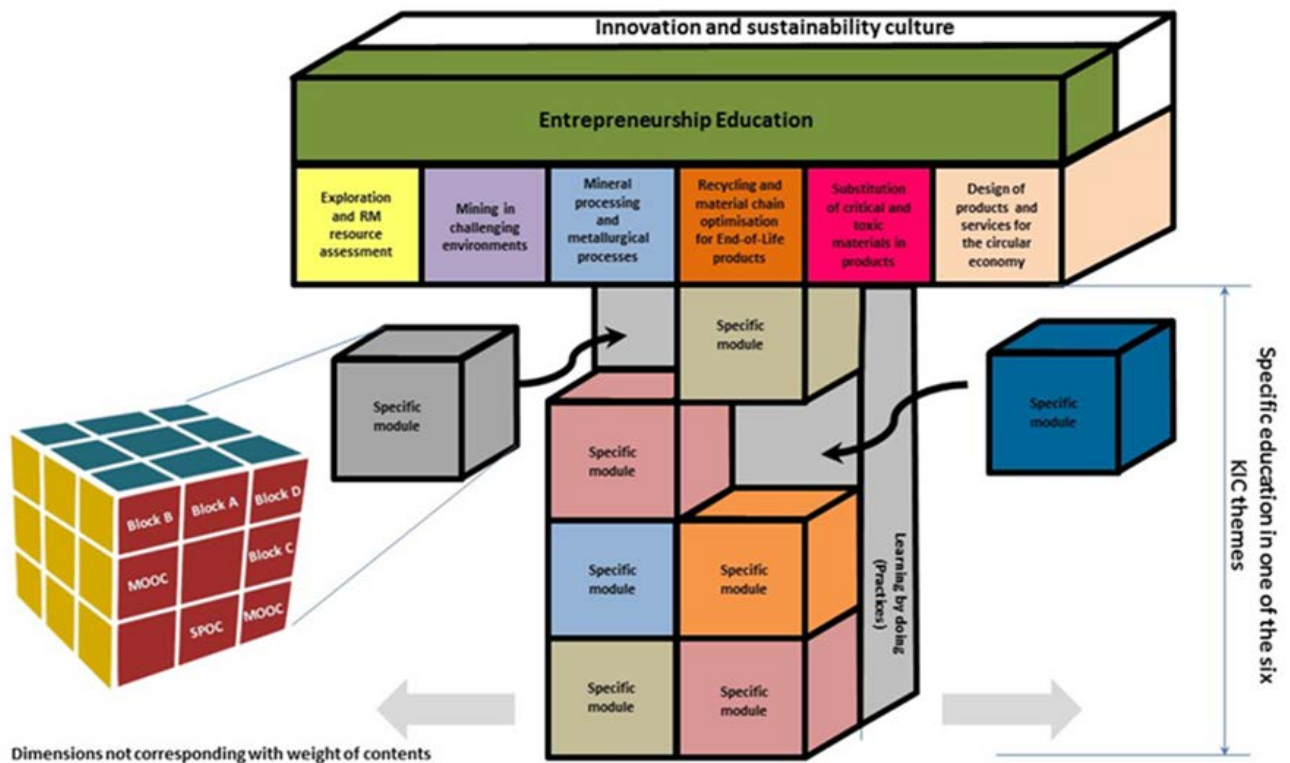
Figure 1. T-Shaped Professionals in Raw Materials (Herrera Herbert, J., 2017).

The majority of the existing innovative labs are facilities oriented for research activities and for the use by researchers and Ph.D. students. They have not been conceived as education labs for students in Graduate and MSc programs. This project focuses on the development of this concept to help in the learning and training of a new generation of mining engineers, especially in the new skills demanded by companies.

This project started beginning in January 2018 and will finish ending December 2019. It is being developed by a consortium constituted by Chalmers University of Technology (Sweden), Universidad Politécnica de Madrid - UPM or Technical University of Madrid (Spain), Luleå University of Technology – LTU (Sweden), Clausthal University of Technology – CUT (Germany), University of Limerick – UL (Ireland), Luossavaara-Kiirunavaara Aktiebolag LKAB (Sweden) and RISE - Research Institutes of Sweden. This paper describes the preliminary results of the development of an innovative lab for undergraduate and MSc students in programs of the School of Mines of the Technical University of Madrid. It also describes how EIT Raw Materials is supporting this kind of initiatives.

EDUCATIONAL INNOVATIVE LAB DEVELOPMENT

Design is all about problem-solving and needs of an attitude of looking at the world around you and contributes to constantly changing and transforming it for the better. On the other hand, Innovation is finding and applying new approaches to address existing problems or serve unmet needs. Innovation is a new solution with the transformative ability to accelerate impact. Innovation can be fueled by science and technology, can entail improved ways of working with new and diverse partners, or can involve technologies, processes or application, new social and business models or policy, creative financing mechanisms, or path-breaking improvements in delivering essential services and products. Innovation has been and will be pivotal for reaching sustained, scalable solutions to the world's complex problems (Desai, A., 2019).

To be truly innovative, companies need to ensure a culture that supports new ideas and new ways of doing business efforts, but also execute those ideas. As mining companies become more ambitious with their capital investments, the difficulty for management teams is prioritising those technologies with the potential for the biggest impact. It's a question of experimenting, piloting, learning and adapting in developing solutions. Involving the workforce in any new technological developments through both on-the-job and classroom-based training can have a radical impact on the successful implementation of new strategies (McGrath, J. 2017). World leading mining companies have embarked on substantial training programs to upskill their workforce to enable them to handle a rapidly changing operating environment.

"To change the world, you have to be taught differently" (Kamp, A., 2017). The revolution that is enabled by *Industry 4.0* covers the spectrum from data science, data analytics, and cybersecurity, to next-generation robotics, advanced manufacturing technologies, smart materials, smart operations, the Internet of Things (IoT), predictive analytics, AR/VR technologies, etc., all of them applicable to any discipline in design, engineering or sciences. Engineers who are suitable for the emerging industrial revolution that is enabled by Industry 4.0, will need an imprint of (Kamp, A. 2017):

- Rigour of technical fundamentals of 21st-century engineering
- Deep skills in data science, data analytics, and cybersecurity
- Designing products and processes for the environment
- Life-cycle systems engineering knowledge
- Commercial awareness
- Protection of products and industrial frameworks
- Empathy for sustainability
- Ethical framework: powerful technologies will lead to unforeseen impactful consequences.

The CDIO Standard "Integrated learning experiences" champions the integration of disciplinary and practical knowledge along with personal and interpersonal skills. This both the most important and the most challenging of the CDIO Standards to implement: all of the experts are discipline-based, and each of them believes that their discipline is the most important thing in the universe. If you tell them they have to enrich that with creativity, ethical, systems thinking or other interdisciplinary skills, they find it extremely difficult because they themselves are not equipped for that (Skoltech, 2017).

CDIO is based on a commonly shared idea that engineering graduates should be able to: Conceive - Design - Implement - Operate complex value-added engineering systems in a modern team-based engineering environment to create systems and products (Malmqvist, J., 2016).

Conceive: includes customer needs, technology, enterprise strategy, regulations; and conceptual, technical and business plans
Design: includes plans, drawings, and algorithms that describe what will be implemented.
Implement: is all about the transformation of the design into the product, process, or system, including manufacturing, coding, testing, and validation.
Operate: refers to the implemented product or process delivering the intended value, including maintaining, evolving and retiring the system.

An education that stresses the fundamentals, covered in the context of Conceiving – Designing – Implementing - Operating systems and products include (CDIO, 2018) (I) a curriculum organized around mutually supporting courses, but with CDIO activities highly interwoven, (II) rich with student design-build-test projects, (III) integrating learning of professional skills such as teamwork and communication, (IV) featuring active and experiential learning, and (V) constantly improved through quality assurance process with higher aims than accreditation.

At this point, the Innovative Lab is an asset that will contribute to provide the training of the students who will become the next generation workforce that will integrate technologies, develop new ideas and execute those projects. The Innovative Lab can be the bridge from innovative thinking to execution, encouraging a culture of continuous improvement through empowerment of this future workforce.

The objective of an Innovative Lab in education is to: (I) train the students to be able to accelerate the adoption of emerging innovations; (II) create between the students a culture that's more conducive to innovation and informed risk-taking; and (III) contribute to enable the students to later be able to develop institutional capabilities to make innovation more strategic and systematic. But one of the main objectives is to show students that innovation labs developed by companies have the ultimate goal of creating new revenue streams or bolster existing ones by improving productivity or speed, and that means that there are many complex aspects to consider.

An innovation lab is a space physically located. They may receive many names ("innovation center", "creativity labs", "innovation space", "studios", "maker space", "innovation gateways", etc.), but generally, there isn't a difference. It's a new kind of physical environment that companies create, and generally, the mission is to serve as a focal point for innovation programs and activities. Other innovation initiatives may not be physically co-located, they can be as radical as Google's model of 20% 'free' time for workers to innovate, or simply involve setting up a group to collaborate with other industries, startups, or academia.

Innovative Labs have become a commonplace across industries from retail, to telecoms and travel; this includes mining companies, that have found a way to have effective innovation and re-innovation developments done in-house (Davies, B., 2016). In a broad sense, an innovation lab is a physical space dedicated to the creation, development, and execution of ideas. It's a space to cultivate, share, and grow not only potential earning opportunities but also relationships within an organization (Cruz, E. 2016). Innovation labs "recreate the atmosphere of a startup": they create an atmosphere in which risk-taking is encouraged, and everything is

geared towards spurring creativity and nurturing new ideas, helping to develop technologies and business strategies, and recruiting tech talent (Innovation Enterprise, 2019). These spaces are places to develop creative efforts and experimental projects that do not necessarily aim to lead to commercial products but will certainly move the company forward through innovation. They allow cross-fertilization from other sectors, business models, and technologies, not to mention opportunities for cost saving and minimising the chance of making expensive mistakes.

Bringing the concept of Innovative Lab to the field of education and using it with undergraduate and MSc students, an Educational Innovative Lab is a place which provides facilities to nurture new ideas and help develop inquisitive perspective in youths of today. They engage students in innovative and creative activities and serve as springboards for new ideas and innovation by promoting student's creativity and helping them to recognize and train the skills they will need to face future challenges and meet rising aspirations. Specifically, embedding such creative pedagogies in science education through Innovation Labs would also have the potential to retain and promote talent.

The facilities used at an educational innovative lab should include:

- At least one interactive science/technology exhibits/experiments area to create excitement about science/technology through exploration and discovery of underlying principles. This will help promote logical thinking.

- A space to showcase innovative ideas/products/implements that have transformed our world or have made a significant impact on the way we conduct our lives along with respective inventors & innovators. This "innovation resources" area must show stories or inspirations behind such innovations/inventions should also be mentioned through appropriate modes. Besides these, implements/samples of appropriate technology and traditional knowledge systems, the possibility to find art and craft and other areas of importance may also be an element to take into account.

- An "Idea Lab" having the necessary basic facilities to pursue creative and innovative hobbies/activities that involve model making, basic science experimentation, design & fabrication of useful gadgets of practical use, teaching/learning kits or aids for better classroom transactions, testing of samples like soil, water, items, etc.
  - A "Break & Remake Corner": Students learn to do things with their own hands, dismantle, reassemble and remake devices/gadgets.
  - A "Build from scraps corner": Students learn more by doing things practically using day to day scrap.
  - An "Idea Box corner": Students generate their own innovative ideas and create an idea bank. The best ideas are chosen for experimentation/model making/project work.

- A "Design Studio": This area will offer a creative environment to design various objects products etc.

PRELIMINARY RESULTS

Although the project will finish in December 2019, some preliminary results in fostering creativity, introduction to the culture of innovation, learning by doing, and other aspects can be shown:

Fostering creativity

Innovative Labs may seem far from the objectives of a School of Engineering. Engineering is a technical subject and gaining a strong understanding of science and math is important, but creativity is also highly valued. Universities and companies are always looking for engineers who embrace their creative side as it helps them to think differently, which is perfect for designing new products or solving problems. The ability to visualise, dream up, draw and think outside the box are fantastic skills.

Problems exist for a reason and they're not simple to solve. Real life problems, don't have a unique and exact solution. That is why engineers have to be creative and use their knowledge, engineering tools, and expertise to solve the biggest problems. An educative innovation lab is an experimental place where students can experiment with the complexity of real problems. The work of an engineer isn't all about detailed measurements. All engineers design, create and innovate, essentially working as 'creative problem-solvers'. Engineers must go beyond the measurement and come up with new ideas and ways of solving problems every day. Design something also makes the work exciting and fun.

Introduction to the culture of innovation

The education innovative lab acts as a bridge between university students and project teams in companies, allowing a better approach to emerging innovations.

Real learning by doing environment

Students must apply their theoretical knowledge to resolve real cases. This will make them understand the importance of a solid background and, at the same time, develop the capacity to understand what new knowledge and skills are needed to resolve the situation and allow them to react to cover the gap.

At the same time, the work on real company needs allows them to train on the functions they will later perform once they leave the School of Engineering.

Innovative labs are not "showcase labs"

While innovative labs developed in companies usually have a small or medium size group of researchers and engineers, an educative innovative lab has to deal with medium to big size groups of students. Furthermore, students are training their skills and have no previous experience.

Another question is the difference between normal labs used in the different subjects that student study at the School of Engineering and the educative innovative lab. A facility of this kind is not a place where lecturer and professor make demonstrations for students but are a place where students can experiment, create and develop without any risk or knowing and understanding the risks. On the other side, and educative innovation lab is not a research lab for the use of Ph.D. students and researchers, as these facilities are equipped with tools and equipment that non-experimented students will use.

Educative innovation labs will not provide real innovation bust students will learn to innovate

This kind of labs must be designed to allow students to experiment and to learn to experiment. Students are there to learn to innovate, but no real innovations should be expected from these labs. The really successful innovation labs are the ones that are tied to a company strategic imperative and meet specific criteria, rather than just creating a cool space and holding meetings or training sessions in it. It's really critical that the innovation lab delivers added value to the corporate strategy, whatever that may be. In an educative innovative lab, the focus is on training as many people as possible, and the added value will come by developing professionals.

Innovative labs are not R&D labs

Discoveries in innovative labs are about ideas, not about discovering something specific. Educational innovative labs must then be about training student to develop their creativity and generate new ideas and concepts that may resolve a real problem. Furthermore, innovative labs are places where relationships and communication skills are fundamental for success, and these are some of the skill that must be trained in the educational innovative lab.

CONCLUSIONS

Engineers that are being educated today will constitute the workforce that will conceive, design, implement and operate the projects of the near future. They will have to work in environments that are in constant evolution. Technology and innovation will make imagination, ideas, and investment from governments and industry necessary to take advantage of opportunities. In other words, those new engineers will have to work differently. But working differently means learning differently, with new skills and wider knowledge in many aspects.

Many of the world's largest companies have developed some form of innovation lab as specialized offices dedicated exclusively to innovation, idea-generation, and free-thinking, with the most innovation-centric culture possible with the mission of think outside the box, throw ideas around and be as innovative as possible. The development of this kind of facilities for education in a university, just to be used as an education technique focusing on undergraduate and MSc students, is an innovative way to have the students getting close contact with real innovation and to develop creativity and engineering skills at the same time they get to understand the real dimension of the knowledge they are acquiring and how to apply it while resolving real problems.

Educational Innovative Labs haven't arrived to replace any conventional laboratory where students must learn the fundamentals of science and technology. Rather than that, these facilities must be focused to develop in the students a spirit to create a breakthrough, to encourage them to think on out-of-the-box solutions, to show them how to address problems creatively and contribute to develop an entrepreneurial mindset in them. Educational Innovative Labs are a complement to the whole program that the students are following, and where the real added value is to make them learn to be creative and how to develop and apply this creativity. But it is of critical importance that those labs are aligned with the study program and its outputs, to assure they can be at their most effective.

The Educational Innovative Labs can apply a wide range of methods and tools to stimulate creativity, guide discussions, moderate collaboration, stimulate group working as well as develop, prototype, and experiment solutions. Their self-proclaimed role is to "bring together the brains, methodology, and diverse tools for innovation. They encourage students to try things out on a small scale, take risks, prototype, test and accept failure as part of progress, re-inventing their own methods and approaches as they go along.

ACKNOWLEDGMENTS

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DESIGN AND DEVELOPMENT OF VIRTUAL ENGINEERING LAB

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ABSTRACT

Virtual reality (VR) is a method of immersing a person into a virtual environment by using a headset with a screen and lenses to simulate a 3D experience. This project aims to test the effect of using VR in engineering laboratories to improve the quality of teaching in Science, technology, engineering, maths (STEM) subjects. In this study, VR technology was used to design and develop an engineering laboratory. This would illustrate the fundamental concepts taught in the real laboratory to the Mechanical engineers. The VR lab was created using Unity, a game development software. The VR lab was tested with students from the School of Engineering and Warwick Manufacturing Group at the University of Warwick. Students participating in the study were given two identical assessments, one before and one after being in the VR lab experience. The difference in student learning depicted by assessment scores was compared to the result attained from the students exposed to the traditional learning style. A final questionnaire was given to each participant, allowing them to share their opinion and show their emotions towards their learning method. It was observed that students attained better assessment scores when exposed to the VR lab experience. In addition, positive comments were received from students, stating they found VR to be an engaging platform for learning.

KEYWORDS

Active learning; e-learning; innovative ideas to teach engineering using virtual reality; digital learning; Standards: 8.

INTRODUCTION

Education and training, especially in STEM subjects, are areas in which continuous improvements and evolution of methods are required to advance at the same rate as the complexity of the subjects taught. "*The problems include a lack of practical skills in modern engineering training, the lack of relevance for industry of the science being taught… As these problems have not been properly addressed and the demand for well-trained engineers has increased steadily, the situation in today's smart society is even more challenging*" (Michael E. Auer, Kwang-Sun Kim, 2016). Engineering education requires a more practical focus in order to properly train modern engineers for the complex systems that exist in the world. Currently, this experience only exists in the form of experimental laboratories; a student may only receive

a few of these opportunities in each university year. Limitations of these current laboratories include a high cost, time, space requirements, and maintenance.

It is suggested that laboratories may lack a clear learning objective and as such could be less useful for the education of students (Lyle D. Feisel, Albert J. Rosa, 2013). The limitations previously mentioned stopping these laboratories from being as effective as they might be. With better training before the laboratory, students may proceed with a better understanding of the desired outcomes before starting the lab; allowing them to take full advantage of the laboratory experience. Currently, these labs are prefaced with a briefing sheet and occasionally a briefing lecture to allow students to prepare themselves in advance of the lab. It is often seen that students barely read the briefing sheet, if at all, and go into the lab with no clear idea of what they are trying to achieve.

This project proposes to test the effect and acceptability of a new method of training: VR. This technology would allow students to take part in a simulated version of the laboratory without as many of the costs and hazards involved with the real version. Further benefits include the ability to go back to the laboratory in their own time to practise or remember the experience to further their understanding. The predicted benefit is that students will understand more about the laboratory before going into it with the VR training compared to the traditional briefing sheet. To prove this hypothesis, an experimental method was set up, along with a VR of the chosen lab, to test student's understanding before and after their training. Students would participate in either the VR or traditional training and measurement of their learning performance is taken, along with their acceptance of the completed method.

The main objective of this project is to research if there exists a benefit of using VR to train students compared to current briefing methods. This research could then act, with existing research, as a basis for the inclusion of VR and similar technologies in education and training within STEM subjects. Thus, it helps improve the quality of comprehension and perhaps allowing even more complex systems to be researched and understood.

The paper has been arranged as follows where Section 1 deals with the literature review, Section 2 explains the experimental method followed by results and discussion in Section 3. Finally, conclusions are presented in Section 4 which is followed by future work in Section 5.

LITERATURE REVIEW

VR uses a small screen and lenses inside a head-mounted display (HMD) to make the user feel as if they are inside a digital three-dimensional world. This virtual world is generated by a game development software package. For this study Unity was used to develop the virtual environment. VRTK (Virtual Reality Toolkit) is a free toolkit used with Unity to easily setup the VR environment. Blender and Substance Painter were used to model and texture the objects in the lab. VR could be used in several different engineering education applications: Lectures, workshops, classes, and labs. It could have the benefit of allowing students to become more engaged in the activity by fully immersing them. Some of these scenarios could potentially work better than others. For example, lectures in VR would differ very little from the traditional lecture providing few benefits. Although, labs in VR would be very similar but offer the benefit of safety and reduced equipment cost, while allowing additional virtual elements to enhance the experience.

E-learning is the use of electronic and online resources for education. Serious games are games designed to educate, rather than to entertain. A meta-analysis of serious games can be found in the Psycnet article (Wouters, Pieter, van Nimwegen, Christof, van Oostendorp, Herre, van der Spek, Erik D., 2013). This showed a significant positive effect in learning and retention; the serious games were just as motivating as traditional methods. E-learners continued to learn more when the games were replaced with other e-learning sources, such as team games, new instructions, and multiple sessions. Therefore, it is suggested that e-learning provides a consistent improvement. E-learning is likely more effective because students can learn in their own time and preferred environment. Since there is no classroom to attend, students can learn when it suits them. Therefore, they are less likely to be sleepy or stressed, which has been proven to negatively affect learning (Dean W. Beebe Ph.D., Douglas Rose M.D., Raouf Amin M.D., 2010). Furthermore, students may participate more as there will be no fear of failure, which is shown to encourage students not to participate to avoid embarrassment (De Castella, K., Byrne, D., & Covington, M., 2013). Since failure is the way humans learn and improve, encouraging students not to fear occasional failure to improve overall will increase the learning resource's benefits (Johannes Bauer, Christan Harteis, 2012). This will also encourage students to explore options, regardless of if they think they are right or wrong. Furthermore, repetition of the material can assist learning (Kang, 2016); students can repeat e-learning material whenever they want but are unable to repeat a class. Without needing to travel, students can learn in a personalised and comfortable environment. Furthermore, e-learning activities involve 2D animations, games, and interactions to attempt to improve attention and learning quality. VR serves to do the same, just in 3D, though similar its benefits include a much greater sense of immersion and attention. The user has a sense of being there, much improving the quality of learning, as shown by the IEEE's study (C.E. Hughes, C.B. Stapleton, D.E. Hughes, E.M. Smith, 2005).

In the Investigation and Application of Virtual Reality as an Education Tool, (John T. Bell, H. Scott Fogler, 1995) the effectiveness of several different teaching methods is discussed. It uses Bloom's Taxonomy, shown in figure 1, which describes a hierarchy of learning objectives which represent how well a person has learned something. This starts from memorising, then understanding, and so on up to evaluating and creating. Furthermore, the article states that alongside Bloom's Taxonomy, that identifying the best methods for teaching is necessary. The paper states that traditional teaching methods typically only provide the first 3 levels of Bloom's taxonomy; If the teaching resource provides an experience where students leave with a comparatively higher level and include all the learning styles, then it will certainly be effective in educational use. To achieve this, each item in Bloom's Taxonomy and the learning styles should be closely analysed and understood. This way, programs developed for education can adhere to these methods to ensure the application is effective in teaching, more so than just an interesting new technology.
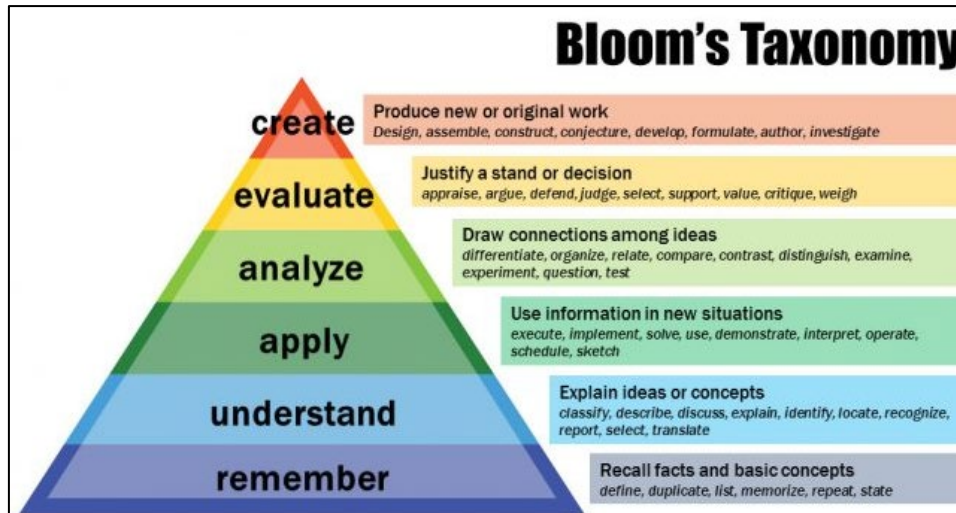
Figure 1: Bloom's Taxonomy Graphic (Armstrong, 2006)

Sensory, visual, and inductive learning styles are known to be preferred by engineering students (John T. Bell, H. Scott Fogler, 1995). As such, they should be focussed on most when considering the development of an educational VR tool. To summarise there are many different aspects to cover if VR in engineering education is going to be useful. It has already been proved that the technology could help, but how to do so has hardly been covered. So, to make VR in education as effective as possible, teaching and learning methods need to be considered. Bloom's taxonomy is useful in considering the different levels of learning and how they can be achieved. The learning styles should also be considered for VR applications to work for students and teachers effectively. Making a VR application which not only demonstrates, but helps students understand, analyse, and create while focussing on a sensory, visual and inductive experience would be the most effective teaching resource to come from the technology.

In the PNAS article (Scott Freeman, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth, 2014), a meta-analysis of active learning was carried out and a 6% increase in exam grade was seen over 225 different studies. Intuitively, active learning should be more effective for STEM subjects. The subjects are involved, complex, and full of design and construct. To learn this, one needs to take part, this is active learning. Learning styles are less to do with personal preference and more to do with the subject. The American statistician's journal entry (Kvam, 2000) examined the immediate and long-term effects of active learning instead of traditional. The experiment showed an increase of retention with average and low scores. This is preferred, as the longer-term learning benefits are much more desirable.

VR provides new possibilities not previously accessible by traditional teaching methods. It allows the incorporation of muscle memory, interactions, and three-dimensional visuals. It has already proven to be effective for motor rehabilitation and with further use and development of the technology it could be worth the investment. In the Biomed Central article (Heidi, 2004), VR was shown to be as effective as the real-world equivalent. Therefore, VR clearly has a positive effect on people in training and rehabilitation scenarios, and it is worth testing if this effect could extend to education and learning. The NCBI article (Neal E. Seymour, MD, Anthony G. Gallagher, PhD, Sanziana A. Roman, MD, Michael K. O'Brien, MD, Vipin K. Bansal, MD, Dana K. Andersen, MD, and Richard M. Satava, MD, 2002) showed VR to give a

significant performance increase and a large failure reduction rate while training for an operating room environment. Those taking part showed a 29% faster performance and were nine times less likely to fail. Training is very similar to classroom education in some cases, so these benefits could be transferable to education.

From the above, a benefit is clearly predictable and therefore the tests are justified. The initial costs included in adopting VR are steep, though the maintenance costs are considerably lower compared to traditional training methods. For example, to train students to take apart an engine, in VR a few headsets and PC's would be required costing a few thousand pounds per set-up. To do this in the real world, the equipment, upkeep, and repair costs are also very high. Students health must be considered, such as motion sickness, soreness, repetitive strain injury (RSI), etc. A combination of both traditional and VR methods would be the most beneficial as VR or traditional methods alone are not effective enough. Traditional and e-learning methods are currently combined in this manner, which proves to be effective. This is called blended learning and is more effective than traditional or purely e-learning methods (Means, B., Toyama, Y., Murphy, R., & Bakia, M., 2013)

EXPERIMENTAL METHOD

The chosen lab for this project was a second-year engineering laboratory: pipe flow. A virtual version of this laboratory was developed using the game creation software Unity. A free collection of code was used called Virtual Reality Toolkit (VRTK) which contains the code required to make VR interactions within the application. Blender was used to model the apparatus used in the lab and a free trial of Substance Painter was used to apply colours and textures to these models to make them look realistic. The interactions between the student using the application and the virtual apparatus were programmed with calculations to simulate the expected results from the inputs given. A tutorial was then coded to guide the user through the method for taking the required measurements, as well as stopping them from making mistakes which could be potentially damaging to them or the equipment in the real experiment. Once the virtual experiment is completed, information on the theory of the lab is then displayed along with diagrams to help their understanding. The final laboratory can be seen in figure 2.
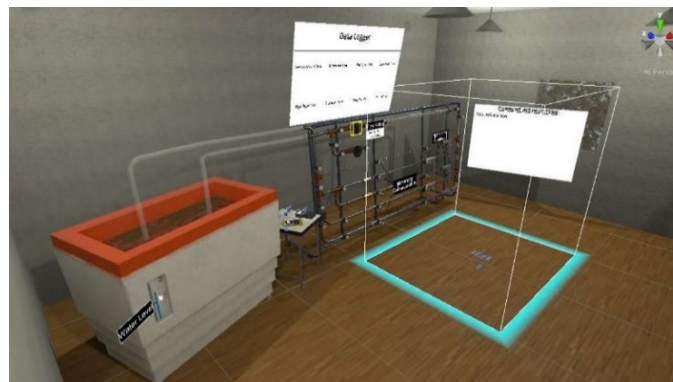

Figure 2: The virtual laboratory designed in Unity for the students to complete.

To understand the effectiveness of the virtual lab, a measurement of the students learning performance and acceptability of the learning method is required. To measure learning performance, an identical test was given to students before and after partaking in their learning method, these questions were chosen to accurately account for theory and practical knowledge that should be acquired before taking part in the laboratory. It was anticipated that

students should be able to answer very few of the questions before, but much more after their learning session. After the students have completed the training and knowledge tests, a UTAUT (Unified Theory of Acceptance and Usage of Technology) questionnaire was given with questions tailored towards the acceptance of the technology. Due to the wording of the questions, they also applied to the briefing sheet and so a direct comparison of acceptance and emotion can be drawn between the two methods.

During the experiment itself, the student is given roughly 15 minutes to complete their training. This is so students have an equal amount of time to understand the laboratory as if they were to take part in it later. Both tests were run in a quiet room, one at a time, to prevent distractions. For the briefing sheet, students would read and take notes as required, but when answering the knowledge tests the briefing sheet and any notes made were removed. For the VR lab, students followed the instructions and a supervisor was present to help them with controls and understanding of the technology itself, but not the content. This is because VR is still a new technology and it is unlikely for participants to be familiar with the equipment and so aid is given to help make it a fairer comparison.

RESULTS AND DISCUSSION

The following tables show the test scores before and after the VR and briefing sheet trials and the questionnaire answers. Measurement of improvement can be taken by comparing the difference in student's correct answers before and after. Each test is out of a total of 23 marks. Table 1 shows the marks given for the 10 questions in each of the participant knowledge tests, followed by a total and an average; participant numbers are given at the top.

Learning Performance

Table 1: Comparison of knowledge test scores for VR and the briefing sheet

	Question Number	Average for VR Participants	Average for Briefing Sheet Participants
Pre-Test	1	0.3	0.3
	2	0.1	0.1
	3	0.0	0.1
	4	0.7	0.6
	5	0.0	0.0
	6	1.2	1.1
	7	0.1	0.2
	8	0.5	0.5
	9	1.1	1.1
	10	0.4	0.6
	Total	**4.4**	**4.6**
Post-Test	1	1.6	0.4
	2	0.6	0.1
	3	0.8	0.6
	4	0.7	0.6
	5	0.7	0.0
	6	1.8	1.3
	7	0.5	0.5
	8	2.4	1.5
	9	2.6	1.8
	10	6.6	2.3
	Total	**18.3**	**9.1**
Difference	1	1.3	0.1
	2	0.5	0.0
	3	0.8	0.5
	4	0.0	0.0

Proceedings of the 15th International CDIO Conference, Aarhus University, Aarhus, Denmark, June 25 – 27, 2019.

528

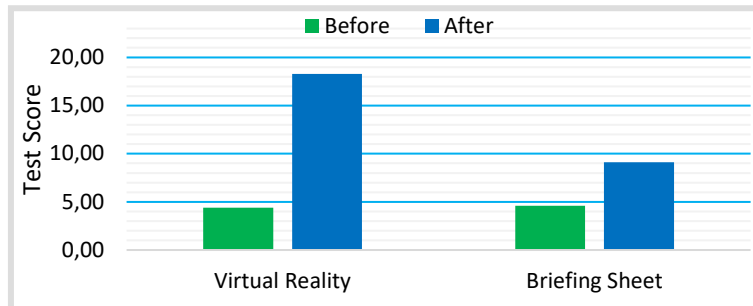|			
5	0.7	0.0
6	0.6	0.2
7	0.4	0.3
8	1.9	1.0
9	1.5	0.7
10	6.2	1.7
Total	**13.9**	**4.5**

Figure 3: A comparison of average test scores before and after the VR and briefing sheet.

Discussion

Table 1 shows the learning performance of students for VR and the briefing sheet. The results before taking the test for both methods are similar, roughly 4 to 4.5 out of 23 for both; this is as expected. The total marks after the trials were largely different between the two methods; the briefing sheet averaging around 9 while the VR has an average score of around 18, this can be seen in figure 3. This is a significant difference between the two methods for test scores. This means that the scored of participants using VR improved by 10 marks higher than the traditional briefing sheet method, as shown in figure 4. VR scores improved from 17% to 78%, while briefing improved from 19% to 34%. Thus, a 44% improvement was made by using the VR method. After completing a T-test for each question it was seen that four questions to have a greater than 99% significance level, one question had greater than 95% significance, two questions had greater than 90% significance, and no significant difference was found for three questions. Overall, this gives statistical evidence that using VR improved the test scores. For the questionnaire results, only three questions did not give statistical evidence, with a further two giving only weak evidence. From the remainder, five questions give statistical evidence and thirteen give strong statistical evidence.
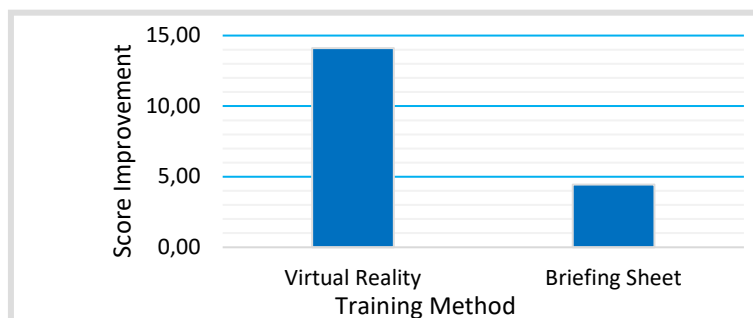
Figure 4: A comparison between the average improvement of VR and briefing sheet

Acceptance and Usage

Table 2: Comparison of the attitude UTAUT questionnaire answers on a scale of 1, strongly disagree, to 7, strongly agree, between VR and briefing sheet.

Question	Virtual Reality Participants											Briefing Sheet Participants										
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	Average	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	Average
Attitude 1	5	4	7	7	7	7	7	7	7	7	**6.5**	7	6	4	4	6	3	3	2	6	5	**4.6**
Attitude 2	5	7	7	7	7	7	7	7	7	7	**6.8**	2	6	2	3	4	3	2	1	3	1	**2.7**
Attitude 3	6	7	7	7	7	7	7	7	7	7	**6.9**	2	6	1	2	4	3	2	1	3	1	**2.5**
Attitude 4	5	6	7	7	7	7	7	7	7	7	**6.7**	4	6	2	4	5	3	2	1	4	2	**3.3**

Discussion

Table 2 is the results from the attitude section of the post-trial questionnaire. These results have been illustrated in figure 5, and it shows, in general, the VR candidates believed they had a much better attitude towards learning than the briefing sheet candidates had. The first question asks if the method they used is a good idea, VR candidates strongly agreed VR was while briefing sheet candidates remained neutral. The second and third question asks if their method makes work more interesting and if working with that method is fun, respectively. VR agreed slightly more than in question one, while the briefing sheet seemed to disagree. Lastly, question four asked if they liked working with the system and while the VR candidates strongly agreed, the briefing sheet candidates slightly disagreed.
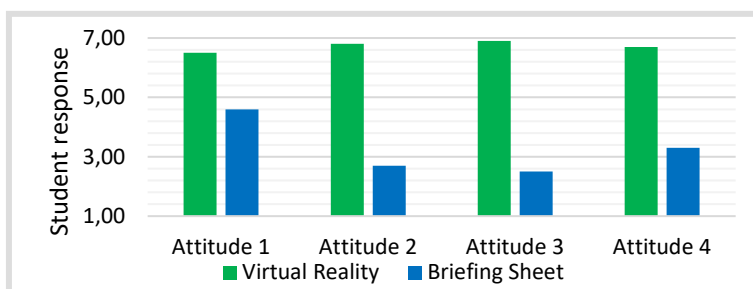
Figure 5: Comparison between the attitude of VR and briefing sheet questionnaire answers.

These results show that those using VR found the system to be interesting and fun. However, the briefing sheet candidates' answers suggest the contrary. A T-test shows these findings to have over 99% significance. A comment received by one of the students stated that technology like this would be very useful to first- and second-year undergraduate engineers, and if it were built into the course it could help the students enjoy the laboratory more and take more from it. On the other hand, these results may be biased by the fact that VR is a new and interesting technology. Therefore, a longer-term study should be conducted to eliminate this uncertainty.

CONCLUSIONS

The VR participants showed a bigger improvement to the briefing sheet. The virtual laboratory shown in figure 1 gave students a detailed experience of the laboratory. The tutorial guided students through each section of the lab, giving them instructions on what to do and why. This means that the students can learn more easily, allowing them to benefit from the real laboratory much more. Those using the briefing sheet did not achieve the same marks as those who used the VR, thus they take less away from the laboratory. The questionnaire results show that students are more engaged and perform better when using the VR method as opposed to the briefing sheet. It can also be seen that students are confident in using the system and would

like to use it if it was made available to them. Overall, this technology is still new and developing, but these results show that it may have a significant benefit in education, specifically in engineering training and teaching.

FUTURE WORK

The virtual laboratory application created for this project was made by an individual with only basic experience in coding and game designing. Thus, the result is only a basic version of what could be achieved with a larger investment. The results may improve with a more sophisticated application, as the controls, features, and information included would far exceed that given in this study. The real benefit of VR comes from the ability to do anything desired, demonstrating things not possible in the real experiment. An example of this is the internals of the pipes, and a visualisation of the flow being available to the participant. Features such as this would allow the students to be able to explore and understand much more of the theory than in the real version of the laboratory. It is recommendable that further research within this subject is conducted to determine if a more advanced application would give greater benefits.

As e-learning is becoming more popular within education, these solutions also provide a more active approach; which may give students the experience needed to succeed in complex subjects. It is necessary to compare VR training methods to other e-learning methods, such as videos or interactive demonstrations, to see if the experience makes a significant improvement to an understanding over these cheaper, readily available e-learning methods. If it does, then the investment in this technology is justified.

The use of VR expands beyond secondary and undergraduate education. There are use cases where higher costs and danger are involved. VR reduces the risk and greatly reduces the cost while giving participants a realistic and familiar training session. Training for heavy machinery, complex manufacturing lines, or delicate machinery could be done using VR. Given the trend of current research, it may be as effective if not more, so much so that it has already been adopted by some companies already and is used as their official training course.

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BIOGRAPHICAL INFORMATION

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THE EFFECTS OF INDUSTRY 4.0 ON TEACHING AND LEARNING CDIO PROJECT AT DUY TAN UNIVERSITY

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ABSTRACT

The current world education trend is to associate training with scientific research and learning to experience. In that spirit, Duy Tan University (DTU) always aims to deploy a new training model for modern, scientific and creative education, serve the purpose of creating a knowledgeable human. "Education 4.0" is considered the education models that DTU is heading to. It is the future of education, which is a student-centred, peer-to-peer, active learning model, flexibility in both time and place, project-based and experience learning, responds to the needs of Industry 4.0. It is a great challenge to transform the traditional education model into a new model, but DTU is making every effort to launch, starting with the CDIO curriculum. Our students have implemented a number of CDIO projects for the practical application of the Internet of Things (IoT) in Industry 4.0. CDIO instructors use a variety of products in Cloud Computing during the CDIO training process. In this article, we will present the effects of Industry 4.0 on teaching and learning CDIO at DTU. In order to improve the efficiency of deploying IoT applications in CDIO projects, we implemented a Flipped classroom approach. Instructors act as a learning supporter, sharing aspirations, co-creating of knowledge with students. The duty of students is to read and understand the material at home. The amount of class time spent will be discussed: student issues, student-led problems, the advantages and disadvantages of the sample designs and how to improve it to suit the actual conditions in Vietnam. To evaluate the quality of students, we propose a Process-oriented assessment approach: research, feedback, and presentation. Finally, we use quantitative parameters to evaluate the effectiveness of proposed methods: percentage of students achieving proficiency or better in ABET outcomes d, e, g, i; the total studying time; the level of satisfaction of students.

KEYWORDS:

Industry 4.0, Education 4.0, CDIO project, Process-oriented assessment, Flipped classroom
Standards: 2, 3.

INTRODUCTION

In recent years, Industry 4.0 has become a trend in many countries around the world. The concept of "Industry 4.0" was launched in 2011 in Germany, to enhance their traditional industry. It quickly spread and became a strategic program by many developed countries like the US, France, Korea, China, etc. [1][2][3].

Industry 4.0 is the achievements of artificial intelligence, automatic machines, 3D printing, Internet of Things, biotechnology, nanotechnology and so on [4][5]. Its core is a digital technology breakthrough, followed by the achievement of the digital revolution that has taken place since computers and the Internet appeared. Industry 4.0 is expected to fundamentally change the way people live, work, and interact with each other. The application of new technologies allows to boost labor productivity, raise income levels and improve the quality of life for people. However, the paper [6] has shown that this revolution can bring greater inequality, especially in the ability to break the laboùr market. Many traditional business and production models in different areas are at risk of being overturned when too many human-made jobs are replaced by automated lines. The World Economic Forum (WEF) held in January 2016 predicts: From now to 2020, 5 million jobs will be replaced by robots, the rate of unemployed and the number of vulnerable areas employees in developing countries tend to increase [7]. Similar research by the International Labor Organization (ILO) also predicts, [8] in the next two decades, about 56% of low skilled workers in 5 Southeast Asian countries, including Vietnam, risk losing a job because of robots. More specifically, 86% of workers in the textile industry and 75% of workers in the electricity and electronics industry in Vietnam are at risk of losing their jobs due to automation [9]. Many studies have shown that the workforce is medium or low skilled, does low-productivity jobs, low income, poor working conditions (e.g. workers in assembly lines, manual labor) will be the most affected people.

On the other hand, although technology revolutions often spark fears of unemployment when machines do everything, researchers believe that reducing the total number of jobs is impossible. The evidence is: in developed countries, with the higher quality workforce, unemployed and the number of vulnerable area employees is expected to decrease in 2018 - 2019 [8]. Because the application of Industry 4.0 with high automation can enhance the productivity of existing jobs and create demand for entirely new jobs in automated manufacturing, cloud computing, big data. These jobs will, of course, require a more skilled workforce, and must be equipped with skills for the future "Meta-skills". (See Fig. 1) [12].

In fact, the advanced workforce can only be trained from an advanced education: Education 4.0. Education 4.0 is the future of education, which is a student-centered learning model, peer-to-peer learning, active learning, flexibility in both time and place learning, project-based learning, actual experience learning and responds to the needs of Industry 4.0. The University of Education 4.0 is not only a place for training - research, intellectual transfer but also a centre for innovation, cultivating passions, promoting the startup spirit of the students. Duy Tan University is gradually implementing Education 4.0 model into teaching, becoming a pioneer in education reform in Vietnam.

It is a great challenge to transform the traditional education model into an Education 4.0 model, but Duy Tan University is making every effort to launch, starting with the CDIO curriculum. Faculty of Electrical & Electronic Engineering (FEEE) has given some solutions in implementing CDIO teaching and learning in accordance with the impact of Industry 4.0. Our faculty has applied the "Flipped Classroom" approach in CDIO class to enhance the system of "Meta-skills" for students as Fig. 1. To evaluate the quality of students, we propose a "Process-oriented assessment" approach: research, feedback, and presentation; focus on work processes rather than exams. Process-oriented assessment helps students to continuously improve their projects, not only the instructor's suggestions but also many other

students. Moreover, students' ability to present and criticize will be gradually improved through presentations. Students can also implement their projects anywhere, use software applications to synchronize work with their team and report to the instructor.
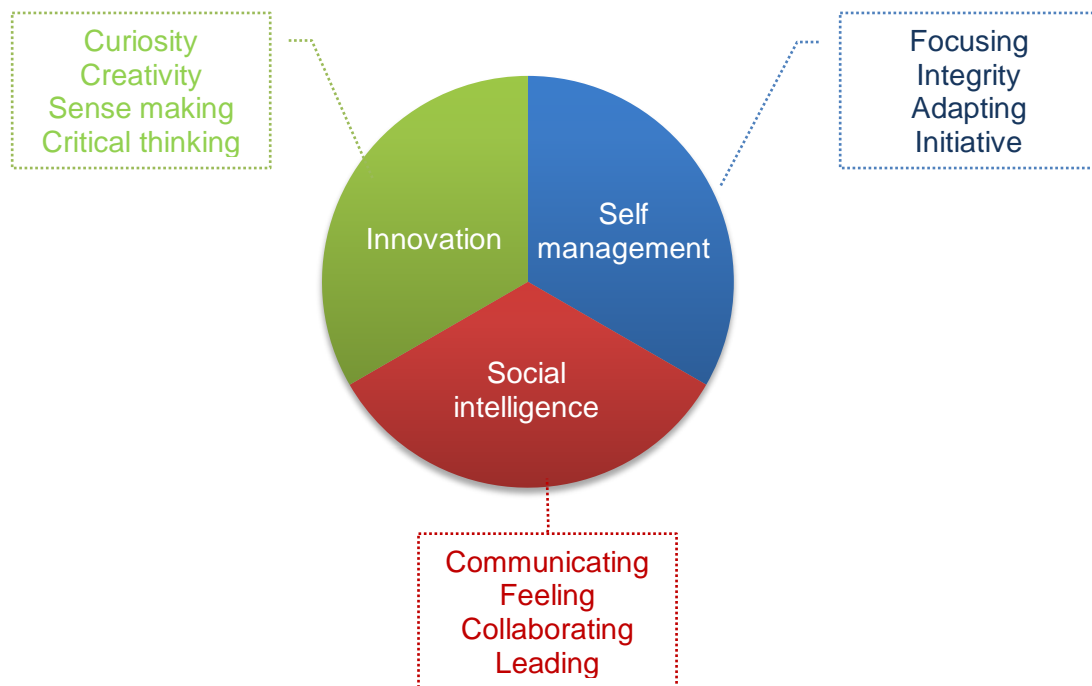

Figure 1. Skills for the future: meta-skills

To evaluate the effectiveness of the proposed method, the authors have conducted a number of surveys with the following parameters:

- Percentage of students achieving proficiency or better in ABET outcomes d, e, g, i [13]. ABET is a form of quality assurance for programs in the areas of applied and natural science, computing, engineering, and engineering technology. ABET accreditation is recognized globally as evidence that a program meets the standards set by its technical profession

- The total studying time spent on the student in the class

- The level of satisfaction of students participating in the class.

FLIPPED CLASSROOM AND PROCESS-ORIENTED ASSESSMENT DESCRIPTIONS

Flipped Classroom (FC) is an advanced educational model that is based on the development of e-Learning technology and modern training methods. The concept of the Flipped Classroom model was proposed by Lage et al in 2000 to meet the different learning needs of learners. The simplest definition of FC is one where students are introduced to content at home, and practice working through it at university [10]. Class activities will be transferred outside the classroom and vice versa. (Table 1)

Table 1. Traditional and Flipped class activities

Type	Activities in class	Activities outside of class
Traditional	Lectures	Homework
Flipped	Practice exercises Presentation Discuss	Lectures Video Lectures Quizzes

The Flipped classroom approach comes from the limitations of traditional classes. The traditional one-size-fit-all model of education often results in limited concept engagement and severe consequences. In traditional classes, students come to university and listen to lectures passively (Low thinking). After that, homework assignments will be given to students. Thus, the new knowledge that students acquire is entirely dependent on lectures by the instructors; and those lectures can only be heard once. According to Bloom's Taxonomy [11] (Figure 2), this task is only at lower levels ("Remember" and "Understand"). The task of students is to do practical exercises and this task belongs to the higher level Bloom's Taxonomy ("Apply", "Analyze", "Evaluate" and "Create"). The obstacle is low-level tasks will be undertaken by instructors, while higher-level tasks are undertaken by students!
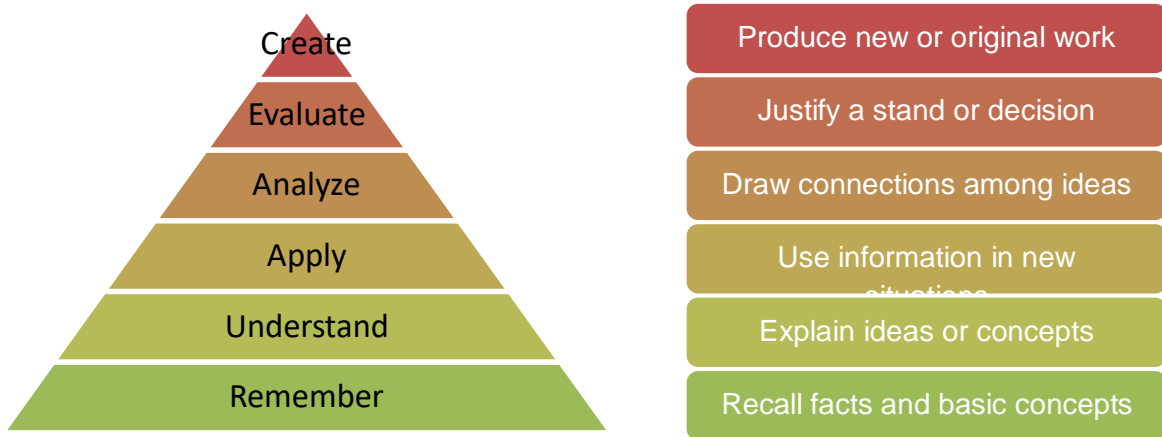
Figure 2. Bloom's Taxonomy [11]

With FC approach, instructors act as a learning supporter, sharing aspirations, co-creating of knowledge with students. Materials are provided to students through a Learning Management System Website. The duty of students is to read and understand the material (Remember and Understand in Bloom's Taxonomy), then do some basic level quizzes at home. In that way, students will be more active in researching new knowledge. They can access the video lectures at any time, can stop the lecture for notes, can review it as many times as needed (this is not possible if the instructor teaches in class). Students can study anytime, anywhere with Internet-connected devices such as Laptop, smartphone, PC... The amount of time spent on the class will be discussed: discussing student issues, discussing some of the student-led problems, discussing the advantages and disadvantages of the sample design students take and how to improve to suit the actual conditions in Vietnam, discuss the real problems from the instructor's experience ("Apply", "Analyze", "Evaluate" and "Create" in the Bloom's Taxonomy). Thus, class time will be for more specialized and interesting topics. This method does not allow students to listen to passively so that they can reduce boredom. This is a learner-centered method of education when most of the class time will be taken by students. This way of learning requires students to use a lot of mental activity

so it is called "High thinking". Thus, high-level tasks are implemented by both instructors and students.

In order to maximize the effectiveness of the FC, the Process-oriented assessment will be done to replace the exams. Specifically, students will be assessed through Quizzes, job logs, presentation skills, critical skills, direct questions with instructors, to train some Meta-skills for them.

- Quizzes: Each E-Learning lecture always comes with Quizzes to assess students' comprehension. Quizzes are divided into several types and levels and are scattered in E-Learning slides. During self-study, students tend to be distracted if the lesson is too long, Quizzes will play a very important role in strengthening knowledge and increasing concentration for them.

- Job log: Students are required to record the content and time of work performed on a regular basis during the project implementation. This work helps to train students with good habits: the ability to present writing forms, ability to arrange work, ability to work according to processes.

- Presentation: The presentations will be held regularly in class so students can practice crowd speaking skills and have the opportunity to give their opinions. After every 2 weeks of implementing the project, each group will present the problem, the direction to implement the topic, the results and difficulties that they face.

- Review: Groups of students are encouraged to raise criticism for the topic. This debate process helps students complete the topic on a regular basis, have a multi-dimensional view of the project they are participating in.

- Direct question and answer: when the topic is completed, instructors and students will exchange directly with each other in the classroom.

Process-oriented assessment can improve the student Meta-skill, meet the output standards of CDIO subjects when being content with many criteria CDIO and ABET (Table 2).

Table 2: Meta-skill is trained according to FC approach and Process-oriented assessment

Assessment	Meta-skill	Sub meta-skill	Satisfied with the standard	
			CDIO	ABET
Quizzes	Focusing	***Sorting:*** The ability to sort information into categories and to understand the relationship between information ***Attention:*** The ability to focus on the present and deflect/avoid distractions ***Filtering:*** The ability to filter out non-essential information and focus on the essential problem at hand	(2.4) Attitudes, though and learning	(i) Lifelong learning
	Adapting	***Openness:*** Being open to new ideas and		

		approaches – having a growth mindset			
		Self-learning: The ability to self educate without the guidance of others			
Job-log	**Communi -cating**	*Giving information:* Giving written in a way that can be best understood by those receiving the communication	(3.2) Communi- cations	(g) Communi- cations	
	Collabora -ting	*Teamworking and collaboration:* Working with others toward shared goals. Creating group synergy in pursuing collective goals	(3.1) Teamwork	(d) Teamwork	
Present- ation	**Communi -cating**	*Listening:* The ability to actively understand information provided by the speaker, and display interest in the topic discussed	(3.2) Communic -ations	(g) Communic -ation	
		Storytelling: The ability to tell stories that persuade, motivate and/or inspire as well as bringing the sharing of knowledge to life through examples and illustrations	(3.1) Teamwork	(d) Teamwork	
	Creatvity	*Visualising:* Translating information and thought into accessible expressions, readable and recognisable images			
Review	**Curiosity**	*Questioning:* The ability to ask questions in order to increase understanding about a subject or experience	(3.2) Communic -ations	(g) Communic -ation	
	Critical thinking	*Logical thinking:* The ability to identify, analyse and evaluate situations, ideas and information in order to formulate responses to problems	(2.1) Analytical reasoning and problem solving	(e) Problem solving	
Direct questio- n and answer	**Initiative**	*Self belief:* A feeling of trust in one's abilities, qualities and judgement	(3.2) Communic -ations	(g) Communic -ation	
		Self motivation: The ability to act without influence or encouragement from others	(2.1) Analytical reasoning and problem solving	(e) Problem solving	
		Decision making: The act of making a considered choice after appropriately using intuition and careful thought			

Thus, we can see the importance of regular, continuous learning and communication in FC approach. Although in FC, CDIO lab will become an open laboratory, both in time and place. Instructors allow students to be flexible about class time. It is not necessary to have full

attendance in class, only required to be present at the presentations. However, that does not mean that students can easily be with them in their study. They have to work more often, more focused so they can keep up with the discussions and criticisms in class. They can only achieve high scores when fully mastering their knowledge.

The instructor must follow the learning process. Each university usually has a tool to assist the instructor in academic management. Today, under the development of software technology and the Internet, universities easily implement a Learning Management System (LMS). The LMS consists of 3 components:

+ Learning: Instructors create courses, and distribute them to students.

+ Management: Instructors manage their online courses: create, change, arrange, classify or remove courses and content courses, and manage students

+ System: Instructors and students interact with each other through this system using the university account provided.

LMS can run on the web so learners can access learning content anytime, anywhere. Every LMS provides the same basic set of tools: directory structure content, assessment tools, group discussion tools, general bulletin boards, grades, surveys...

FLIPPED CLASSROOM CDIO TEACHING AND LEARNING PROCESS AT FEEE, DUY TAN UNIVERSITY

FEEE's development orientation is to train students with knowledge of "Industry 4.0: IoT and new energy". The course that the Faculty first aims to standardize the teaching outline is CDIO. The products of CDIO project will serve Industry 4.0: intelligent measurement, network management, handheld devices, sensor network... With our efforts, we look forward to helping students get closer to the emerging technology issues in the new era. Students, who really study hard, after finishing 4 years in university, not only hold a University degree but also some experience.

The system of CDIO projects in FEEE Duy Tan University is divided into 5 projects with increasing complexity. Each project focuses on each C-D-I-O criterion [13]. At present, the FC is applied in CDIO CR347 project - the project of focusing on design; electronic circuit design. This project is applied in the 3rd year of the student's academic program, providing knowledge and skills in the design and construction of craft and industrial electronic printed circuit board (PCB).

Specifically, the FEEE has developed a FC process as Fig. 3 and Fig. 4. The CDIO Instructor first task is to set up courses according to the curriculum of FEEE. This is done through the MyDTU system which is LMS of DTU. This work includes the following steps: entering course syllabus, scheduling class activities and managing student information. Normally, each CDIO course will take 2 months to deploy. Students have two face-to-face meetings with the instructor at CDIO Lab weekly. The schedule is public on MyDTU at the beginning of the semester. The Skype meeting schedule is also agreed upon at the first CDIO session and remains the same throughout the semester. Besides that, each week CDIO Instructors will spend 4 hours at the Library to meet students. At DTU, we call it "Academic Advisor". This time is for students who have not caught up with the previous lesson and have the

opportunity to question their problems. The second task of instructors is to prepare lectures using MS-Word and MS-PowerPoint. Besides, video lecture format is indispensable for self-study methods. Currently, almost all students have at least two devices that can access the Internet and watch videos (laptop and smartphone), so the video lecture format that is considered to be the most optimal in conveying knowledge. In our experience, lecture videos should be 3 to 7 minutes in length. Video content must be short, intuitive and portable. If video lectures are too long, we should divide them into smaller modules. The reason is that the longer videos are, the harder to follow. We think that arranging out-of-class activities and class activities should be interspersed during the week, and the Academic Advisor at the weekend is most reasonable.
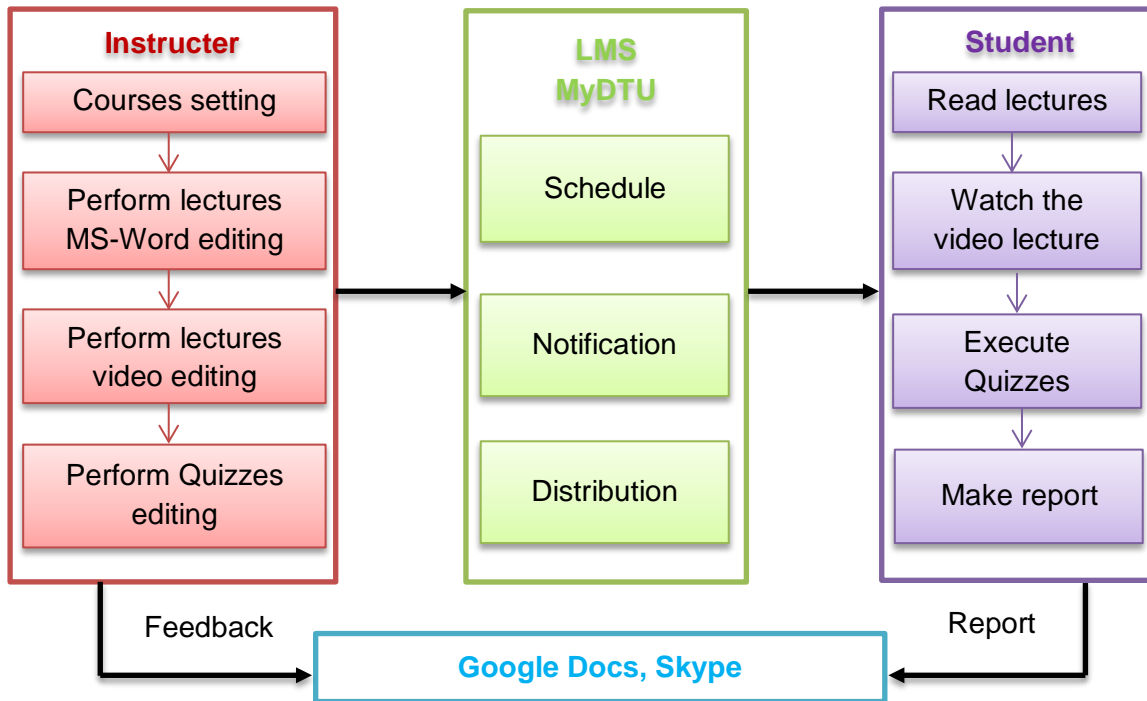
Figure 3. Out-of-class activities of Flipped Classroom at FEEE
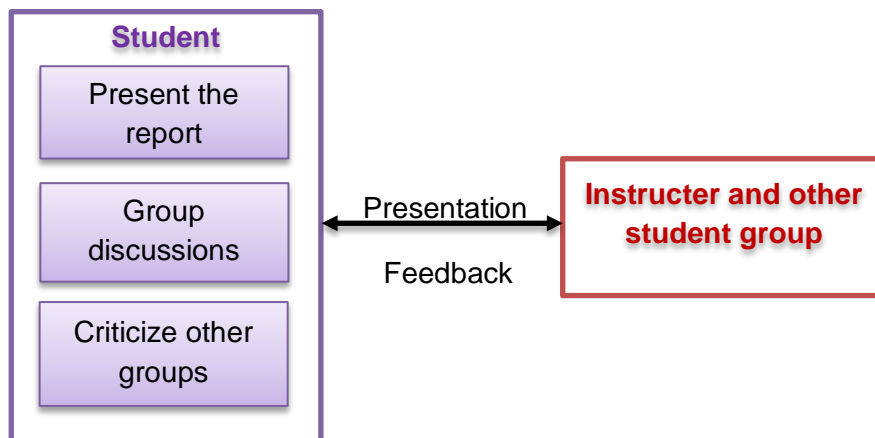
Figure 4. Class activities of Flipped Classroom at FEEE

A useful tool when writing a lecture is Ispring Suite 9.0 [14] which is an add-on for MS-PowerPoint as Fig 5. The instructor can make a summary slide with Quizzes system using

this software. This software supports packaging the presentation into web standards HTML5. This format can run on computers or smartphones and students can directly interact with these slides. Students simply need to access the website provided by the instructor without purchasing any copyrighted software.
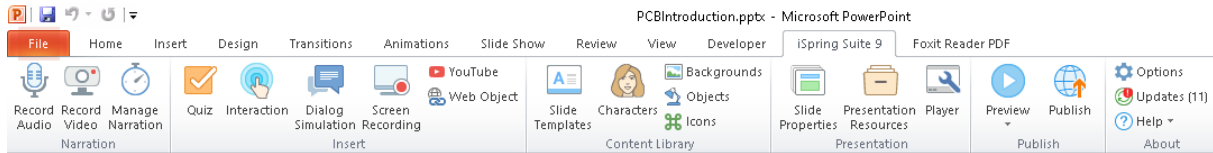
Figure 5. Ispring Suite Add-on in Powerpoint

As mentioned above, Quizzes is extremely important in reshaping knowledge and increasing student focus during self-learning. We use iSpring QuizMaker [15] to create a variety of interactive quizzes types: True / False, Multiple Choice, Multiple Response, Type In, Matching, Sequence as Fig. 6. This software will score and print the results for students after completing Quizzes. We should only use self-learning Quizzes at the first two levels of thinking: Remember and Understand.
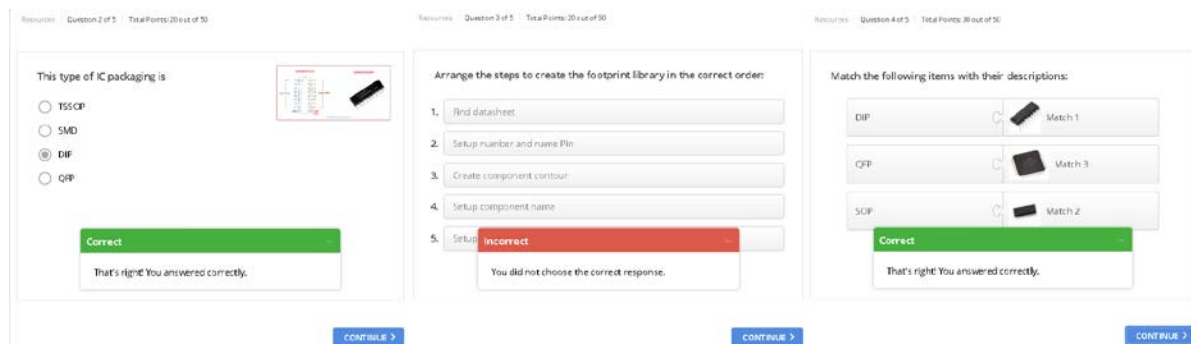
Figure 6. Several types of Quizzes questions

The entire lecture content and teaching schedule are checked by the department head before uploading to MyDTU. Students are required to follow the process: read lectures, watch videos, do Quizzes and make reports. These documents will be granted access by the Instructor as Fig. 7. These reports are mandatory for every student, and job-logs are required for each group. It must be properly formatted, submitted on time, attached Quizzes score given by iSpring. The content of this report represents the main ideas of the lectures but must be rewritten according to the student's understanding. MyDTU provides information feedback systems, but it is less flexible, so we use Google Docs and Skype as an interactive channel. Students make reports via Google Docs, allowing editing for the whole group and Instructor. Instructors easily follow up and give feedback immediately. Skype is also a good choice, which provides good group management and file reception. Group meeting via live channel allows instructors to help students quickly. At the same time, students can be evaluated more often. We can see that outside of class time, the instructors and students' interaction process have been carried out through these cloud services. This interaction process is a very important part of Process-oriented assessment. We want to evaluate students regularly, but not through exams, but through fun lecture videos that inspire students' self-study spirit. Students who successfully complete this homework are students with good academic attitudes, this is an indispensable virtue of a global employee.
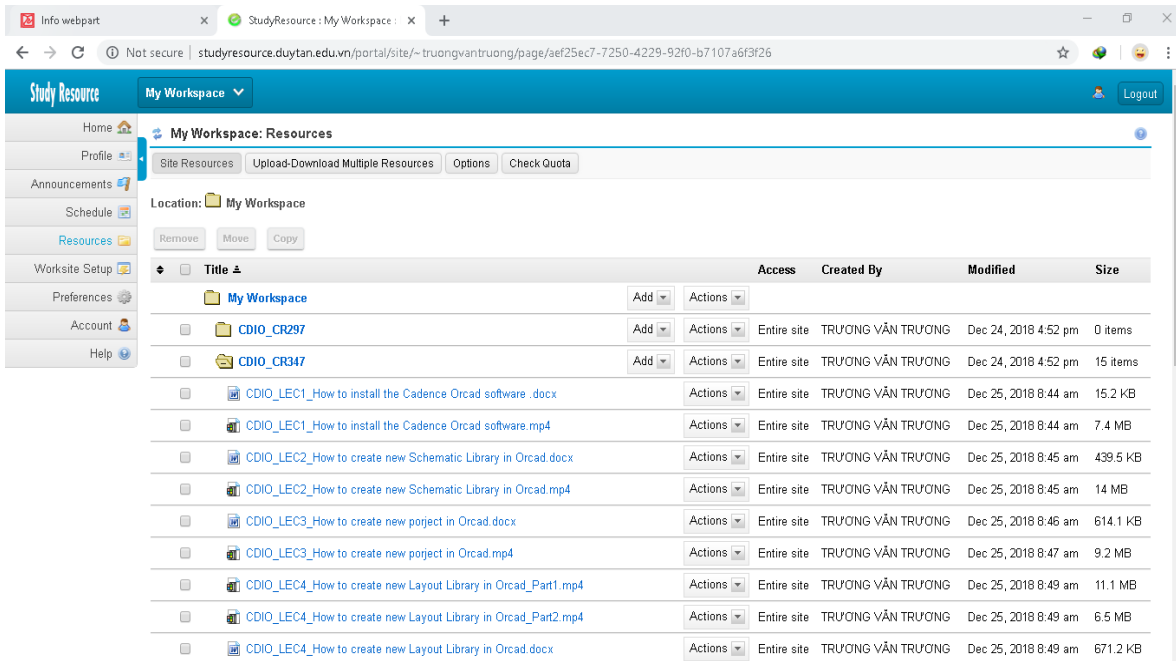
Figure 7. Learning materials are distributed on MyDTU

In class, students will be held group discussions. The time for presentations and discussions is up to 50%. Each group will give presentations and receive feedback from instructors as well as other groups (Fig. 8). This is one of the factors that help instructors assess students' comprehension and ability to express themselves. These presentations will focus on "How to improve the skills that students have self-learned at home". Specifically, in CDIO CR347 of FEEE, students are very interested in sharing methods of PCB layout and PCB anti-interference. At the end of each presentation, instructors synthesize knowledge and continue to add more advanced lectures to students into MyDTU. The process "Research, Feedback, and Presentation" are held regularly throughout the learning at home and at CDIO class.

Figure 8. A presentation and group discussion of Flipped Classroom at FEEE

To finish the CDIO CR347 course, students are required to complete: the PCB is designed and executed manually, the summary report and the job-log. Students will have a presentation in front of three CDIO instructors council. This final presentation weight is up to 50% of the grading module. In this session, case questions are provided to assess the group's problem-solving skills and teamwork skills. Students must use presentation skills and all the knowledge they have to convince all CDIO Instructors. Each individual student also

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Aarhus, Denmark, June 25 – 27, 2019.

discusses the technical issues of project based on job-log and is given a separate score.

ASSESSMENT

We use quantitative parameters to evaluate the effectiveness of proposed methods: percentage of students achieving proficiency or better (project score higher than 7.0) in ABET outcomes d, e, g, I; the total studying time spent of a student in the class; the level of satisfaction of students participating in the class. The parameters were collected on 4 CDIO CR347 classes in the 2017-2018 and 2018-2019 academic years. In which, 2 classes in the academic year of 2018-2019 are applied FC approach. The average number of students per class is 20.

We have calculated the composition of 82 students according to the 4 criteria analyzed in Table 2. The results show that when applying the FC approach at CDIO classes, the percentage of students achieving proficiency or better in ABET outcomes d, e, g, i increases and exceeds 80% of the total students (Fig. 9).
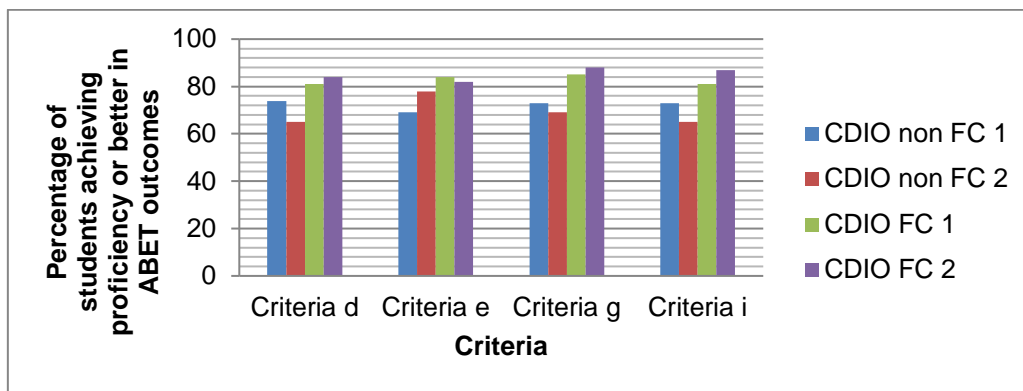
Figure 9. Percentage of students achieving proficiency or better in ABET outcomes d, e, g, i

We use a Google sheet to consult 50 students who have attended the Flipped Classroom CDIO class [16]. This survey focuses on 6 criteria: 1. Course/Unit Content & Structure, 2. Delivery Methods, 3. Training Activities, 4. Instructor/Facilitator, 5. Project execution time outside the classroom and 6. Project execution time in class (statistics according to job log).
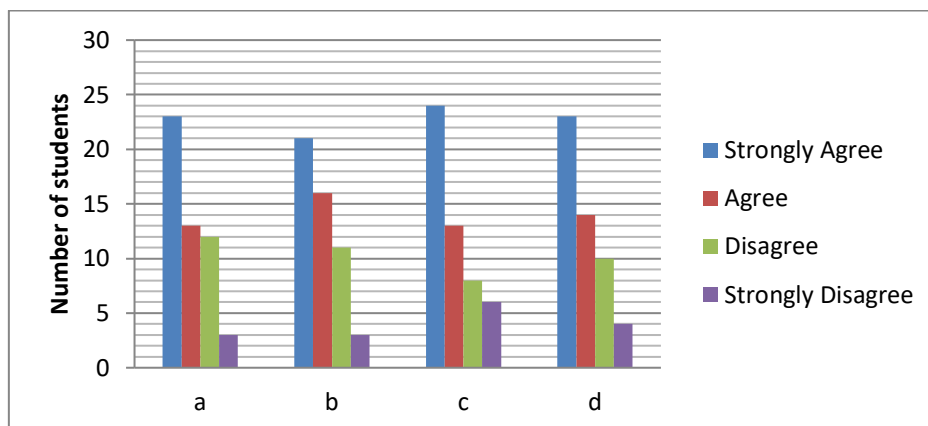
Figure 10. Delivery Methods

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The statistical evaluation criteria in Fig 10 include a. The electronic media used in the presentation assisted to better my learning and understanding, b. The delivery methods were suitable for the content of this training, c. The delivery methods assisted my learning and understanding, d. The method used by the instructor made the content clear and easy to understand. As a result, more than 70% of students grasp new learning methods.

The statistical evaluation criteria in Fig 11 include a. The group activities encouraged my participation, b. The activities increased my learning, c. There were sufficient activities in the session, d. The method of assessment was a fair test of my skills and knowledge. As a result, more than 71.4% of students were interested in discussions and presentations in class. 73% of students are satisfied with the assessment method.
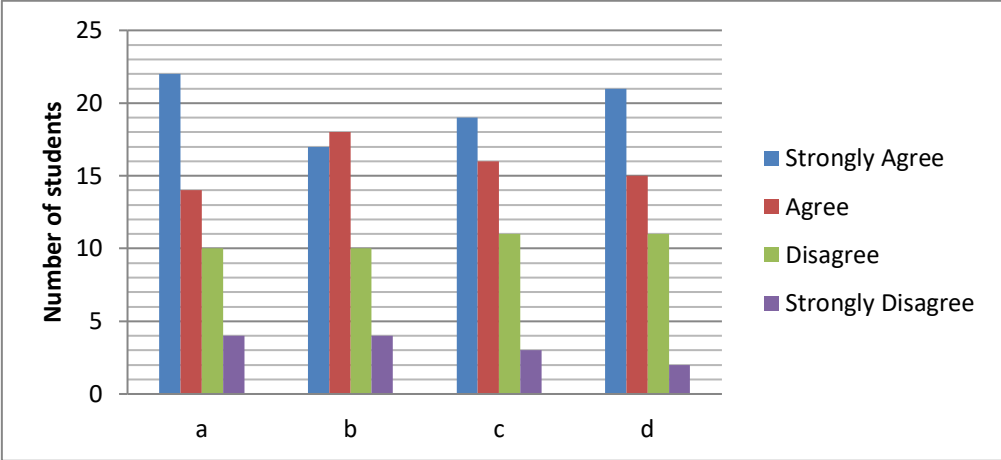
Figure 11. Training Activities

To complete the project, students have to spend a lot of time studying at home, namely, 58.3% of students have to spend >150 hours and 14.6% have to spend >100 hours (Fig. 12). This is a very encouraging parameter, as students are willing to spend a lot of time researching a new problem. They spent a lot of time to practice Electrical & Electronic Engineering skills for this subject at home: PCB design, PCB processing, component welding, measurement and testing.
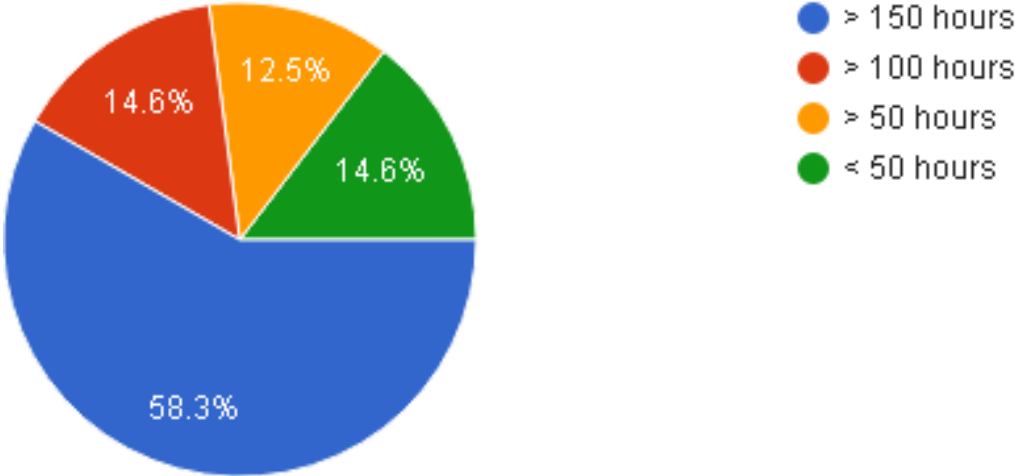
Figure 12. Project execution time outside the classroom (statistics according to job log)

Meanwhile, the class time of students tends to decrease when only 10.4% of students attend 45 hours. Most students attend class if that day is a compulsory presentation (52.1%) (Fig. 13).
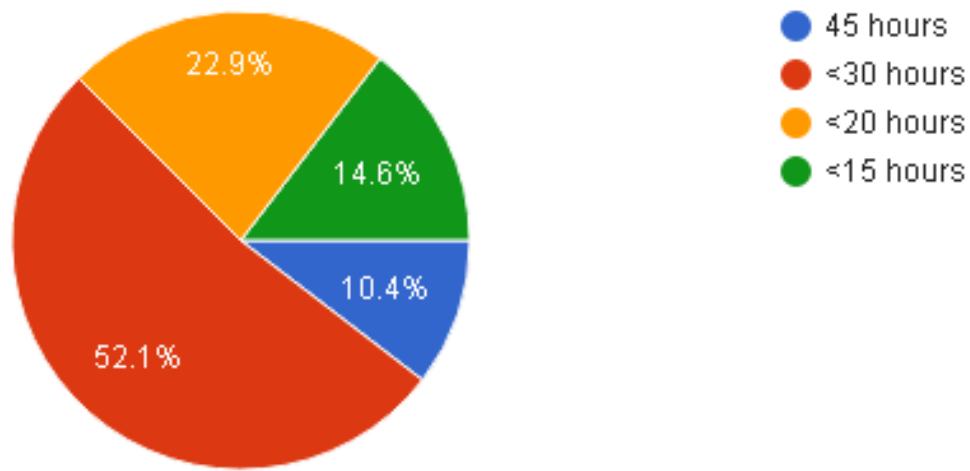
Figure 13. Project execution time in class (statistics according to job log)

The statistics show very positive results when applying the FC approach to CDIO classes. Students tend to spend a lot of time for self-learning and are interested in learning through the LMS. Class activities are exciting and of high quality, complementing the knowledge and skills for students. Class time is reduced, but the output quality of students increases.

CONCLUSION

In this paper, we presented the Flipped Classroom approach and Process-oriented assessment in CDIO CR347 FEEE, Duy Tan University. We have implemented this method for 2 semesters and conducted an effective assessment. The results were very positive as many ABET criteria (representing the Industry 4.0 employees' qualities) were improved in FC classes. Our CDIO project system has 5 subjects, currently, we have only applied this method to CR347. We want to apply this method to other subjects, but this requires a thorough review of the scientific council of my faculty. And it should be noted that not all projects are in accordance with FC architecture. In the future, we hope to continue to expand this method for subjects or some modules in the CDIO project because of its positive characteristics.

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ACTIVE LEARNING IN QUALITY CONTROL AND STANDARDIZATION IN PRINTING AND PACKAGING

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ABSTRACT

A Quality Control and Standardization in Printing and Packaging course in Digital Printing and Packaging Technology program, Faculty of Mass Communication Technology at Rajamangala University of Technology Thanyaburi (RMUTT) has adopted a CDIO framework in developing better teaching and learning strategy. Students who take this course will develop knowledge in basic concepts of Quality Control (QC), recognize quality tools and understand a process of QC planning. In the past, only traditional lectures, midterm and final examinations were used as tools for teaching activities and assessment methods. The student struggled in class and could not nurture deep learning. Thus, the instructor seeks for methods to overcome this challenge. This paper, hence, aims to share the redesign of active learning activities to encourage students for learning (standard 8). Formative and summative assessments (standard 11) were adapted to the class. In addition, to provide the student with design-build experience, project-based learning was initiated. Feedback from students in redesigned classrooms was expressed regarding the student engagement and the pedagogical improvement process

KEYWORDS

Active learning, quality control, printing and packaging, CDIO standards: 2, 5, 8, 11.

INTRODUCTION

The printing industry is an important manufacturing industry in many countries. Printing processes convert original text and pictures into an image on a carrier. The main types of process are named according to how this image is carried. Types of printing industries regarding their main techniques can be classified as follows: Relief, Lithography, Engrave, Stencil, and Digital Print. The Relief Printing uses a printing surface that is in relief. Letterpress and flexography are examples of this process. In the Lithography Printing, the image and non-image areas are in the same plane on a plate, which can be of metal, plastic or paper. This

type of printing is known as offset. Engraving technique is applied for gravure printing. In this technique, the printing areas are tiny recesses inscribed on a cylinder below the non-printing areas. These recesses are filled with ink, the surplus ink is removed and the substrate is pressed against the printing cylinder. Screen printing is an example of the Stencil Printing, in which the printing and non-printing areas are carried on a screen. The non-printing areas are formed by blocking out parts of the screen, while the ink is forced through the non-blocked parts onto the substrate. The Digital Printing produces an image directly onto a substrate using digital information without the creation of an intermediate permanent image. In recent year, disruptive technology has an influence on the printing industry. New technology offers lower cost but having higher ancillary performance. Digitization is one of the disruptive technologies by which the printing industry is affected (Kilkki et al., 2018). Smyth (2017) forecasts a size of the publishing market will decrease from 20% to 17% and commercial printing markets from 16% to 15%, respectively. This disruptive technology also impacts the working skills. In 2014, the European Union carried out the survey in the topic of future skills in the graphical industry. The result showed that cross-media, digital management, engineering, teamwork, and entrepreneurial skills were required as important skills. It is noticed that teamwork and entrepreneurial skills associate with CDIO syllabus (CDIO, 2019; Crawley *et al.,* 2011).

The CDIO framework was first introduced in mechanical and aerospace engineering and then has been widely implemented in the field of engineering education (Crawley *et al.,* 2007). Not only CDIO framework was adopted in the field of engineering, but also in the field of non-engineering (Doan et al., 2014; Malmqvist, 2015; Malmqvist *et al.,* 2016; Hladik *et al.,* 2017; Tangkijviwat *et al.,* 2018). The Digital Printing and Packaging Technology (DPPT) program has adopted the CDIO principle as a context since 2015. The program objective is to produce hands-on professional graduates who meet the industrial and social requirements. CDIO Syllabus was tailored to match the printing industry's knowledge and skillsets. CDIO Standards were fully implemented for continuous improvement of the quality of teaching and learning. In order to enhance student engagement and deeper learning, the active learning concept was initiated. The active learning enables students to learn and retain information better than through traditional lectures (Rotellar and Cain, 2016). This paper, therefore, is dedicated to the redesign of teaching and active learning activities, the change of learning environment, and the improvement of assessment to promote student learning and engagement for the Quality Control and Standardization in Printing and Packaging course.

THE APPLICATION OF CDIO STANDARDS

Students who take this course will develop knowledge in basic concepts of QC and quality tools for the printing process, recognize the QC planning as a process for enhancing the productivity in printing and packaging industry. After taking this course, the student should be able to:
1) have the basic knowledge of QC
2) select the suitable QC tools for the printing production control
3) design and evaluate a QC plan for printing and packaging industry
4) have experience in a collaborative working environment

Standard 2 - CDIO knowledge and skills set survey

CDIO syllabus v.2.0 (CDIO, 2019) was adopted as a guideline into the DPPT curriculum. The stakeholder survey was conducted to acquire CDIO knowledge and skills proper to the printing and packaging industry. In 2018, the stakeholder survey of CDIO knowledge and skills set was

collected from the printing and packaging companies and fourth-year students who have experience in cooperative education (Tangkijviwat *et al.*, 2018). The result in the top three of desired learning outcome was expressed as first, second, and third ranking, respectively as shown in Table 1. In the section of technical knowledge and reasoning, both of industry and student aspects agreed that core fundamental knowledge is the most important skill. In the section of personal and professional skills and attributes, we founded a different requirement between industrial and student aspects. The industry focused on system thinking, professional skills and attitudes, and personal skills and attitudes, while the students indicated system thinking, reasoning and problem solving, and professional skills and attitudes, respectively. There was clearly a result in the interpersonal skills section. The consensus was as followings: teamwork, communication, and communication in foreign languages. The skill of conceiving and systems was required in general in the section of enterprise and societal contexts. In addition, enterprise and business context skill was found in the industry side, while leadership skill was expressed in the student side. In sequentially, the obtained CDIO skills are integrated into the curriculum to ensure that the qualification of graduates will meet industry expectation. In this study, teamwork and communication skills, hence, were adopted in the subject as intended learning outcome. A variety of learning activity such as collaborative working, think and share, project-based-learning, and gallery walk was arranged for giving the student experience in teamwork and communication skills.

Table 1. Desired CDIO knowledge and skills set from stakeholders.

	Industrial aspect	4th year student aspect
	1.Technical knowledge and reasoning	
1st Rank	1.2 Core fundamental knowledge	
2nd Rank	1.3 Advanced fundamental knowledge	
3rd Rank	1.1 Knowledge of underlying science	
	2. Personal and professional skills & attributes	
1st Rank	2.3 System thinking	2.3 System thinking
2nd Rank	2.5 Professional skills and attitudes	2.1 Reasoning and problem solving
3rd Rank	2.4 Personal skills and attitudes	2.5 Professional skills and attitudes
	3. Interpersonal skills: Teamwork & communication	
1st Rank	3.1 Teamwork	
2nd Rank	3.2 Communications	
3rd Rank	3.3 Communications in foreign languages	
	4. Enterprise and societal contexts	
1st Rank	4.3 Conceiving and systems	
2nd Rank	4.5 Implementing	4.7 Leading endeavors
3rd Rank	4.2 Enterprise and business context	4.5 Implementing

Standard 5 – Design and build experiences

The design and build experiences were used to promote the development of new skills and reinforcement of fundamentals in the CDIO approach (Crawley *et al., 2014).* Project-based-learning (PBL) delivered in the Quality Control and Standardization in Printing and Packaging course. The students were divided into five/six person groups for solving the project as group work. This project offers opportunities to demonstrate and develop learning and professional skills, such as system thinking, teamwork, communications, and leadership skills. The aim of this project is to design quality planning and build quality control tools for the printing and packaging company. Each group was asked to design the quality planning for enhancing print

production productivity. The C-D-I-O steps were tailored to P-C-D-I-C as a stage of the project that was followings:

Preparing stage: The objective of the assignment was given to the student. The instructor provided guidelines formatively throughout the learning process. They were aware of how to achieve the project goal.

Conceiving stage: The student performed literature reviews, proposed a company where they would like to collaborate and prepared an interview question. Then, they collected information and requirement from the company. The conceiving information was received from both literature reviews and company's interview. A brainstorming and post-up techniques, then, were used for analyzing the information.

Designing stage: The combination of fundamental knowledge and conceiving information were used for designing the quality control system. Each group was asked to design the printing process diagram, the workflows of the printing process, the key process requirements, the quality control points, and the key performance indexes for the printing and packaging industry.

Improving stage: The student presented their projects in a gallery walk environment. Peer feedback using Bono's six thinking hats technique was conducted. Each student group received valuable comments and suggestions from their peers and from the collaborating company.

Conclusion state: The final stage required oral presentations of the finished projects from all student groups. The communication and presentation skills were assessed using rubric scores.

In the end of the project, we found that PBL provided the learning environment to integrate system thinking, teamwork, communication, and leadership skills. The PBL concept has encouraged students to participate actively in class and constructed their knowledge. Our result corresponds to the previous study by Weerakoon and Dunbar (2018) in applying a PBL technique as a framework for a second language, communication and engineering learning outcomes. They found that PBL is a tool for enhancing the communication and language skills for engineering graduates.

Figure 1. Collaborative working in the Quality Control and Standardization in Printing and Packaging course.

Standard 8 – Active learning

To improve teaching and learning, an active learning concept was adopted in this course. In the past, this subject consisted of traditional lectures given by the instructor with problem-solving exercises in class. There were very few interactions between the instructor and the student. The communication among the student was also very limited. It was noticed that the student neither participated nor contribute their knowledge in class. In addition, they misunderstand the significance of quality planning for controlling the process and cannot apply their knowledge into the real-life working situation.

Active learning is an important approach to develop students' learning skills. Bonwell and Eison (1991) stated that during the use of active learning, student move from being passive recipients of knowledge to being participants in activities that encompass analysis, synthesis and evaluation. In order to fulfill the main objectives of this subject in terms of knowledge, understanding, and the application of theory and concepts, the active learning approach was implemented through various activities. The instructor had redesigned the active learning activities that aligned with the learning objective for particular topics. There are Jigsaw classroom, Collaborative team learning, Think-pair-share, Group discussions, Brainstorming for problem-solving and Gallery walk presentation. Figure 1 shows a collaborative working classroom.

The reflection after class revealed that active learning can encourage and engage students for their own leanings. Our result showed a positive perspective as the same as that found in the previous study by Sivan et al. (2000).

Standard 11 – Learning assessment

In the past, only a summative assessment is major for giving grades. For this course, the A-F grade system is used. Out of 100%, 90% was allocated to the final examination and laboratory reports, with 10% of class attendance. We noticed that the students did not have the motivation to study this course. For this reason, an increasing of formative assessments was required.

The formative assessment is used to monitor students learning style and ability and to provide ongoing feedback for improving student learning. In the recent class, the instructor had added a number of formative assessments: one-minute paper, self-reflection, classroom contribution and peer feedback. Peer assessment was introduced to the student to reflect their own collaborative teamwork both inside and outside the classroom. This tool is effective in problem-based learning as reported by Segers and Dochy (2010). A one-minute paper technique was also used for checking student's understandings on a specific subject matter. For monitoring the improvement of learning, students were asked to reflect their perspectives and ongoing self-feedback. We found that formative assessment helps students identify their strengths and weaknesses and target areas that need additional work. It also helps the instructor recognizes where the student struggle and address problems immediately.

For summative assessment, report writing and oral presentations were added to the traditional final examination. A written examination was used to assess the extent to which students are able to define, analyze and solve problems. These assessment tools were selected based on the alignment with the learning outcomes and classroom activities. Moreover, in some assessment, the criteria were co-design together with the student, such as the assessment rubric for teamwork and presentation skills.

STUDENT PERSPECTIVES ON ACTIVE LEARNING

For the second semester of the academic year 2018-2019, there were 28 3rd-year students enrolled. In the first week of the class, the students were asked to reflect their past learning experiences in terms of learning environment, learning activity, learning assessment, learning outcome, and lectures with a questionnaire provided by the instructor.

For the learning environment, the students reported that they feel bored due to a long lecture. They could not concentrate for a long time in a passive learning environment with very few chances of participation in the class. In the case of learning activities, students proposed that it would be better if the teacher can offer several class activities. Many courses did not provide course learning objective. The student did not fully understand the core knowledge. This caused a weak connection between knowledge constructions and assessment tools. There were limitations for students to involve their assessment criteria. Some assessment lacked fairness. The misalignment of the learning outcome, teaching and learning activities and assessment cause surface learning. The student could not detain knowledge from previous classes to apply with the other classes. The student's reflection on their past learning experience was used to redesign a variety of learning activities and assessments in this course.

In the last week of the class, the students were asked to carry out a questionnaire. The questionnaire consists of a variety of topics as followings; learning environment, learning activities, learning assessments, learning outcomes, and the instructor. They have reflected their perspectives with 5-point Likert scale from 1 (strongly dissatisfied) to 5 (strongly satisfied). The students respond specifically based on their level of satisfaction in each subtopic. Table 2 showed the response from student perspectives. In general, the student reflected a positive satisfaction in all subtopic with a score that is higher than 4.0. The top three of highest score occurred in subtopic of a variety of activities in the class, lecture spend time for Q&A in the class, to promote your participation in the class, opportunity to collaborate work with your friends, lecture is open-mind for the opinions of others, and creating the learning environment with a mean score 4.8, 4.7, 4.6, 4.6, 4.6, and 4.6, respectively. Our result implied that the active activities offered were effective to encourage student engagement. Our results agree with previous studies (Bonwell and Eison, 1991; Sivan *et al.*, 2000; Leslie *et. al.,* 2018; Meikleham *et. al.,* 2018; Shimizu *et. al.,* 2018; and Weerakoon and Dunbar, 2018) and suggest that the active learning help student for enhancing their learning.

CONCLUSION

The aim of this work was to share the effectiveness of an active learning concept as a mode of teaching delivery. We have shown that CDIO framework can be adopted into non-engineering program. The case of the Quality Control and Standardization in Printing and Packaging course expressed how to apply active learning activities (CDIO standard 8) into the course. A variety of summative and formative assessments were applied for enhancing the student skills (CDIO standard 11). A PBL was also used as a learning activity to provide the student with a design-build experience (CDIO standard 5) as well as teamwork and communication skills. The reflection from the student indicated that they had more chances for participating and contributing their knowledge and skills in the course. Furthermore, positive perspectives from both the student and the lecturer appeared. Future work to improve this

course can be a comparison between pre- and post- evaluation to increase the learning effectiveness of the students.

Table 2. Mean response of satisfaction from the student perspective in the class of quality control and standardization in printing and packaging.

Topics	Mean	S.D.
Learning environment		
To promote your participation in the class.	4.6	0.62
To stimulate your attention during learning.	4.0	0.61
To activate your idea or your thinking.	4.2	0.44
To help you take more responsibility.	4.2	0.53
How much you enjoy in the class?	4.1	0.60
Learning activities		
Opportunity to contribute your idea.	4.1	0.70
Opportunity to debate among lecturer and your friends.	4.4	0.71
Opportunity to think and decide in the class.	4.1	0.70
You play as important role in the class.	4.1	0.66
A variety of activities in the class.	4.8	0.56
You have fun and pay attention in the class.	4.1	0.70
A variety of teaching materials.	4.5	0.62
Opportunity to collaborate work with your friends.	4.6	0.62
Learning assessments		
You know the objective of course before learning.	4.4	0.62
You know the criteria of assessment in each activity.	4.3	0.69
Your participation in learning assessment.	4.4	0.62
Fairness in assessment.	4.5	0.51
Recommendation and suggestion by lecturer for your improvement.	4.3	0.59
A correspond between learning activities and assessments.	4.4	0.62
Learning outcomes		
To promote your memory.	4.2	0.66
To promote your understanding.	4.2	0.75
To apply for other course.	4.2	0.56
To further develop and expand your skills.	4.1	0.56
To encourage your lifelong learning	4.1	0.75
Instructors		
Open-mind for the opinions of others.	4.6	0.57
Spend time for Q&A in the class.	4.7	0.47
Stimulate student attention.	4.4	0.61
Create a supportive learning environment.	4.6	0.51
Understand in a student aspect.	4.2	0.75
Pay an attention to all students.	4.5	0.80

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Natha Kuptasthien is currently as assistant to president for International Relations and an associate professor at the industrial engineering department, faculty of engineering, RMUTT. She has conducted a number of CDIO workshops at the faculty of Mass Communication Technology to promote CDIO with non-engineering programs. Natha graduated with a Bachelor of Engineering in Industrial Engineering from Chulalongkorn University, Master of Science and PhD in Engineering Management from University of Missouri-Rolla, USA.

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A Proposed Closed-Loop CDIO Model to Improve the Startup Ability

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ABSTRACT

The total population in Vietnam was estimated at 95 million and approximately 40 percent of whom are less than 25 years old. Vietnam is considered as the third largest market in Southeast Asia and startup is being encouraged by the Vietnam government nowadays. The students in the Electrical & Electronic Engineering (EEE) majors have the ability to create some products through CDIO project-based learning for startup. However, they lack continuous innovation ability to achieve startup effectiveness. During implementing the CDIO framework in our university, we have accumulated some experience to solve this problem and obtained some positive results that will be presented in this paper.

The first contribution is a proposal of teaching and learning framework for improving startup ability, namely Closed-Loop CDIO based on the conventional CDIO model. After Operation stage, the students are encouraged and trained to continue to conceive a new idea to improve or to create a new product based on the previous one. The improving issues include functions, specifications, cost, maintenance, etc. The Closed-Loop CDIO framework enables us to improve the continuous innovation ability of EEE Students for enhancing the competitive ability of their products. In this proposed model, we emphasise the nonstop innovation to meet the consumer's requirements.

The second contribution of this paper is the evaluation of this proposed framework based on the accepted products on the market. We statistically investigated after five years of this framework implementation in our faculty from 2013-2014 to 2017-2018 and the results confirmed the effectiveness of this considered model. In order to clarify the efficiency of this framework, we also present one real case, i.e., smart home products. In that case, we describe the detail process of applying of Closed-Loop CDIO framework to enhance startup ability based on smart home products. We will discuss more detail about our works to solve these problems in full paper.

KEYWORDS

CDIO standard No. 5, 8, 10, Closed-Loop CDIO framework, CL CDIO model, startup, innovation, products

INTRODUCTION

With a large population of 95 million and young people occupy the majority, approximately 40 percent of whom are less than 25 years old, Vietnam becomes the third biggest potential market in Southeast Asia. It brings big opportunities for entrepreneurs exploiting this emerging market.

Aware that issue, Vietnam government has been encouraging startup spirit from whole society in recent years (www.startup.gov.vn). Duy Tan University, the cradle of human resources training for startup, has been also deploying to provide the startup knowledge to her students. To start a business, we must not only have knowledge of management, marketing, soft skills but also have certain knowledge about the product or business services. In particular, to increase the competitiveness of young businesses, the owner must have innovative and unique products, (Adam Szirmai, 2011). Constantly innovating ideas is key to innovative products or services (Fei Bian, 2013). However, innovation ability cultivation in the particular field of Electrical & Electronic Engineering (EEE) becomes even worse here due to mass education in Vietnam if we do not have any improving activity on it. There are many works focusing on improving the innovation ability of the student. For example, in "*Innovation Ability Cultivation of Automation Major Students*" (Wang, Yangqin et al., 2013), the author presented the teaching method to enhance the innovation ability of automation major students. By deploying of the innovation education concept, building innovation experiment platform, constructing teaching staff and building innovation team, the students' innovation thinking, innovation spirit and innovation ability was cultivated. In the work of "*Research Experimental Teaching System Based on Innovative Practice Ability*" (Wu, Tong Q. et al, 2013), an experimental teaching system based on innovative practice ability was presented.

Duy Tan University has been deploying startup program from the year 2009 and CDIO framework in EEE education programs from the academy year 2011-2012. At that time, we proposed a new teaching and learning framework for scientific research, namely CDIE (Conceive – Design – Implement – Evaluate) that exists paralleled with CDIO model (Binh Dac HA et al., 2017). The combination of scientific research and CDIO teaching method enables us to improve the innovation ability of EEE Students in our university. In that proposed model, we emphasized the Evaluate phase for all the projects that have new academic results. This work helped students know how to evaluate the new results of their projects. However, at that time the combination startup and CDIO has not been considered as a key to open the door of electrical & electronic product market for EEE students.

Two years later, from the academy year 2013-2014, our faculty has proposed and deployed a novel model, namely Closed-Loop CDIO framework to enhance the innovation and startup ability to our students. EEE Students only focus on their prototype working or not, but they do not consider much about their products for startup. And they do not consider how to continue improving their products to meet the market's requirements. In order to solve these problems, we integrate EEE's major content and business knowledge during implementing CDIO courses.

CLOSED-LOOP CDIO MODEL DESCRIPTIONS

In EEE's education program, there are five CDIO courses, namely CDIO 1 – CDIO 5, for 4 years and a half of training as Table I. Each course has different learning outcomes, detail in Table 1. In CDIO 1, we focus on the activities to cultivate the brainstorming ability for students, so we put the weight for Conceive higher than others. In CDIO 2, we train the students how to design a product and we give the assessment ratio of Design higher than others. Similarly, in CDIO 3 and CDIO 4, we emphasize Implement and Operate abilities, respectively. Finally, in the last CDIO 5, we orient each team to do a project that can evaluate each C-D-I-O at the same level. Each course lasts for 3-4 months.

Table I. List of CDIO courses in EEE education program

No.	CDIO Course Name	Course Learning Outcome	Assessment Ratio
1	CDIO 1	Conceive	C40%+D20%+I20%+O20%
2	CDIO 2	Design	C20%+D40%+I20%+O20%
3	CDIO 3	Implement	C20%+D20%+I40%+O20%
4	CDIO 4	Operate	C20%+D20%+I20%+O40%
5	CDIO 5	Conceive-Design-Implement-Operate	C25%+D25%+I25%+O25%

In order to cultivate the startup ability, we have been implementing the Closed-Loop CDIO framework in Duy Tan University for several years as Figure. 1. The start point of this loop is Conceive, which is the same as the conventional CDIO framework. However, this CDIO framework is tried to apply for 4.5 years with closed loop for selected teams. Specifically, in CDIO classes, we divide it into some groups or teams. We let them decide whether pursuing the startup objective or not. The team, who pursue the startup objective, is assigned running a business project. In this project, they will pursue an idea of EEE's product family that can provide to the market, for example, smart home. In each CDIO course, we flow to the CDIO framework as mentioned above. However, this team does not need to change their product from one course to another course. In other words, they only focus on one kind of product that can be sold on the market. This kind of product will through five courses as follows.

In the course CDIO 1, the students are asked to propose ideas of a product in EEE's field. Ideas can come from field trips at the business, from observations in the daily life of students, or perhaps from practical experiences of faculty in the field of Electrical - Electronics. From these ideas, students begin to learn and research products and markets. Next, they discuss their ideas in their team and decide the final product. Then, they design their idea by drawing and building a simple prototype to convince their potential customers. Finally, they adjust their idea according to the results they got from their survey.
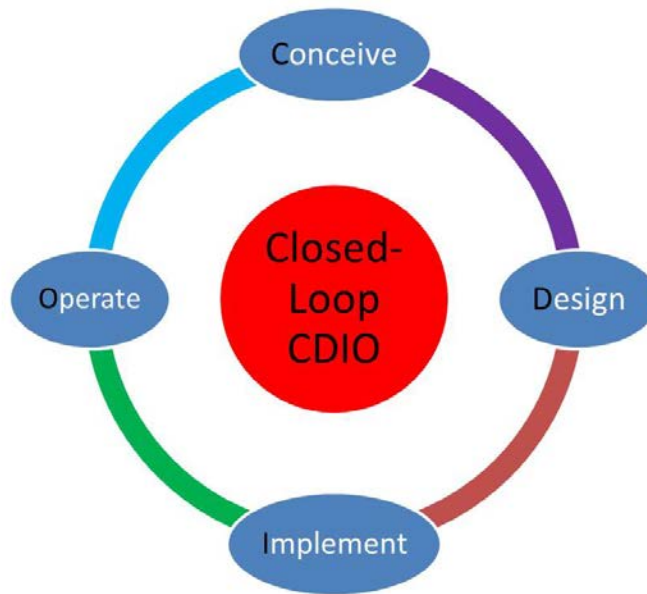
Figure 1. The Model of Closed-Loop Conceive-Design-Implement-Operate (CL CDIO model)

In the course CDIO 2, the selected teams continue their ideas but they should put their concentration on the Design stage. They not only focus on designing for product running but also consider their appearance, cost, convenience and so on to meet the market's requirements. Of course, during this course, they should propose the idea to obtain the best design results. They also are asked to use some software and tools to design and simulate their products. Then, they complete their products by making a 2nd version prototype. Finally, they investigate the customers about this product's design and discuss in their team to optimize their design.

In the course CDIO 3, the selected team seeks for at least one customer to be willing using their product. This product is installed to use in the customer's place. The team will design the manufacturing and installing processes and then implement product installation for its users. In addition to finding test customers, teams can use their products to participate in competitions in the field of Electronics - Electronics. This will help the team to have the first practical experience before deploying to customers. Finally, they evaluate their product's operating based on user investigation and numerical results.

In the course CDIO 4, the selected team continues to propose some ideas to improve the operation meanwhile maintain the operation of their product in customer's place by improving some functions or adding a new function according to customer's requirement. They not only improve functionality, but also focus on the form of products: models, boxes, weight, and ability to integrate into existing systems that can become a commercial product. At finally, they evaluate their product's operating based on user investigation and numerical results.

In the last course CDIO 5, the selected team can establish a company or join an organizer to run this business project of the product family which has been developed in previous CDIO classes. The mentors provide more knowledge about business management to them and guide them how to run a business project. The students of the selected team continue proposing some ideas to bring their products to the market.

In order to assess the course learning outcome of each CDIO course, we focus on the following major evaluation criteria which similar to the criteria in (Binh Dac HA et al, 2017):

Criteria **1. Novelty and originality of ideas (of ideas, prototypes or products)**

This is a major issue for each project, in which the idea of promoting the project and facilitating the creation of new or prototype products is the most important. Even if a project is unsuccessful, the idea of promoting it can still earn it at a higher level if it is considered completely new and original. However, the assessment of novelty and originality of ideas is often subjective. As a result, our Faculty of Electrical and Electronics Engineering has established the CDIO Project Evaluation Board to review all of its CDIO projects in any semester. Students are required to write a report of the project ideas, their interests, who will receive benefits, how much the product will be replaced, what products are expected to exist in their market, and so on.

Criteria **2. Logical structure (of the project)**

With project ideas, first of all, students will need to develop a roadmap for their projects. Then, they need to choose a suitable product development lifecycle and set up all the details of their project around that lifecycle. The evaluation of the logical structures of the projects will be carried out directly by the project advisors throughout the duration of their classes. For this, we assigned our experienced faculty members to do this assessment.

Criteria 3. Design Effectiveness

Design is an important component of any electrical and / or electronic engineering project, and the advisors of each project will accompany their students through the design phase for every little assessment or evaluation needed. Typical questions about how much new design costs are, how much energy the design saves, how to integrate new designs with other designs, and so on should be on the checklist of all design reviews. However, not every mentor has mastered the skills and knowledge in various aspects of the design of the controller or circuit design or sensor design, etc.; As a result, we have made great efforts to closely connect our faculty members together for mutual consultation whenever needed. In practice, this requires not only over time but also regular championship of division leaders in specific categories of electrical and electronic projects.

Criteria 4. Market Ability (of Product or Service)

To assess the marketability of some products or prototypes of a student product is a long shot even for our CDIO Evaluation Board. Although mentors can make an assessment and classification of the product's marketing and product prototypes, only a few projects are judged to be exceptional exceptions. The above prices will be selected to assess the full potential of faculty marketing. Each faculty and student will have the opportunity to assess the marketability of this project as part of a transparent and democratic process. In addition, for CDIO 5 we also assess the project according to the comments of customers and revenue or profit.

Under the traditional CDIO model, Criteria 1 will be evaluated during conception, Criteria 2 will be evaluated during the design and implementation phase, and Criteria 3 will be evaluated during the design phase; But within the scope of our new CL CDIO model, all items Criteria 1-4 will be reassessed more comprehensively during the period considered for the Operations

phase. Assessments at this time tend to be more accurate as we have already had product or prototype student products from their Implementation phase. In addition, we also invite the business management specialists to join our Evaluation Board to assess the feasibility of a project for startup. This is very effective in helping students learn from feedback from a variety of sources, and there is plenty of time for students to acquire new knowledge in the process.

CASE STUDY AND ASSESSMENT

Case study

In this Section, we present an example to explain the process of Closed-Loop CDIO framework deployment. A typical EEE's product of our CDIO project is smart home which developed by a team from K18EVT students. The name of "smart home" means that it is an integrated electrical and electronic system that can be programmed to control the household appliances, such as home electric, furniture and so on automatically according to the user requirements.

In CDIO 1, the students are asked to investigate the market about smart home. Next, they propose their ideas in their team after they know about the product of smart home on the market. And they discuss to make the decision of the idea on smart home. Then, they design and build a simple prototype to introduce to their potential customers, as Figure. 2. Finally, they adjust their idea according to the comments they got from their survey.
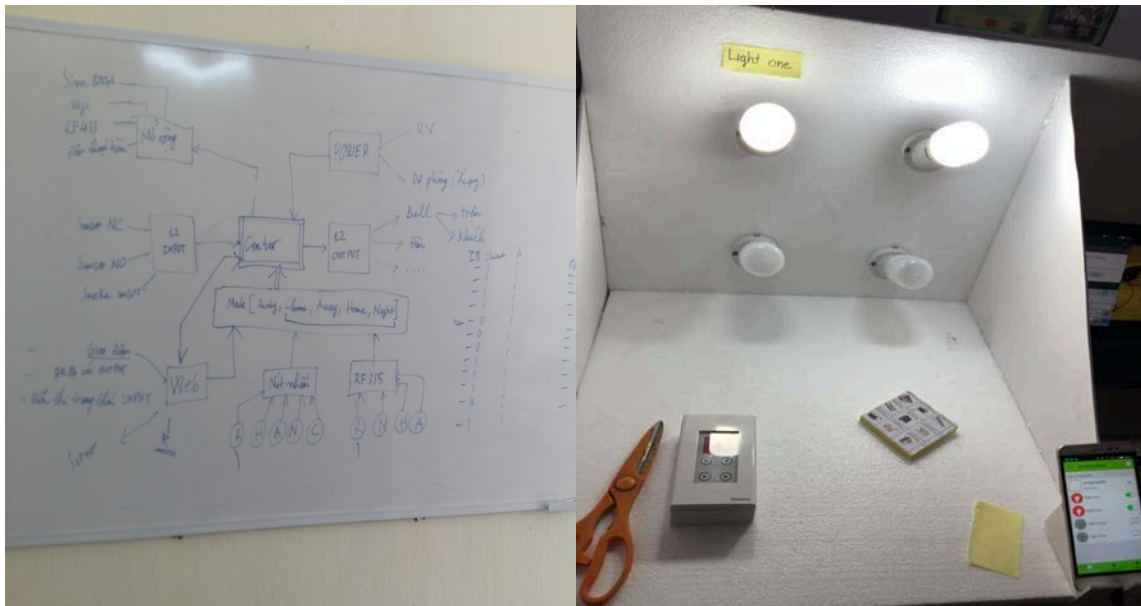
Figure 2. A design of smart home

In CDIO 2, the selected teams focused on the design of a real product. They took into account the appearance, cost, and convenience of using to meet the market's requirements. They complete their products by making a 2nd version prototype as Figure. 3. They investigated the market by asking some customers about their product's design and discussed in their team to optimize their design. For example, their design should be easier to manufacture, install and use, more aesthetic, and so on.
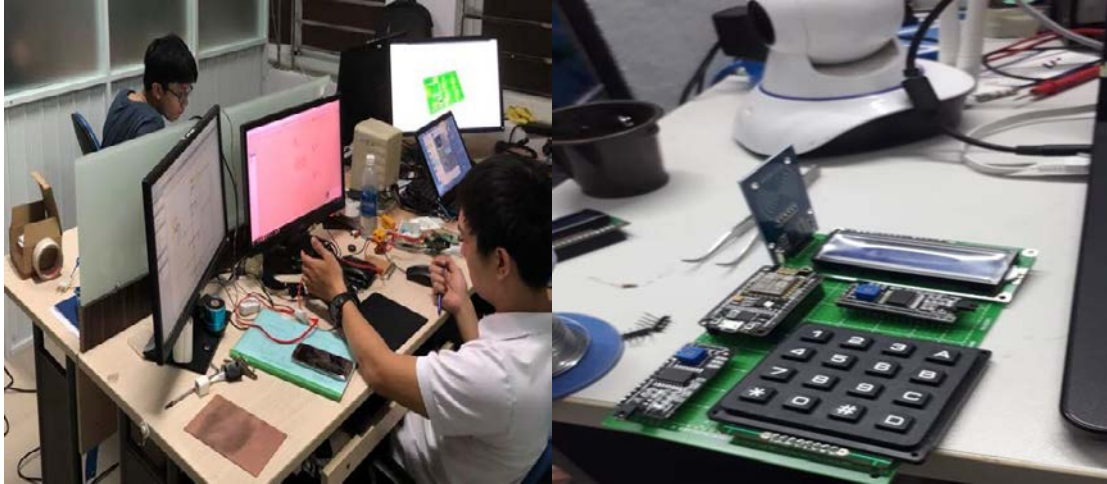
Figure 3. The 2nd version of smart home

In CDIO 3, the selected team installed their smart home product in the customer's place as Figure. 4. The team has designed the manufacturing and installing processes and then implemented product installation for their user's house. Finally, they evaluate their product's operating based on user investigation and measurement results. During this stage, they have improved the installation process; change the design to meet the personal requirements of the house's owner.

In CDIO 4, this team continued to propose the ideas to improve the operation meanwhile maintain the operation of their product in the customer's place by adding a new function according to customer's requirement. Because of the personality and tastes and preferences of homeowners per person, they have requested to add or remove some features for smart home. For example, a staircase in a Vietnamese house has a special place. It has a moderate amount of geomancy (feng shui) with high aesthetics, so the lighting system and decorative lights must also be specially designed. Or in-house washing machines are also required to automatically wash off-peak hours to benefit according to the hourly electricity price policy. Figure 5 depicts the installation of the control system integrated with smart home system. Finally, they evaluate their product's operating based on user investigation and measurement results.

Figure 4. An example of smart home installation

Figure 5. An improved design of smart home

In CDIO 5, this considered team established a company, namely Efil Company limited (https://doanhnghiepmoi.vn/thong-tin/CONG-TY-TNHH-EFIL-47393.html), to run this business project of the product family. The mentors, who from the Faculty of Business Management, also

help them by providing some knowledge in the business field. In addition, they have also joined Da Nang business incubator (https://www.linkedin.com/company/danang-business-incubator) to obtain more support from Da Nang city government.

Assessment

During applying this CL CDIO model in our Faculty of Electrical and Electronics Engineering, Duy Tan University, we evaluate the effectiveness of this model based on the startup spirit of students via the business projects. However, this proposed model has the following advantages and disadvantages:

Advantages:
- Can nurture the entrepreneurial spirit of students.
- Create a habit for students to constantly innovate and perfect the product.
- Give students the habit of persistence, not giving up.

Disadvantages:
- Difficult to implement due to the knowledge and skills in the field of business.
- Requires implementation of the project in real life.
- Involves many difficult issues such as safety, money, law.

CONCLUSION

In this paper, we have presented an improved CDIO implementation, namely Closed-Loop CDIO framework. The effectiveness of this framework has been verified by some practical results during implementing in Duy Tan University. The results have shown that this proposed CL CDIO model can help students improving their startup ability. We will continue implementing this model in our university to obtain more understanding and benefit from this model.

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BIOGRAPHICAL INFORMATION

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ENHANCING STUDENTS' SOFT SKILLS BY IMPLEMENTING CDIO-BASED INTEGRATION TEACHING MODE

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ABSTRACT

Currently, the software industries are paying crucial attention towards soft skills at the time of hiring new professionals, so there is a stringent need to enhance the role of the soft-skills in software development curriculum. During the four-year program, software engineering students are trained with a comprehensive amount of theoretical and applied coursework but soft skills training is not given significant importance. Moreover, students as compared to other subjects pay little attention towards soft skills. At Duy Tan University, with close vision to enlighten soft skills importance, we integrated two courses, which are focus on CDIO procedure (CDIO project level 1 (CMU-CS 297) and CDIO project level 2 (CMU-CS 397)), into the training program to offer students with practical experience in supervision, project management, quality control and decision-making. Student teams composed of 4 or 5 members are primarily responsible for solving game's problems (in CMU-CS 297) and developing a software project (in CMU-CS 397). In CMU-CS 397 course, the finished product is delivered upon project completion. The project evaluation is based on formal technical reviews of prototypes produced during the project life cycle basing on the stages of CDIO approach. Two instructors are appointed as mentors during course flow to support teams from conceiving to operating product. The objective of this paper is to present a field study in which 45 students are interviewed from these two courses to analyze their viewpoint regarding soft skills importance towards making themselves, successful professional software developers. The study is also conducted via group discussion with instructors to figure out the best possible information for research. The paper answers mainly two research questions: (1) What soft skills are appropriate for software developers, and (2) How instructors should possibly organize and conduct CDIO courses to enhance soft skills for students? After thorough analysis, that Leadership, Debate, Presentation, Teamwork, and Time management skills are the most valued for students. In CMU-CS 297 course, instructors should provide multiple types of games to enhance Debate and Time management skills of students. For CMU-CS 397,

mentors should encourage students to apply Scrum or Agile methodology to improve the Leadership skills for overall development.

KEYWORDS

CDIO-based integration teaching mode, Soft skills, Software Engineering, Teaching Methodology, Standard 3: Integrated Curriculum

INTRODUCTION

Dealing with human errors is much more difficult than technical problems for developers. The main cause of this trend is that human factors are usually related to soft skills such as teamwork, motivation, emotions, commitment, leadership, multiculturalism, interpersonal skills, etc. (Ahmed, Capretz, & Campbell, 2012). As a results, employers prefer to recruit developers who have both technical and nontechnical skills. While technical skills are relatively to evaluate by looking into academic credentials, certifications, professional experience, etc., which can be gained through education, training programs, certifications, and on-the-job training. Meanwhile, the non-technical skills focus on mentioned soft skills that are much harder to define and evaluate (Dumke & Richter, 2015). Recently, about 80% of the individuals who tend to fail at work because of their inability to relate or communicate well with others in a team (Kappelman, Jones, Johnson, McLean, & Boonme, 2016).

Software Engineering (SE) is a discipline deeply linking to practical aspects of developing software products within cost, schedule and quality requirements (Boehm & Sullivan, 2000). It requires software engineers to have technical and managerial expertise. Many learning and teaching methodologies are used in this field; however, most of the courses of SE are based on the classroom learning model (Ghavifekr, Rosdy, & Science, 2015). The teaching methods primarily focused on lectures and tutorials are not sufficient for SE students to develop the skills required for real-world problems solutions. Students must complete their tasks mostly on their own, in contrary to professional practice of team environment and collaboration. The need for modern approach to teaching SE is not new, but the supplying students with real problems and real teamwork environment is not really leveraged (Richardson & Delaney, 2009).

In addition, the curriculum of SE program is set in a real-world engineering context of a complete product lifecycle, i.e., conceiving, designing, implementing, and operating (CDIO), with design-build experiences integrated throughout the program (Vo, Nguyen, & Ha). The goals of CDIO include educating graduates with a deep and working knowledge of engineering fundamentals, who can lead in the development and operation of complex technical systems, and who have a strategic understanding of the role and impact of technology in society (E. Crawley, Malmqvist, Ostlund, & Brodeur, 2007). However, to enhance the soft skills of SE students we need to integrate other activities into the CDIO approach.

At Duy Tan University, we build up two courses focusing on introducing CDIO to freshmen and letting them getting familiar with CDIO spirit for further leveraging this method into advanced courses. The two courses are named CDIO Project level 1 (CMU-CS 297) and CDIO Project level 2 (CMU-CS 397). For CMU-CS 297, we provide various types of games for students to play in-group. During the time to solve the problem of the games, students will learn and upgrade their soft skills. For the upper level, in CMU-CS 397, instructors let groups

of students work on small software project. They are required to follow every step of CDIO approach. Thanks to the soft skills that are trained in CMU-CS 297, students are able to work well in their project with team members.

This study presents a case of the mentioned CDIO courses in the SE program at the International School of Duy Tan University. Data is collected from 45 students of the same course in the Fall semester of the academic year 2018-2019 by various methods such as on-site observation, historical report review, and structured interviews. The findings show the effectiveness of this integrated learning framework, especially in improving the soft skills of IT students. The experiences and lessons learnt from the implementation of this framework, along with challenges are also discussed in this paper.

THEORETICAL BACKGROUND AND CONCEPTUAL FRAMEWORK
Introduction to Conceive-Design-Implement-Operate approach (CDIO)
The CDIO is an open architecture endeavour that is specifically designed for, and offered to, all university engineering programs to customize and adapt to their specific needs. The vision of the CDIO is to provide students with an education that stresses engineering fundamentals set in the context of Conceiving - Designing - Implementing - Operating (CDIO) real-world systems and products (Gustafsson, Malmqvist, Newman, Stafström, & Wallin, 2002). It aims at developing a new model for engineering education (Gustafsson, Newman, Stafström, & Wallin, 2002).

- The Conceive stage includes defining the need and technology, considering the enterprise strategy and regulations, developing the concept, architecture and business case.

- The Design stage focuses on creating the design, that is the plans, drawings and algorithms that describe what will be implemented.

- The Implementation stage refers to the transformation of the design into a product, including manufacturing, coding, test and validation.

- The Operate stage uses the implemented product to deliver the intended value, including maintaining, evolving and retiring the system.

The proposed implementation framework
A good software engineer need grasp the software theory and basic knowledge, but also must have a deep understanding of the software industry and software project. They also require having a solid innovation design ability, communication skills, teamwork spirit, ability of lifelong learning etc. To work together effectively, the members in software development team need to have different non-technical skills such as teamwork, time management, operational management and overall team management skill. Therefore, we integrate two courses of CDIO into the curriculum as follows:

- In the course CDIO Project level 1 (CMU-CS 297), students are encouraged to play games to enhance soft skills through providing solutions for assigned problems such as team management and time management.

- In the course CDIO Project level 2 (CMU-CS 297), students also work in group to deliver a software product by putting the fundamental knowledge in software engineering into the procedure of four steps: Conceive, Design, Implement, and Operate.

After students finish those two courses they are able to apply advanced knowledge in SE field to complete the project of other advanced courses and Capstone project 1 and Capstone project 2. The proposed framework is described in Figure 1.
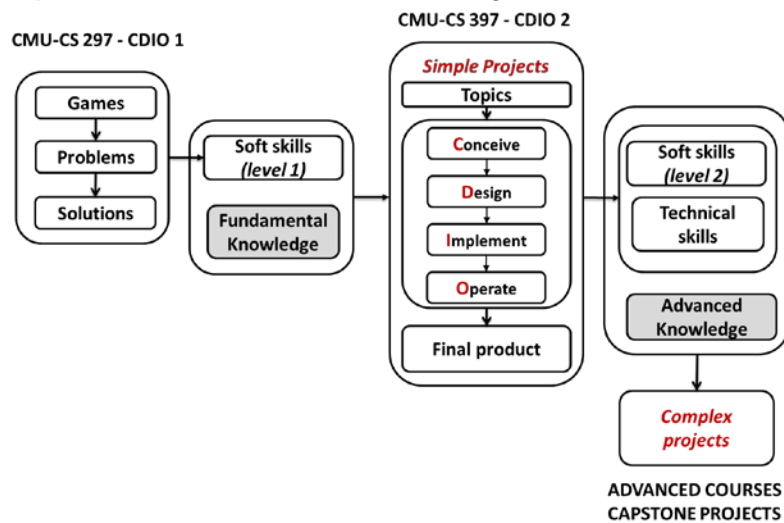

Figure 1. Proposed Implementation Framework

RESEARCH METHODOLOGY

The description of course CDIO project level 1 course (CMU-CS 297)

The course CMU-CS 297 consists of fifteen hours of classroom teaching in total, two or three hours per week for a duration of seven weeks in the second year. In this course, students are required to provide solution for the games. Instructors need to support them develop soft skills such as teamwork, problem solving, communication. Those skills are needed before entering the course CMU-CS 397. Teams are assigned topics to play an innovative game with pre-prepared materials. The games used for teaching and learning in this course are as follows:

Game 1: Think outside the box

Purpose: This game aims to let student consider different perspectives when solving problems. They can earn experience of problem solving in groups and add knowledge and information to each other.

Material: A copy of the brain strain hand-out (provided) for each player. The question of this game is "Without letting your pencil leave the paper, can you draw four straight lines through the following nine dots?"
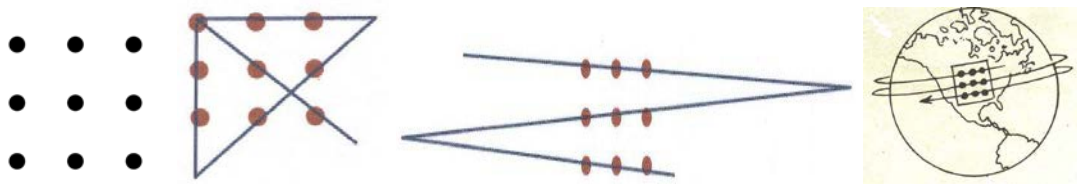
Figure 1. Think outside the box

Time required: 20 minutes

Procedure: Firstly, instructor deliver question with the photo to each player. Each individual has 10 minutes to look through the questions. Then instructor lets the players work in groups of 3 to 5 people to discuss to provide the solution.

Discussion questions: Before ending the game, instructor provides question to let students discuss:

- Working alone and in a team, what kind of performance do you find? What is the difference?

- What can you learn from your team members?
- How can we apply this to real life?

Reflections: The basic idea of this game is to build creativity, as the players need to challenge their own assumptions and look at things from a fresh angle. They need to break out of conventional thinking and take off the blinkers formed by experience. The usual way of presenting this problem is for a creativity trainer to give the first set of instructions. Once we start to think "outside the box", we open up many more possibilities and it becomes easy to solve the problem. In this game, team members must communicate in order to unify the topic, to assign appropriate tasks for each person, and debate with other groups to get the supporting or opposing. They can improve the skills of debating as well.

Game 2: Save the egg

Purpose: This activity is useful to illustrate the importance of teamwork. Ask everyone to reflect on how their group accomplished the task, what worked, what was challenging, etc. This team-building task gets teams working together, thinking creatively and managing their time.

Material: Raw eggs (one for each group plus extras in case of accidents), cardboard, duct tape, several thin straws (at least 40 per group), paper towels for clean-up, a way to enable a high drop.

Figure 2. Save the egg

Time required: 30 minutes

Procedure: The instructor divides the group into small teams of 3-4 students. Give each team one raw egg and other materials (depend on the instructor). Then he/she explains the rules of the teambuilding activity to tell them that the goal is to design and build a structure that will prevent their raw egg from breaking from a high drop. Teams will be given about 15 minutes to make the structure. If more than one team is successful, then the team that uses the least amount of materials wins. Before students start to work on their product, instructor gives 10 minutes to let them propose the ideas, design the product and explains the reason of their solutions.

Discussion questions: Before ending the game, instructor provides question to let students discuss:

- The designs changed or evolved over time.
- The traits or characteristics of good leadership or teamwork, or meaningful contributions during gameplay.
- Teams would do anything differently in the next time.

Reflections: Teams must work together to find a way to "save" the egg. That could involve finding the perfect soft landing, or creating a device that guides the egg safely to the ground. All members in team need to coordinate and assign tasks effectively to be able to complete

the product in the shortest time. After finishing the final product, every group has compulsory brief presentation to introduce their product designed to other groups for receiving the feedback-regarding positive/to be worked upon ideas.

Game 3: Build the paper tower

Purpose: The purpose of this game is to let student learn how to compete against other teams to see who can build the tallest tower. This is a great teambuilding activity involves creativity, coordination, and teamwork. The goal is to build the tallest or highest tower made of newspapers or paper.

Material: A measuring tape; for each team, also provide one stack of newspaper, 1 large roll, of masking tape, and scissors. Thus, an activity with four teams would require at least four stacks of newspapers and four rolls of tape.

Figure 3. Build the paper tower

Time required: 20-25 minutes.

Procedure: The instructor forms teams of 3-5 students. If necessary, the teams can be larger, but small teams are ideal to allow players to all stay involved. The instructor supplies each team with a stack of newspaper and a roll of masking tape. Each team will have a couple minutes to plan and discuss strategy, and then start a timer for 20 minutes. Each team will build a tall tower using the materials supplied. When time is up, instructor stop everyone and use the measuring tape to determine the winner. Towers must remain standing and not fall.

Discussion questions: Before ending the game, instructor provides question to let students discuss:

- What did you just do together? How did you feel while you did the activity?
- What was one positive thing that happened during this activity? What was one of the challenges of doing this activity?
- What did the group have to do or believe to be successful?

Reflections: Sum up the different ideas and feelings that students expressed, and restate ideas and learning moments the participants shared. Instructors provide examples of successful and unsuccessful design approaches to let students compare and learn the lessons. They need to have a clear vision and a plan of how to achieve it, then leadership skills can be developed.

The description of course CDIO project level 2 course (CMU-CS 397)

The course has a total of 45 hours, three to four hours a week for 12 weeks. To pass the course, a minimum of 80% attendance is required; in addition students have to submit a software product or a mobile application which is evaluated on the basis of CDIO stages

(Conceive-Design-Implement-Operate). In this course, students need to form their idea by themselves instead of getting form the instructor. Students can apply all skills, which were developed in the course CMU-CS 297 to fulfil the project such as problem solving, time management, leadership, and debate. CDIO is an outcome-based framework mostly for students in engineering and technology disciplines to develop real-world systems and products. This approach has three overall goals to educate students who are able to:

- master a deeper working knowledge of technical fundamentals.
- lead in the creation and operation of new products, processes, and systems.
- understand the importance and strategic impact of research and technological development on society.

In this course, students are required to manage a project using the learned principles in teams of 3-5 persons. The teams are self-selected by the students and every team has a team leader. The project teams can choose their individual project topics from a catalogue of ideas or choose other topics under supervision of the instructors. We have already set up an explicit criterion for this practice assessment based on stages of CDIO approach (Table 1).

Table 1. CDIO stages

Stage	Description	Required outcome
Conceive	Defining customer needs, considering technology, enterprise strategy and regulations, and developing conceptual, technical and business plans	Proposal, Requirements
Design	Creating detailed information, description of the design; the plans, drawings, and algorithms that describe the system to be implemented	Software/System Architecture, Database Design, User interface
Implement	Transforming the design into the product, process or system, including hardware manufacturing, software coding, testing and validation	Source code, Testing plan, Test case, Test report, Bug report
Operate	Using the implemented product, process or system to deliver the intended value, including maintaining, evolving, recycling and retiring the system	Demo Feedback Presentation

In the experiment guidebook, we make a list to let students know what they must complete and submit at each phase, and how they can get high scores. At each phase, we choose one team to present their process of project management in classroom; other teams can comment and ask questions for their presentation. At last, the instructor will review and summarize for the presentation. After the presentation, students should revise their project plan according to the comments and suggestions. At the final acceptance phase, every team should submit their project, documents and prepare for an oral defence. Students are assessed individually as well as in teams. Each team and every student must have an individual oral presentation for their work. A students' final course grade depends on their written reports, daily performance and oral presentations.

Students are more eager to produce something that has value beyond the classroom. Impressionable students are forming opinions of the utility of computer science and questions whether students would eventually change computer science study for another study with

better chance of giving them a career with some more noble purpose. By choosing a problem that is not within the experience of most students forces students to develop a high-level understanding and design before coding, as early implementation is not feasible. Through this experience, students get insight into the project requirements and constraints from the client perspective, learning how to overcome misunderstandings between clients and developers in terms of vocabulary, technology complexity and capabilities. Focusing on real-world projects in courses means that student's assignments do not have predefined problem or solution sets, which makes them harder to grade, but drive the students to extend their decision-making skills.

Data collection and analysis

For the purpose of this paper, we are using two different data sets. One set is the student survey. The other set is a focus group interview with 3 academic staffs who are the instructors of CMU-CS 297 and CMU-CS 397. We send out 100 survey and collect 45 responses. Most of them belongs to the International School, and 7% of them are in Faculty of Information Technology. The 80% of them are senior students and the rest of them are junior students. The ranking of the importance of the soft skills are presented in Figure 2. The highest score is 5.0.

- Teamwork skills (TEA)
- Presentation skills (PRE)
- Leadership skills (LEA)
- Time management skills (TIM)
- Debate skills (DEB)
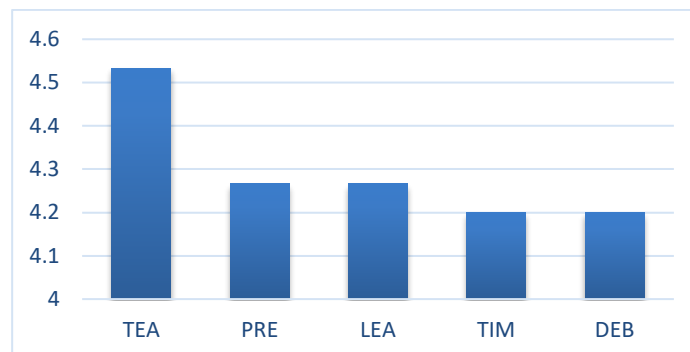
Figure 2. Ranking of soft skills

Students also provide suggestions to improve the CDIO courses. For CMU-CS 297, they want to have more games to practice the debate skill. Meanwhile, for CMU-CS 397, they need to get more knowledge on development software process and decrease overall CDIO's scope. To support them develop updated software, they suggests that instructors should add more lesson on new technologies or techniques and provide more free tools for software development.

After that, the authors conducted focus group interview with three instructors. The focus group interview was chosen since it would admit the instructors to interact as a group while describing their experiences of teaching at the program. In CMU-CS 297, there are some students do not really participate in the whole process of handling the problem (figure out the solution of the game or the project). In addition, students do not take much time for

proposing and designing idea. They start to solve problem upon receiving the question and correct the wrong solutions. Therefore, they do not have enough time to provide the best solution. The instructors need to change the evaluation scale and types. The peer evaluation should be added in to let other member grade themselves. The size of group should be reduced from five to three members to let them work closely and control the time. In addition, before working in team, students much to figure out solution individually to enhance their creative skills.

In CMU-CS 397, the instructor found that most projects are implemented at the basic level only. They lack of the tools to implement ideas such as programming languages, technologies. The team leaders still are unable to manage the members and assign the tasks effectively, and then they have not much time operate and test products. The instructors need to provide material in advance to let student read before coming to class. Students are also encouraged to spend more time on the project at home. Since within 4 hours at class they cannot fulfil all stages of CDIO approach. The instructors also suggest the management board provide more space for this course to let students have environment to work on their project together. Moreover, the English skills also become the obstacle for students to research the materials and work on modern technologies. The commitment of each group member is not high, which leads to the delay of the progress. Instructors suggest having teaching assistant to participate in technical guidance and assistance will increase the cohesion and curiosity of the juniors behind. It is necessary to organize CDIO product contests to award a monthly award to encourage creativity and scientific research of students.

DICCSUSSION AND CONCLUSION

To enhance soft skills of the students, not only for their professional development but also for real-world problems solutions and interaction is utmost necessary. To facilitate soft skills enhancement among the students, CDIO based course is introduced in CMU-CS 297 and CMU-CS 397. For CMU-CS 2917 course, multiple games are played for enhancing time management and soft skills and Scrum or Agile Methodology with real-world problems-based projects in team work are used in CMU-CS-397. This paper proposes modified framework for both courses by adopting CDIO based framework. And the study conducted on 45 students indicate that students have better experience towards soft skills, high team coordination towards problem solving and efficient utilization of technical skills in solving real-world problems. In the future, we tend to modify other courses of Software Engineering with CDIO based methodologies for enhancing knowledge building and soft skills in students.

In addition, the knowledge and practical ability of instructors has a deep effect on engineering education, and therefore, universities and colleges must have excellent instructors with professional capacity and practical skills. Several methods are used to improve instructor's professional and application ability. The first is encouraging instructors to become "double-professionally-titled instructors". The second is regularly carrying out curriculum teaching and research activities, to discuss the method and means of teaching, and allowing instructors to learn the teaching experience from each other. Third is to provide various opportunities and financial support to encourage instructors to attend profession training and all kinds of important education conferences about teaching reform and practice reform, where they can communicate and discuss with colleagues in other universities or in IT Company. Instructors should be encouraged to update their knowledge and teaching materials to keep pace with times.

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COMBINED STRATEGIES TO PROMOTE ACTIVE LEARNING AND RETENTION

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ABSTRACT

Retention rates in engineering courses in Ireland and worldwide are an increasing problem. There are numerous reasons for students not progressing to the second year of their STEM courses, which can include everything from issues related to the transition from a school setting to University and living away from home. The volume of theoretical work undertaken in large lecture theatres can be off-putting to new students, who can feel isolated and can struggle with the new content and learning environments. In the first year, students often cannot visualize how the individual subjects covered are going to lead them to their engineering degree. This paper aims to analyze the introduction of an active learning component through the repurposing of a first-year spring semester module while maintaining the existing learning outcomes. A Design-Build-Compete (DBC) project requires students to work in teams to design and build a vehicle to transport a payload up a 15m slope. It requires students to use mechanics calculations along with engineering design and drawing principles to design this vehicle. Students are encouraged to employ related prior learning such as computer coding and mechanics equations learned in the previous semester to optimize their designs. To support students at the developmental stage of their designing, the module assessment approach utilizes Adaptive Comparative Judgment (ACJ) as a medium to engage students in peer assessment. This process is based on the students making multiple holistic comparative judgments on peers' work, presented in an e-portfolio, generating a rank order of perceived quality by the group. Students also generate formative feedback through the ACJ platform, which contributes to the knowledge-building process. This has an added meta-cognitive benefit where the student is encouraged to reflect on their own design based on their judgement activity prior to receiving feedback on their individual submission. This process is repeated later in the module when the final team report/portfolios are submitted. Students work on different sections of this report and submit it as a team and then build the vehicle in the workshop using basic workshop tools. At the end of the module, all teams take part in a timed race, sponsored by local industry (Modular Automation and J&J Automation Centre of Excellence). At this event, each team is interviewed by practicing engineers who provide feedback on the project and ultimately award a number of prizes related to performance, design and teamwork.

KEYWORDS

Design-Build-Compete; Adaptive Comparative Judgement; Integrated Curriculum; Student Retention; Active Learning; Team-Based Approach, Standards: 3, 4, 5, 7, 8, 11.

INTRODUCTION

The University of Limerick in Ireland enrolls 160-180 students each year into a general engineering program. At the end of their first year, they choose their preferred engineering discipline from one of: Biomedical Engineering; Civil Engineering; Design and Manufacture; and Mechanical Engineering. There are excellent examples of CDIO activity in these programs including aeronautical engineering's Design-Build-Fly project (Young, 2007), Problem Based Learning (PBL) activity in Civil Engineering (Cosgrove, Phillips, & Quilligan, 2010) and general work from the BE degree in Design and Manufacture since the University joined the initiative in 2010 (Ryan, Gordon, Tanner, & Williams, 2017; Ryan, 2013). Introducing CDIO into a program is not a trivial process and can take a long time to make significant changes. The aim presented in this paper is a bottom-up approach, where CDIO methods are introduced to a single module in the first year of the program and analysis is undertaken to see how this has affected the implementation of CDIO elsewhere. Senior management supports this approach in terms of resources, however, implementing CDIO in a single module clearly cannot cover all of the CDIO standards. Based on the outcomes of this module, it is hoped that other academics will also implement CDIO initiatives in their modules.

The first year of the engineering program consists of some recap of subjects covered in secondary school, such as Design Communication Graphics and Applied Mathematics, to bring all of the students to an equivalent standard. One of the modules taught in the second semester of the first year is called "Introduction to Design for Manufacture". In this module, students learn the basic principles of engineering drawing and communication through sketching and manual board drawing and cover basic manufacturing methods, including machining, joining, casting, metal forming, additive manufacture, materials selection and process capability. The first iteration of this program was implemented in 2015. It has been refined year-on-year, based on critical-reflection by the academic team and informed by student, technical and industrial feedback. Some details of an earlier iteration of the module undertaken can be found in the proceedings of the 13th CDIO conference in Calgary, Canada (Tanner & Power, 2017).

In the initial implementation of the module, some clear objectives were identified:

1) Improve retention by creating a practical "hands-on" module for first year engineers (Standard 5 – Design-Implement experiences). The University of Limerick has implemented a number of wide-ranging solutions in recent years to address first year student retention, through the "Student Engagement and Success Unit" (Diggins, Risquez, & Murphy, 2013; Gibbons & Smalle, 2017). These initiatives cover the entire range of degrees that the University offers, but as outlined in recent CDIO and engineering education literature, retention is a pertinent issue internationally for engineering programs (Bennedsen, 2011; Joyce & Rodriguez-Falcon, 2010; Knight, Carlson, & Sullivan, 2007; Godfrey & King, 2010) (Green, 2010; Godfrey, Aubrey, & King, 2010). It is interesting to note that all of these articles include active learning to help address the retention problem and this is further expanded upon by Hermon (Hermon, 2016).

2) Engage with local industry to give first year students a perspective on the world of work that will be available to them after graduation (Standard 4 – Introduction to Engineering). Recent engineering education literature suggests that developing a tangible connection with engineering practice is important for retention and ensures that graduates are ready for the

world of work (Male, King, & Hargreaves, 2016; Tio, 2016; Edelbro, et al., 2017; Chong, Yng, Kwong, & Wah, 2017; Edelbro, Eitzenberger, Edstrom, Jonsson, & Swedberg, 2017).

3) Move away from exam-based assessments to a continuous assessment and team-based approach where the assignments have a connection with industrial applications and go "beyond the classroom". This helps to develop an integrated learning experience that also helps to introduce students to the world of engineering (standard 4 – Introduction to Engineering; standard 7 – Integrated learning experiences; Standard 8 – Active Learning; Standard 11 – Learning Assessment) (Dym, Agogino, Eris, Frey, & Leifer, 2005; Prince & Felder, 2006).

4) Use the content in this module to create a link across the first year program and to give some context for future modules (integrated curriculum – standard 3). Students complain that the mathematics that they learn is not applied and they rightfully demand that relevant examples are given to their area of study. Recent CDIO publications have sought to address these issues (Chong, Yng, Kwong, & Wah, 2017; Hallenga-Brink & Sjoer, 2017; McCartan, Hermon, & Cunningham, 2010; Enelund, Larsson, & Malmqvist, 2011).

DESCRIPTION OF DESIGN-BUILD-COMPETE PROJECT – CURRENT ACTIVITIES

The Design-Implement (DI) project is described in more detail in an earlier paper (Tanner & Power, 2017), so only a summary is given here – some images can be found in Figure 1 and a flowchart is given in Figure 2. In the first week of the semester, students are given a selection of parts including wheels, pulleys, a motor and a sheet of 1mm thick aluminum from which they manufacture the chassis. They also receive a handout, which contains a procedure from which they can optimize their designs to maximize speed and a series of reporting deadlines. There is a range of possible "correct" effective outcomes, depending on the design that students choose. The assessment considers this, as outlined in the following sections.

Figure 1 Some images from the DBC event held at the end of the semester each year. The image on the left shows the racetrack in action in front of the students union; The image on the right shows the cars being lined up at the end of the race.

First Assessment – Mathematical calculations

In the first assessment, requested at the end of week 4 of the semester, students complete a set of engineering calculations to estimate the speed of the vehicle based on their choice of pulley and wheel sizes, and overall mass of the vehicle. Students input these results through a quiz on the University Learning Management System (LME) called Sulis (based on the Sakai system). Student's answers are opened in an excel spreadsheet from which their calculations

can be checked and marks allocated accordingly. Each student receives a mark /5 for their calculations.

First Assessment – Engineering Drawings

In the first design assessment, students create individual design solutions that outline the positioning of components and chassis design using two orthographic views. They can also include two further sheets outlining their design evolution and solution. These are then uploaded onto an Adaptive Comparative Pairs software system, where students can also include an audio file to help explain their design solutions (Seery, Canty, & Phelan, 2012). Students are then required to make approximately ten judgements where they are presented with two of their peers' design solutions. The students must select which design they believe is better and justify their decision. As part of the process, they must also give feedback to their peers on observed qualities and areas for potential development or improvement. This has multiple positive outcomes including students developing a greater awareness of quality through their analysis and generation of feedback as well as receiving a wealth of feedback on their own work (Seery & Canty, 2017). The activity also produces a rank order of the quality of the work as perceived by the student-judging group, which offers potential for further discussions on quality as the module progresses. This process is moderated to ensure feedback is valid and appropriate. Further details of the alignment of this process and the CDIO framework can be found in the Proceedings of the ASEE Engineering Design Graphics Division 72nd Mid-year conference (Hyland, Buckley, Seery, Gordon, & Canty, 2018)
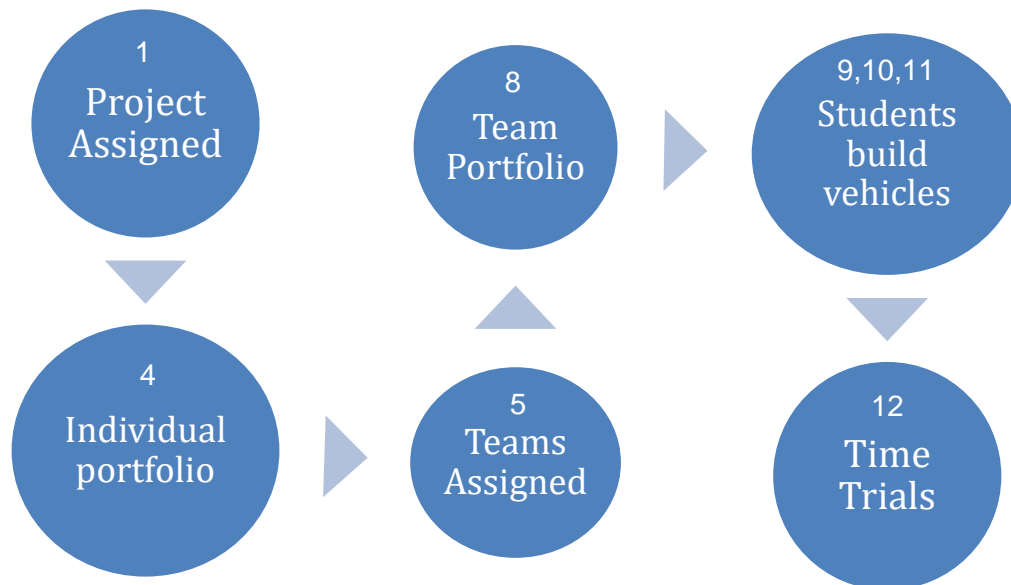
Figure 2 Flowchart indicating major events during the design build compete project. The numbers at the top of each item indicate the week during the semester when they occur.

Assignment of teams

Students are allocated to workshop groups limited to 24 students based on health and safety requirements. From these workshop groups, four students with the highest scores from the first assessment are selected as "Team leaders" around which the Design-Build-Compete teams are built. Using the LME system, students are polled on their favored role on the teams

from the following options: Project Leader; Design Leader; Mechanical Designer - Propulsion; Mechanical Designer – Engineering Drawing; Generally, not all students complete this quiz, so almost all students get their first choice in terms of role on the teams. Based on the results of the first assessment, teams are carefully created to ensure that all teams have a similar mix of abilities, so that one team does not end up with all of the students who have either not engaged or who are exceptional. This coordinated approach to group formation has been shown to increase learning outcomes and reduce negative outcomes associated with dysfunction group dynamics (Godfrey, Aubrey, & King, 2010).

Up until now, no attempt was made to ensure that female students weren't left isolated as the only female on the team. In future, every attempt will be made to ensure that each team has a minimum of two female students as emphasized by Kacey Beddoes at the CDIO Gender presentation held in Chalmers University in October 2018 (Beddoes, Panther, Cutler, & Kappers, 2018).

Second assessment – week 8

At the end of week 8, students submit a group report, which communicates all details of their design solution through the medium of sketches, drawings, photographs, mathematical calculations and justification for their chosen design. In week 11, they also submit a video of the DBC process, which is assessed using ACJ, where the focus is on establishing the team with the best communication output. Each student receives 10% for their section of the report and they receive another 10% for the overall team performance.

During week 9, 10 and 11, students are allocated to their workshop groups and have 6-hours of workshop time to complete their build. Finally, during week 12 of the semester, students are invited to take part in time trials, where each team is given three attempts to climb the hill. The teams that come first, second and third overall in the race and in the final report are awarded prizes by Modular Automation, a local automation solutions company with expertise in "Design-Build-Control" for manufacturing industry internationally. A second award is also presented for the "Best Overall Design and Team Spirit" by the Automation Centre of Excellence at Johnson & Johnson in the University of Limerick. Videos produced from previous years' race days can be found online (University of Limerick, 2017; University of Limerick, 2018).

PRELIMINARY RESULTS – SELF-EVALUATION

This section presents preliminary results from a broad self-evaluation of the degree programs that take this module. Given that the aim of the paper is to analyze the effect of a bottom-up approach to introducing CDIO, it is felt that this self-evaluation across a range of programs that share common modules is most appropriate.

Standard 3 – Integrated Curriculum

At the start of this module development, it was recognized that there was a need to analyze the curriculum and an initial map of the skills learning outcomes was undertaken (1/5 from CDIO Rubric). The module is now fully integrated into the first year engineering program and draws information from other modules in the first year, including engineering science, engineering computing, materials and engineering mechanics. At the time of planning, future work and study by the students as they progressed through their respective engineering programs as also considered. Evidence of its impact is observed when students at the University of Limerick undertake a cooperative education experience at the end of their second

year and have industrial interviews for these placements at the start of their second year. Anecdotal evidence suggests that students are asked to explain their role on the team for this DBC and they discuss the teamwork aspect of the projects. Students in later years also undertake projects using finite element analysis, for example, where they re-design the original project with the new skills that they have learned. Based on the changes, that have been implemented, a self-assessment of this standard now results in a score of 3/5.

Standard 4 – Introduction to Engineering

Prior to the introduction of this module, there were two modules in the first year, which covered Introduction to Engineering. These modules have always been very strong and contain elements of active learning and an integrated curriculum in that the modules are supported but by the University "Writing center". Anecdotal evidence suggests that when students were being questioned in relation to teamwork, leadership, communication skills etc., that the DBC activity was significant support for them to articulate and demonstrate evidence of their skillset. In spite of this, the score for this rubric has likely remained the same (3/5).

Standard 5 – Design Implement Experiences

Prior to this module, there were design-implement experiences within the programs, but there were none in the first year. CDIO experiences were also stronger in some programs. In Aeronautical engineering, for example, there has been a Design-Build-Fly project embedded within the program since 1996 (Young, 2007). As a result of the DBC integration in this first year engineering module, a proposal for government funding to further develop CDIO experiences was submitted in November 2018. Regardless of funding, there is now a distinct plan that these CDIO experiences are essential to engineering programs at the University of Limerick. Being a little conservative, a score of 3/5 can be attributed to standard number 5.

Standard 6 – Engineering Workspaces

While engineering workspaces were not part of the original objectives of this project, new engineering workspaces have been developed to help accommodate this module and a module in Civil Engineering where the students build a bridge as part of their DBC. The workshop space used for this module has also been redesigned to accommodate the students and give them improved collaborative space for projects. Since this program began, the score for engineering workspaces has increased from a self-evaluation score of 1 to 3/5. There are also plans to introduce more CDIO spaces across the faculty.

Standard 7 – Integrated Learning Experiences

The DBC project has been core to developing standard 7. Previously, students in this module worked on individual parts in the workshop and produced individual reports and artefacts. They now work as teams and are assessed as teams. They must learn to work together on the DBC project by combining their expertise to produce a common artefact and report. As part of the final assessment, a team of engineers from a local J&J company interviews all of the teams and probe the interpersonal relationships within the team. The feedback from the engineers is outstanding and they are always extremely impressed with the standard of the final builds and the personal attributes demonstrated by the students through the DBC activity. Some of the students end up taking on their cooperative education experience with these companies due to the work that they complete and their attitude in the interviews. (Score 3/5).

Standard 8 – Active Learning

Each student taking this module has six contact hours per week, where they spend two hours per week in an engineering design laboratory and two further hours in an engineering workshop using lathes, milling machines and workbench tools. The remaining two contact hours are spent in a lecture theatre. Clickers are used with powerpoint presentations in the manufacturing lectures in an attempt to keep the learning active and are now used in about 20% of the modules in the first year. In most courses, there is a plan to include active learning across the curriculum. The DBC is essentially an active learning task where the learners are required to take ownership of the task and drive it forward to meet the intended learning outcomes of the module. Supporting this through pedagogy is of critical importance to help students navigate the path of uncertainty and ultimately reach their goals. The module supports active learning with dedicated laboratory/tutorial time with tutors, with e-portfolios to help students communicate their thinking and designs and through the formation of working groups that create an opportunity for discussion and collaboration between learners. Creating and delegating roles that simulate work teams in the industry also supports the authentic development of attitudes, skills and knowledge relevant to an engineering career. Finally, the introduction of the peer assessment activity supported through ACJ provides a catalyst for the students to conduct in-depth analysis and synthesis of the quality of work and to develop skills of critique and judgment through the feedback and assessment process.   (Score 3/5)

Standard 11 – Learning Assessment

A significant innovation in relation to assessment in this module is the introduction of peer learning and assessment. The benefits of integrating this approach are that it supports the development of skills of collaboration and teamwork, develops skills of communication through the externalization of ideas and concepts to their peers and the assumption of responsibility by the group, deciding on their needs and planning a strategy to address them. Boud (Boud, Choen, & Sampson, 1999) outlines that assessment can actually foster peer learning but only with strategic planning from the outset of the design of the learning task. To this end, the module team considered the ACJ assessment process as being suitable in delivering on this requirement. The process requires the students to make holistic judgments on the quality of peer work, based on overarching criteria that are formulated as the learning progresses through the task. Students are exposed to a broad spectrum of quality of work through the judging process and both create and receive multiple pieces formative feedback on the work. This feedback is generated early in the module (Week 5) and is a central catalyst for discussions when the teams are created, and members try to finalise on one design for the group. This aligns with the principles of good peer review and assessment (Nicol, Thomson, & Breslin, 2014; Sadler, 2009). The inclusion of additional feedback from the industry partners (and the academic team complement this assessment approach leading to an inclusive and informative assessment model that supports the learner. The current score for the program for standard 11, is probably 3/5, but with the impact that ACJ has had, we would hope that the score would increase further in coming years when the opportunities that ACJ presents are better understood by fellow academics.

CONCLUSIONS

The paper aimed to look at developing CDIO in one first year module and analyze the effect that this has had in the remainder of the program. The module has gained a lot of attention from management and some of the ideas have filtered into other areas of the program and into

other teaching and learning groups in the University. The introduction in this one module has clearly had an impact on standards 3, 4, 5, 6, 7, 8, and 11. There is still a lot of work to do in developing the remaining standards and applying the techniques learned here into other courses/modules. The effect on retention is difficult to assess, but retention figures have improved year-on-year since this program was introduced, but these could potentially be linked to other changes in the overall structure of the engineering program, such as the introduction of a common entry and first year. There is no doubt, though, that the introduction of this CDIO module has had a positive effect on the students and those involved in teaching first year engineering at the University.

Possibly one of the greatest finds in terms of CDIO was the link with ACJ. As previously discussed ACJ as an assessment method is compatible with the CDIO initiative and contributes to multiple standards. However, it can also be thought of as a pedagogical strategy. Requiring students to act as peer assessors provide a wealth of feedback that would not otherwise be possible without significantly increased resources. There are associated benefits when students are exposed to a wide range of quality in peer work. This allows students to form a more accurate impression of what excellence looks like and aids in self-evaluation of similar work. Similarly, it facilitated the involvement of our industry partners to engage remotely with student work prior to a competition setting. This allowed for a more complete partnership where feedback from partners could be incorporated into the module design and further developed when industry partners were engaging students in small group settings. While the ACJ system is a particularly useful tool, it should not be considered an easy fix. It requires a sound conceptual rationale for inclusion and a considerable amount of supporting structures in order to ensure students benefit from the experience.

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EVALUATION OF NOVEL LEARNING SPACES FOR MIXED ON-CAMPUS AND ONLINE STUDENTS

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ABSTRACT

This paper will evaluate the effects of new learning spaces for mixed on-campus and online students. In 2015, the Electronics Engineering study programme at Aarhus University School of Engineering (ASE) in Herning decided to provide an online learning option in addition to the traditional classroom instruction. Consequently, the flipped learning approach was introduced in both the online and on-campus teaching, allowing online students to join the classroom teaching synchronously and asynchronously. However, due to a high dropout rate, various initiatives for improving online student retention have been implemented since 2016, and despite heavy legislation affecting the university, which makes it almost impossible to work full-time while also studying full-time, the majority of the 2016 online student intake is still actively engaged. A number that continues to increase with the 2017 and 2018 intakes. From 2016-2017, data was collected and evaluated to gain further insight into what it is like to be an online student. The findings have led to new strategies for collaboration, student-centred learning and optimised learning spaces for how we conduct flipped learning at ASE in Herning. Some of the new strategies have been introduced to the 2018 student intake; among these are *Slack* and *RealTimeBoard*. Likewise, new ways of team collaboration, where the students sit in their teams at round tables, have been implemented. Each team consists of a mix of on-campus and online students, and the lecturers connect to the students' (virtual) workspaces via an iPad, thus combining a physical and virtual experience in the learning space. Conclusion is that organising the classroom with round tables together with RealTimeBoard supports the strategy of creating a more modern classroom with a student-centred approach to learning and a better integration of on-campus and online students, while Slack was not considered an appropriate 'candidate' for a modern communication platform.

KEYWORDS

Online learning, flipped learning, teamwork, personal skills, socialising, engineering workspace, interaction, retention, Standards: 1, 2, 3, 6, 7, 8.

BACKGROUND

The background for introducing the online learning option at ASE in Herning was a critically low intake of students in 2014. The teaching staff related to the study programme initiated a process that should lead to a strategy for increasing the intake. To understand and conceive the problem, several tools were used, including the university's own development method 'EUDP' (Embedded Unified Development Process), which is compliant with the CDIO concept. Quite early in the process, it was decided to offer an online concept with the mission to:

- Create a study programme with both on-campus and online students.
- Create a great study environment for both on-campus and online students.
- Include unique teaching methods.
- Stand out positively from existing engineering programmes.
- Give the students the opportunity to follow the teaching independently of time and place.

To offer the study programme as an online option, it was necessary to implement the flipped learning approach in teaching. A process started in the spring of 2015 where the teaching staff was to 1) *conceive* the concept (i.e. gain an understanding of flipped learning), 2) *design* the concept (i.e. create explanatory videos), 3) *implement* the concept (i.e. integrate the videos into the university's learning management system 'Blackboard') and 4) *operate* the concept (i.e. conduct flipped learning in the teaching). Subsequently, the CDIO process has been repeated through several iterations, as we learn and experience new things all the time.

With only eight students in 2014, our goal was a student intake of 40, which we reached in August 2015. However, the dropout rate remained very high, particularly among the online students, and consequently, several strategies to improve the learning and reduce the dropout rate were initiated. Among these are:

- Mixing teams of on-campus and online students.
- Informing the students about the workload before they begin their studies.
- Organising a social event before semester start.
- Coaching the students in effective studying and study planning.
- Introducing project days where all students must attend on-campus sessions.

The strategies have resulted in reduced dropout rates going from 67% (2015) to 50% (2016) to 38% (2017) and to 20% (2018).

In 2016, the Danish Accreditation Institution published a report that focuses on Massive Open Online Courses (MOOCs) (MOOCs – Kvalitet og perspektiver, 2016). Although MOOCs have positive features, there are some concerns in terms of learning environment, intentions, interaction, motivation, dropout rate, etc. For instance, the MOOCs dropout rate is more than 90%, which is the main reason why we have chosen another online learning method.

At ASE in Herning, we have three categories of students: On-campus students, synchronous online students (who follow the teaching online at the same time as the on-campus students) and asynchronous online students (who follow the teaching online wherever and whenever they have the time to study). When looking at the dropout rate for each of the three categories of students, the dropout rate for the 2018 intake so far is:

- On-campus students: 0%

- Synchronous students: 23%
- Asynchronous students: 47%

The dropout rate for the asynchronous students is still too high and calls for a further reduction. In conclusion, however, it seems that the strategies implemented to reduce the dropout rate have had a positive effect. One of the most effective tools has been to emphasise to the applicants that having a full-time job while studying full-time is not an option. Surveys show that the number one reason for dropping out is lack of time (H. Slavensky, P. Lysgaard, 2018).

SCOPE AND METHOD

This paper will evaluate three new initiatives toward novel learning spaces for mixed on-campus and online students: The modern classroom as an interactive learning space as well as the use of Slack and RealTimeBoard as modern communication platforms. The effects of lower dropout rates cannot be evaluated yet, but student satisfaction based on qualitative interviews and quantitative surveys can and will be measured.

THE MODERN CLASSROOM AS AN INTERACTIVE LEARNING SPACE

Inspired by Bergman and Sams (2014) and P. Young et al. (2016), it was decided to establish a modern classroom as an interactive learning space with on-campus students in their teams and online students represented via monitors. The primary aim was to foster team spirit and facilitate a student-centred approach to learning instead of the traditional classroom instruction (H. Slavensky and P. Lysgaard, 2018). When introducing the online learning option in 2015, the teaching was flipped by creating video sessions for the students to be watched before an in-class lecture, and the time in class was spent on exercises and enhancing the students' engineering learning space. This corresponds to the CDIO Standard 6 ('Engineering Workspaces') and the CDIO Standard 2 ('Learning Outcomes'), i.e. personal and interpersonal skills. Watching the videos at home corresponds to the two lowest levels of Bloom's taxonomy (remembering and understanding; see Figure 1 below), while the time spent on exercises in the classroom (the learning space) is applicable to Bloom's higher levels of taxonomy (applying, analysing, evaluating and creating).
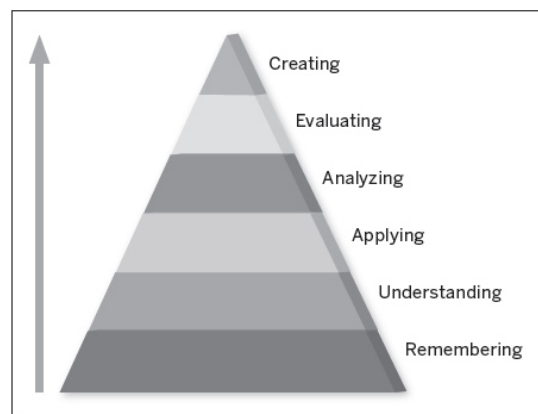
Figure 1. Bloom's taxonomy (J. Bergman and A. Sams, 2014)

From 2015 to 2017, the learning space was not well established; the physical setup in the classroom was still traditional rows of tables and chairs, facing the lecturer sitting at a desk. Although the students were divided into teams based on their Insights profile (Insights Discovery, 2019) and the statement from the CDIO Syllabus report (2001) ("Graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment"), the students sat randomly in the classroom. In addition, not all team members were represented in the classroom, and as a result, the lecturer could not support the students team by team. Starting in August 2018, it was therefore decided to reorganise the classroom, seating the students in their teams at round tables in small 'table islands' (see Figure 2 below).

Figure 2. Students seated at the round tables

At each table island, two to four on-campus students and two synchronous students were represented. The on-campus students were invited to have a dialogue with the synchronous students via virtual Adobe Connect meeting rooms. This setup worked well, but unfortunately, it also created too much noise in the classroom. Therefore, noise-dampening materials in the form of partition walls were installed.

Figure 3. Introducing partition walls as noise-dampening material

In Figure 3, the classroom partition walls between the teams can be seen. The students, however, disliked the walls and removed them. In order to create ownership, the students were encouraged to find the setup *they* preferred. In addition to the noise level, the students indicated that the tables were too small; they suggested bringing back the big squared tables, and arrange these as islands instead. As to the noise level, the students proposed the use of headsets in the learning space. This way, the noise from the loudspeakers from the synchronous students was removed, but the setup made it difficult for the lecturer to interact with the teams. It was suggested to integrate a 'plugin', enabling the lecturer to enter the room via a PC or mobile phone by running Adobe Connect using headsets. The outcome was a solution where the lecturer used an iPad and a wireless noise cancellation headset. As stated previously, each team has been enrolled in individual Adobe Connect meeting rooms, to which the lecturer can log into when supervising a team. In Figure 4 below, the final setup, which has been used by the author of this paper in the autumn of 2018, can be seen. The setup has proven to be a very efficient workspace, where the students can go through the cycle of conceiving, developing and implementing (a product, process or system). In fact, a quantitative survey conducted among the online students showed that they would prefer the rest of the teaching staff to implement the same setup in their teaching. Thus, starting in January 2018, the 2nd semester students will have the same setup in all classes.

Figure 4. Introducing iPad and headsets

In the traditional classroom, students usually need help from the lecturers when they are stuck on a difficult problem. This is most often the case when they work on an assignment at home or when the lecturer is unavailable (J. Bergman and A. Sams, 2014). With the interactive learning space concept, the lecturer is available as a facilitator and expert when needed, and, additionally, the students can help and motivate each other. However, this concept is only valid for on-campus and synchronously students. The asynchronous students face the same problems as in the traditional classroom; the lecturers are not available during weekends or at other times outside of normal working hours. In order to help the asynchronous students, each team consists of both on-campus and online students, ensuring that the asynchronous students can get help from fellow students (however not always in time). Another way of motivating the asynchronous students is to offer interesting project-based courses, where they can join the class synchronously or asynchronously. The social aspect of studying is extremely important, and thus, two project weeks during each semester, where all students must be present on campus, are held. In order for the students to conceive and design as well as implement anywhere at any time, the students are equipped with a 'lab-in-a-box'. On campus, we have various lab facilities for implementing and operating the projects, providing a unique learning space compared to the traditional classroom instruction.

MODERN COMMUNICATION PLATFORMS

A qualitative analysis on student socialisation and learning spaces (Slavensky and Lysgaard, 2018) has revealed that the students at the Electronics Engineering study programme in Herning do not have a specific favourite communication platform, but the online students agree that Skype, Facebook, Discord, email, Google Drive and Trello work well. None of the online students uses the Adobe Connect platform or Blackboard, both of which are provided by the university. One reason could be that the students often experience sound problems with Adobe Connect in the learning space. Another reason could be that Adobe Connect and Blackboard do not offer the same 'smooth' connection as the students' preferred platforms; they have to log into the systems with their username and password, which is more

inconvenient than using their smartphones. This could call for other modern communication platforms supported by the university (Slavensky and Lysgaard, 2018). It should be noted that the use of modern communication platforms is solely for supporting collaboration *between* on-campus and online students; it is not to provide information about the students to the university. When implementing a new communication tool, it is also important that the university has approved the tools to comply with the General Data Protection Regulation (GDPR).

Slack

In the conceive phase, the cloud-based team collaboration tool Slack came up by recommendation from the CDIO development lab. According to Slack's website, Slack is a workspace facilitating team communication to enhance workflow by organising communication in channels and supporting integration with commonly used services and apps. Slack offers access to the collective information of a class (Slack, 2019). As mentioned above, the university currently uses Blackboard as an internal communication and learning platform for all courses and activities. The students generally like Blackboard, but they do not use Blackboard when communicating and collaborating. Thus, when learning about Slack, it was decided to try the platform for communication and collaboration between on-campus students and online students.

Before implementing Slack to the students, it was introduced to the teaching staff. Having tested the platform, the lecturers found Slack useful for communicating and sharing information, so it was decided to introduce Slack to the students who started in August 2018. In Figure 5 below, the setup of Slack on 23 February 2018 is illustrated. The # channels represent the 1st semester courses, and the channels with a lock icon are private channels visible to the lecturers only.
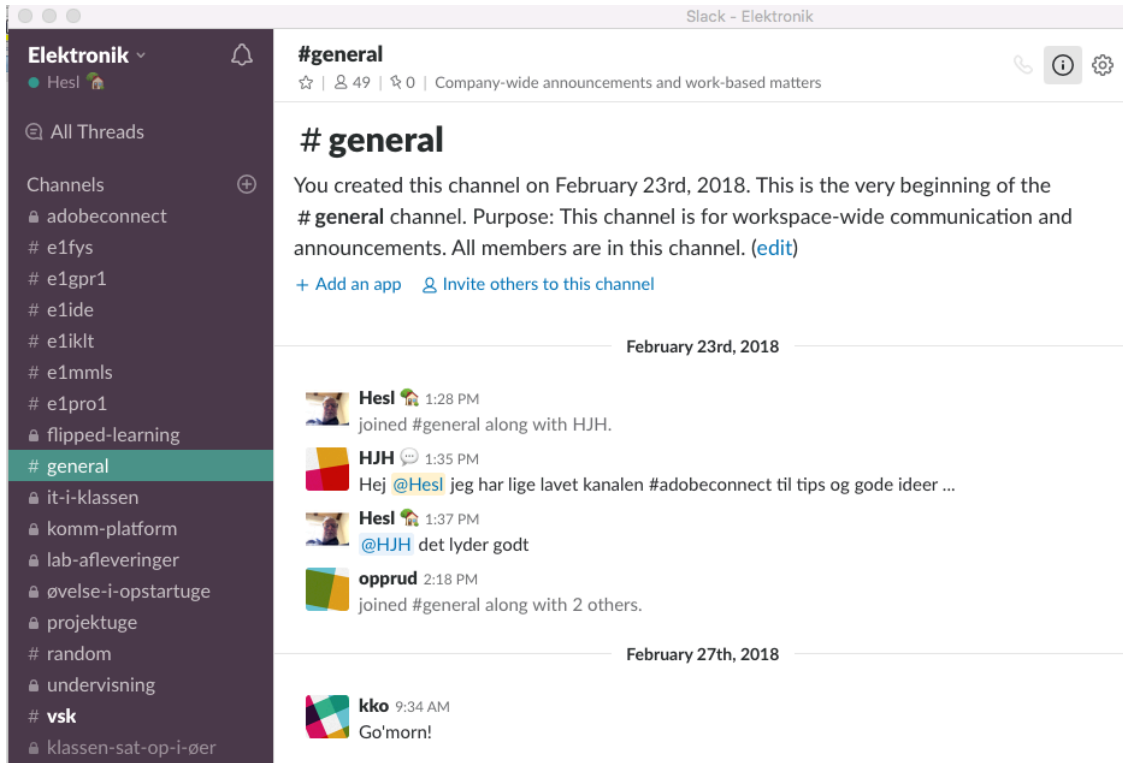
Figure 5. The first setup of Slack (23 February 2018)

In Table 1 below, the channels, members and posts are listed. The table reveals that only half of the students have added themselves to the channels, and only a few have posted items on the channels. The '# vsk' has the lowest number of members, but the highest number of posts (the last posted on 5 December 2018). The reason for the relatively high number of posts on this channel could be that the course lecturer has used Slack for saving official course documents as a supplement to Blackboard.

Table 1. Slack channels, members of the channels and posts

Channel	Members	Posts
# e1fys	22	2
# e1gpr1	29	8
# e1ide1	22	5
# e1iklt	19	0
# e1mmls	22	0
# e1pro1	20	4
# vsk	12	22

Due to the low number of members and posts, it was concluded that Slack was not used as intended or hoped. Despite the fact that it was properly introduced to the students, and the students were encouraged to use it, it was not their natural choice. Some students reported that they did not see any clear need for Slack; others said that Slack was too complicated/confusing to use. Consequently, Slack was not considered an appropriate

'candidate' for a modern communication platform to support collaboration between the on-campus and online students in Herning.

RealTimeBoard

RealTimeBoard is a cloud-based whiteboard service. It enables simultaneous and real-time synchronised collaboration and communication activities by any number of team members across any number of infinitely large whiteboards (RTB, 2019). In contrast to Slack, it filled a gap in the portfolio of collaboration tools. RealTimeBoard is geared towards productive team collaboration, specifically with features for interactive joint visual problem solving, visual team organisation with Scrum boards, etc. Hence, RealTimeBoard directly supports the teams and interpersonal focus of the engineering programme (and of CDIO). RealTimeBoard was deployed to a pilot team consisting of two on-campus students and five online students. Of the five online students, three to four were asynchronous and one to two were synchronous (with one living in the GMT+8 time zone). For this team, RealTimeBoard became a central component in a collaboration toolchain also consisting of SharePoint for file storage/sharing, Facebook groups for posting short messages, news and updates (both formal and informal) as well as Adobe Connect for conducting online meetings. It was found that RealTimeBoard could support the learning objectives and interpersonal development focus of the students in three major ways.

First, using RealTimeBoard as a collaboration tool enhanced the appeal of and decreased the barriers to participating in the joint learning space. For the students, the flipped learning preparation at home can support the basic learning objectives of remembering and understanding concepts and methods from the curriculum (Bloom's taxonomy, Figure 1). Reaching the higher learning objectives towards mastery of the curriculum however requires an in-depth application, analysis and evaluation of the theory to problems. Indeed, this is where RealTimeBoard fits in. A key finding was that the asynchronous students benefitted from the material written on the whiteboard developed in the synchronous learning space, although they had not attended the classes. The whiteboard served both as a visual artefact of what had taken place during class and as a reference/source that could support the students in their own problem solving later on. To illustrate this point, one asynchronous student reported (translated from Danish), "It is great that I can go on the board and keep track of what the others have worked on during the day. I use that a lot."

Second, RealTimeBoard supported the problem-based process of the semester project exceptionally well. The project was a 'make-it-fly' type of project with a well-defined end goal but allowing a relatively free process through the CDIO phases with a competitive element added for extra motivation. Solutions for several interdependent elements of the project had to be conceived, developed and implemented, each step requiring coordination and joint problem solving. A key success factor in having non-co-located students develop interdependent solutions was the ability to easily share, refer to and annotate technical documentation. It was a common observation that a question or request for information, presented visually or in text by one student, was resolved later by another student through pinning explanations, measurements, drawings or annotations directly together with references to technical documentation.

Third, the observations above indirectly illustrate the key point that better and simpler tools for collaboration can reduce barriers for teams of mixed on-campus and online students to productively cooperate and thereby develop their interpersonal skills.

Figure 6. Example of online visual collaboration on a problem in a physics lesson

A qualitative interview showed that the team found RealTimeBoard a key success factor in the 1st semester. It was a factor in the successful delivery and good collaboration process for the semester project. Additionally, it also contributed to increasing the efficiency of the learning space for individual learning in the courses. In conjunction with a voice connection over Adobe Connect, the tool has been important in the social integration process and the cohesion of a highly distributed team.

CONCLUSION

This paper has evaluated three new initiatives toward novel learning spaces for mixed on-campus and online students: The modern classroom as an interactive learning space as well as the use of Slack and RealTimeBoard as modern communication platforms. The results of our efforts are not yet reflected in lower dropout rates, but based on qualitative evaluations of student satisfaction, we can conclude that organising the classroom with round tables together with RealTimeBoard can support the strategy of creating a more modern classroom

with a student-centred approach to learning and a better integration of on-campus and online students. Slack was not considered an appropriate 'candidate' for a modern communication platform, supporting collaboration between the on-campus and online students in Herning. Based on this learning, the university will further develop and implement better student-centred approaches to learning. In particular, we will need to find best practices for facilitating online learning that is effective and engaging for all students, including asynchronous students. Perhaps asynchronous students need more flexibility than the current learning paths offered to our on-campus and synchronous students today.

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BIOGRAPHICAL INFORMATION

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DIGITAL TOOLS FOR SELF-STUDY AND EXAMINATION

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ABSTRACT

Digitalization and increased use of information and communication technology (ICT) are major change processes taking place in engineering education today. Self-study and examination are areas with high potential for beneficial use of digital ICT tools. Some advantages with such tools are that students' can continuously assess their own learning in relation to the course objectives while they also can provide an opportunity to meet the teachers' needs to control how the students absorb the course material. Moreover, automatic provision of quick or instant feedback through digital tools can stimulate students' commitment and active learning and allow students greater flexibility in their learning process, with tests that can be conducted online regardless of time and space and can be repeated as needed. The purpose of this paper is to investigate how different types of ICT-based self-study and examination practices can be implemented in courses on topics such as project management, product development, and entrepreneurship, and build a knowledge base necessary for future systematic implementation of digital examinations. Our study is based on an educational development project at Linköping University, where we tested and evaluated different models and approaches for digital knowledge testing in a number of selected courses. We discuss both positive and potentially problematic aspects of the use of digital tools and conclude that successful implementation is dependent on well-planned integration of such tools into the overall course where different types of activities enhance each other. Thus, this study connects the areas of digital self- study and examination and provides examples of first steps on the way towards implementation of ICT-based examination practices.

KEYWORDS

Digital tools, ICT-based self-study, self-assessment, Standards: 8, 11.

INTRODUCTION

Digitalization and increased use of information and communication technology (ICT) are major change processes taking place in engineering education today. While the use of ICT helps solve a number of problems, it also brings new challenges (Mostert & Quinn, 2009). One area with high potential for beneficial ICT use is digital examination. Digital exams are already being implemented at Swedish universities and initial tests show positive results from both the teachers' and the students' perspectives (Berggren, et al. 2015). At the same time, changes in

the examination should be carried out without compromising the overall course design and logic (Biggs, 2003), and therefore require carefulness and coherence (Bertheussen, 2014).

One way to ensure gradual and continuous implementation of digital tools in connection with examinations is to start with digital self-study. By making both students and teachers more comfortable using ICT-based knowledge testing, and collecting experiences about how such tests can be constructed and how they are received and used, the way for digital examinations is being prepared in a thoughtful way.

Digital tools can be used to help meet students' needs to continuously assess their own learning in relation to the course objectives. At the same time, digital tools might help to meet the teachers' needs to see how the students absorb the course material in order to adapt their teaching. Moreover, the automatic provision of quick or instant feedback through digital tools can stimulate students' commitment and active learning. Also, students are allowed greater flexibility in their learning process, with tests that can be conducted online regardless of time and space and can be repeated as needed.

The purpose of this study is to investigate how different variations of ICT-based self-study and examination can be implemented in courses on topics such as project management, product development, and entrepreneurship, and build a knowledge base necessary for future systematic implementation of digital examinations. Our study is based on an educational development project at Linköping University, where we test and evaluate different models and approaches for digital knowledge testing in a number of selected courses.

ICT-BASED SELF-STUDIES

The use of digital tools in higher education is expanding. Different kinds of ICT-based tools have shown to improve learning processes and results, i.e. by enhancing students' self-monitoring and problem-solving skills (Ang, et al. 2012; Muianga, et al. 2018). Another factor contributing to the success of these tools is the flexibility in using them as they can be accessed anytime and anywhere, given a working internet connection (June & Leong, 2006). Importantly, the use of such tools results in more active student engagement (Ang, et al. 2012) and enable the shift from teacher centred learning (where learning is accomplished thanks to a teacher who conveys knowledge) to student centred learning (where learning is the result of knowledge construction by students) (Muianga, et al. 2018). Thus, the continued and growing use of digital tools is well in line with the CDIO focus on active learning (cf. Standard 8 – Active Learning) and with the overall philosophy of promoting more effective and exciting engineering education and stimulating deep learning (Crawley, et al. 2011).

One implication of the diffusion of the student-centred approach and active engagement is the increased use of digital tools for self-study. Some of those tools, such as video lectures, are incorporated into teaching activities, while others, such as digital self-assessment tools, are also related to examination practices. Below we discuss different types of digital self-study tools in more detail.

The use of digital lecture materials has been documented in several studies (e.g. Ang et al., 2012; Bhadani et al., 2017; Viksilä, 2013). Those include both audio recordings, powerpoint presentations with audio commentaries and full video lectures (Ang et al., 2012). A number of positive effects of integrating digital lectures have been discussed, such as enhanced understanding of concepts, decreased dependency on teachers and overall higher appeal for

students compared to traditional lectures (Bhadani et al., 2017). Although they lack an interactive component, digitalized lectures are viewed as a step on the way towards student-centred personalized learning (Bhadani et al., 2017). From the teachers' perspective, digitalized lectures are perceived as more time efficient which frees up resources to other types of support for students' learning (Viksilä, 2013).

However, digital lectures need to be carefully integrated into the course curriculum and used in combination with other traditional and digital tools. One specific issue discussed with regard to digital lectures is the lack of immediate feedback possibilities (Bhadani et al., 2017). This issue can be at least partially overcome by using another type of digital self-study tools considered in this paper, digital self-assessment tools.

Digital tools for self-assessment are a part of the course's overall assessment strategy which is crucial for student learning and motivation (Heap, et al. 2004). Digital self-assessment tools are often implemented in a form of web-based tests for practice, including a variety of question formats (multiple-choice questions, matching options from different lists, drag and drop questions, answers provided in input boxes) (Heap, et al., 2004). Digital self-assessment tools have the overall advantages of ICT-based methods, such as flexibility, interactivity, and time-efficiency. Apart from that, they can (although not obligatory) be viewed as a preparatory stage before introducing digital examination which also has shown very promising potential for both students and teachers (Berggren, et al. 2015). Thus, both the development of digital tools for self-assessment and digital examination methods correspond well with the CDIO Standard 11, Learning Assessment, which underline the need for a variety of assessment tools to ensure greater assessment confidence.

However, it can be noticed that the use of digital self-assessment tools has been overshadowed in existing research where most attention has been given to other digital tools for learning and examination. Therefore, one of the contributions of this paper is to provide a broader empirical base for the use of digital self-assessment tools.

Another example of ICT-based tool for self-studies are MOOCs. The first Massive Open Online Course (MOOC) was developed and offered in the late 2000s by Canadian professors (Blackmon & Major, 2017) and since then there has been an increasing interest in and development of MOOCs. Common features of MOOCs are (ibid, referring to Major & Blackmon, 2017):

- Massive: No limits of participants and the courses could potentially have large numbers attending.
- Open: Often free and accessible to anyone.
- Online: Offered online.
- Courses: No credits are offered. However, the courses have specific content and often a syllabus or some other structure for elaborating the course material. There are often assignments and self-assessments.

Integrating parts of MOOCs in university courses offers both advantages and drawbacks. Earlier studies have reported advantages, such as the possibility for blended learning and self-paced learning for students (Bruff, Fisher, McEwen, & Smith, 2013). Offering the students different types of course contents has also resulted in richer discussions among the students, and the teachers may redesign courses without developing online material themselves (Israel, 2015). A main challenge in integrating MOOC-material in university courses is the difficulty to

match the online material with activities in class and embed the material in the university course (Bruff et al., 2013).

IMPLEMENTATION CASES AT LINKÖPING UNIVERSITY

Digital tools during lectures

One possible way of using digital tools is through quizzes during lectures. In order to implement such an activity, the teacher needs to first create one or several questions that can range from simple yes or no questions to multiple choice or open-ended questions. Questions and answer options are then entered into a digital tool such as Mentimeter, Kahoot or Socrative. During a lecture, the teacher asks the students to answer the questions on their mobile devices. Provided answers can be presented and discussed with the students immediately. We have used these tools for analytical exercises as well as rehearsal exercises during lectures. Thus, digital tools can help to turn the lecture into an interactive event and can stimulate discussion of the course content. Furthermore, short written answers to open-ended questions can be collected in an efficient way through this method – both to questions regarding the course content or to evaluative questions regarding teaching methods etc. Furthermore, questions for such exercises can be viewed as one step in collecting a questions bank for future digital examinations.

Online courses in project management and entrepreneurship

Since 2011 we have run distance and semi-distance courses at our department. Our first such course was 'ETE324 Entrepreneurship' which focused on entrepreneurship in the healthcare sector. In this course, all lectures were given on distance. During the first years, they were given live at scheduled timeslots using Adobe Connect. Adobe Connect is a platform that is useful for these purposes as it allows the teacher to monitor the lecture, give the students an opportunity to write questions, speak or even show own presentations. Furthermore, the faces of the presenter(s) and participants could be displayed as well as PowerPoints or desktops. This software can also be used for more open online seminars and meetings. Through Adobe Connect, the lecture can also be recorded. Alternative platforms for this type of lectures include Skype, Discord or Microsoft´s Teams. In this case, during the first years the course was run only partly on distance and the students had to come to the university for an examination day where exams were written, and group assignments were presented. During the latter years (it was run for the last time during the spring 2017 and is now winded up), it was given fully over distance. Since 2015 online lectures are provided using the platform online Lisam. Another change was the move (in 2015) from live to recorded lectures created in the software Camtasia.

Today, we run two distance courses, one in Project management (TEIO91) that is a 90% distance course and one in entrepreneurship (TEIO05) that is a 50%-distance course. TEIO91 is run the same way as we run ETE324, i.e. with video lectures, online assignments and a final exam at the university. TEIO05 uses more of a 'flipped classroom' approach, which means that all lectures are recorded and available at the course web, while all seminars (which follow the lectures) are teacher-led. In both courses, we use 'discussion boards' instead of teacher-led traditional seminars on assignments. Students are also given direct feedback from the teachers on their assignments.

Knowledge tests have been used in our distance courses. In TEIO91 the students had to come to the university and conduct a written exam as in normal courses. The same holds for TEIO05,

historically, but this spring (April 2019), we used an electronic exam, where the students could sit at home and make their test online. The basis of this online exam was originally developed in ETE324. It consists of a bank of about 50 questions with alternative answers. Alternatives are designed either as 'radio buttons' where only one alternative can be chosen or as multiple-choice where several alternatives can be chosen. The grading is set up so that the question is worth one or several points depending on its complexity. Regarding the grading of the radio buttons, it is set up so that the right answer is given 100% of the assigned points and the wrong alternatives are given 0%. Regarding the multiple-choice percentages, points are given according to the number of right alternatives which implies that e.g. two correct alternatives give 50% each, while two incorrect alternatives give -50% each. This implies that a student that has picked two right alternatives and one wrong will get 50% of the total points assigned to the questions. To prevent students from cheating the test is designed so that each student is given 20 random questions out of the total 50. The questions are also grouped into categories and these are in turn weighted so that every area of the course gets represented among the randomly given questions. This test has also been used for training purpose/self-assessment in current non-distance entrepreneurship courses.

We have not yet obtained quantitative data on this examination practice from course evaluations since the courses are still ongoing. However, we have asked the students for their opinion. In TEIO05, where the online test is a part of the individual examination, students highlight that the online test fulfils its purpose and that it is convenient and flexible. Moreover, it is perceived as less demanding than a usual classroom exam, but due to the time constrain (30 minutes) the students could feel stressed during the exam even though they were able to complete the test with a good margin to the time limit. The use of the test for self-study purpose is appreciated as a good learning tool since it helps to draw attention to important areas of the course and provides an understanding of what type of questions that may appear in a written test.

Using MOOC-material for self-study in courses in product ergonomics

The MOOC-course 'Work and Technology on Human Terms' (www.onhumanterms.org) was introduced in August 2017 as a complement to the earlier published book (Bohgard, et al. 2011). The course was developed by the publishing company Prevent in collaboration with five Swedish Universities of Technology to achieve a modern highly accessible study material in Ergonomics. It encompasses 20 hours of study, which can be carried out whenever suitable for the student. The course includes theories and models supported with animations, interviews with experts and knowledge tests. The content of the MOOC is directly related to different types of businesses, which is reflected in interviews with product developers, managers and safety representatives. A further description of the MOOC-course is found in Lagerström, et al. (2017).

The MOOC material was used in two courses in Product Ergonomics in the form of suggested voluntary, alternative material for the students' self-studies and in one course also as mandatory, selected course material that was discussed in follow-up seminars. In the case of suggested voluntary course material, the content and structure of the MOOC were introduced during lectures. The students were then recommended to use the MOOC if and as they wished. In the other case, specific parts of the MOOC-material was mandatory. There were assignments in which the MOOC-material was elaborated by the students and later discussed in seminars. For a further description of the uses of the MOOC course, see Osvalder & Berglund (2018).

An evaluation of the use of the MOOC-material showed that the students found the material relevant for their studies. It was considered as a good introduction to Ergonomics. Some students found the material too shallow for specialization. However, depending on what was in focus in the different courses in product ergonomics, the corresponding parts in the MOOC-material was found most valuable. In general, the students selected different parts of the MOOC. The MOOC-material was used in different ways. Some students considered the MOOC as a complement to the literature, others considered it sufficient to pass the examination. It was also used as a back-up if the students had missed a lecture. The students further pointed out the advantage of being able to use it whenever suitable for the student and at one's own pace.

DISCUSSION

In our experience, there are several benefits of using digital tools in teaching, but there are also a number of challenges. Using digital tools to integrate quizzes into lectures can make traditional lectures more interactive. This is especially valuable when addressing large student groups. Engagement and interactivity are stimulated as every student with a mobile device can participate anonymously and test their own knowledge without being forced to reveal to others whether they are right or wrong. It also gives the teacher an opportunity to identify parts of the course content that students find difficult as well as parts that are well known to the students already. Each student that participates gets an individual sense of which parts of the material they know well and which parts they need to study further. Even when answering correctly a student receives instant confirmation of their knowledge – this is important since the provision of positive feedback can otherwise easily be overlooked by busy teachers. Additionally, this type of activity means that mobile devices are used in a positive and beneficial way in the classroom. The use of digital tools for quizzes and questions ensures manageability of collected data, and taking time to do this during lectures might lead to a higher participation rate than other methods such as sending out a survey or providing questions on the course website. The use of quizzes in lectures can be viewed as an intermediate alternative between traditional lectures and video lectures. While making a step towards using digital tools, the lectures not only retain but even increase interaction, thus managing to overcome the issue of fully digitalized lectures as discussed in previous literature (Bhadani, et al. 2017).

With regard to online courses, interaction is more challenging. Simply putting up an interactive newsfeed or a discussion board is not enough – our experience is that such tools are not used spontaneously. So, to facilitate interaction and discussions we need to provide clear requirements, e.g. a minimal number of posts and comments to which each student is supposed to contribute. It is also of importance to assign clear subjects for discussion, e.g. a specific assignment or an area from the literature. It is also beneficial if the teachers engage in the discussions themselves since this provides recognition and makes the students aware that their comments are also read by teachers. Engagement in such discussions is an example of new ways of supporting students' learning that become possible through digital tools and how teachers' time can be shifted from delivering lectures to other activities since pre-recorded lectures can be re-used (cf. Viksilä, 2013).

Group work during campus-based courses is often most beneficial since it involves mutual learning and interaction. However, we have identified that in online courses, and especially in cases where the courses are electable, group work is risky. This is the case since the teacher lacks control over the students and their work and thereby cannot aid in time when problems arise. When group work cannot be used teachers should consider facilitating other forms of

interaction between students since this should be an integral component even in online courses.

When designing lectures for distance courses there is always a risk that recorded lectures become impersonal, because the lecturer is invisible. This could be remedied by showing the teacher's face in the webcam during the start of a lecture. After the introduction, the webcam can be turned off and focus can be put on the slides. Showing the teacher's face again at the end makes the student connect the lecture to the teacher. Our experience thus shows that it is beneficial to combine different types of digital lectures (both powerpoint presentation with audio commentaries and video lecture) (cf. Ang, et al. 2012).

Compliance with the intended time plan for a course is another challenge. In distance courses, there is always a risk that students save the work for later and then ends up in panic and failure as time passes by. That is one of the implications of flexibility provided by digital tools (cf. June & Leong, 2006). To remedy this, we recommend a stepwise approach, where a sequence of assignments builds upon each other. By structuring the course like this, the students are given the incentive to be active from start to end. This way the benefits of student centred learning (Muianga, et al. 2018) can be maximized. Finally, to succeed in online courses a well-functioning, stable and flexible online platform is needed. In our case, our university has built its own platform based on office 365, which allows for stability and multiple functions. Use of the platform requires an investment in the form of time for learning about all the features but is rewarded through being able to use a variety of functions.

CONCLUSIONS

The purpose of this study was to investigate how different types of ICT-based self-study and examination practices can be implemented in courses on topics such as project management, product development, and entrepreneurship, and build a knowledge base necessary for future systematic implementation of digital examinations.

We have tested several digital approaches in our courses and our overall conclusion is that digital tools are beneficial in terms of increasing the level of activity among the students and for activities such as self-study and self-assessment, which make them highly relevant within a CDIO-based education.

Based on our experiences, we would like to conclude the following:

- Digital tools, such as quizzes, are an efficient way to raise the activity level and facilitate learning during teacher-led activities in the classroom
- Provision of online content such as MOOC-material for self-study or video lectures is beneficial in many ways but requires complementary activities that enhance interaction among students – especially for courses that are given entirely online
- A well-functioning and flexible digital platform is a prerequisite when using digital tools for self-study
- Campus-based courses can be improved by implementing features used in online courses
- Online tests with multiple choice questions seem to work both as examination tool (maybe not as a main tool though) and as a tool for self-studies.

To start with the first point, the use of digital tools such as quizzes during teacher-led classroom activities is beneficial not least since the ICT-tool can be used as an intermediate between the teacher and the students. During traditional seminars, students may feel exposed when answering questions and this can, in turn, imply that they prefer to keep quiet and thereby withhold answers or comments that they might have. This can work against their learning.

During fully digitalized lectures however, the teacher cannot interact with the student at the same type of instant level, which in turn makes the learning less efficient as the process becomes slow. This entails that for such circumstances, other strategies for the creation of interaction are needed, e.g. discussion boards with clear requirements on the level of engagement.

The second point, the online lectures are efficient by means of flexibility for both teacher and students, however the interaction with the students is a challenge as video lectures tend to be impersonal. The communication is also in one direction instead of being mutual. Some of these problems can be remedied by making the lectures more personal, through e.g. showing faces on the film, or adding discussion boards. It could also be solved by following up the video lectures in classroom activities such as teacher-led seminars. This model used in our entrepreneurship courses and in these cases the video lectures are part of a flipped classroom approach where the videos help the students to 'conceive' and the teacher-led workshops helps them to 'design' and 'implement'.

Regarding digital platforms for education, a well-functioning system is a prerequisite. Essential functions are communication interfaces such as information feeds that allow for communication between teachers and students and the ability to upload documents and hand in and mark exams in a convenient way. Video channels, possibility to create own pages, discussion fora, group rooms and so on are other features that enable e-learning. Having access to a good education platform entails that the pedagogic structure of online courses could be implemented also in the campus-based courses. This is beneficial as it gives the students opportunity to blended learning, which has shown to enhance learning.

Finally, online tests are an interesting area for further development. The experiences gathered have encouraged us to continue this work. From a teacher perspective, there is a learning threshold regarding how to design such tests, but when working they can give a good picture of the student's level of knowledge and they can save time as they are automatically corrected.

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A MODEL FOR RESEARCH/EDUCATION-INTERACTION
AT A DANISH UNIVERSITY COLLEGE

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ABSTRACT

Danish university colleges are currently making a transition from institutions with primary focus on education to institutions that incorporate applied research as well. As part of this change, university college programs are now required by legislation to provide research-based education. This article discusses various understandings of the term "research-based education" and provides a visual model to promote a clearer understanding of the various approaches that can be utilized to achieve research-based education. The approaches described in this article are intentionally pragmatic in nature as opposed to idealized, extolled and conceptual statements of intentions. The model is embedded in the context of a bachelor degree program for engineering and an engineering research program at a Danish university college. By utilizing this explicit case, it is intended that the model will provide greater practical value. The article concludes that multiple channels for providing research-based engineering education are available. The "right" choice or choices for an institution must be identified through a prioritization procedure. The final selection of approaches to provide research-based education depends on the organizational structure of the educational institution, the teaching/research staff identity and the student body. In addition, the selection of approaches depends on how many students are touched, the profoundness of the learning experience and the ease of implementation.

KEYWORDS

Research-based education, teaching-research nexus, University College, CDIO competences, CDIO syllabus, CDIO Standards: 2, 3, 4, 7 and 10

INTRODUCTION

Engineering education in Denmark

The Danish engineering education landscape consists of two players: Universities and University Colleges. A master's degree (typically 5-year duration) is offered at 4 of the 8 universities in Denmark, while a bachelor's degree (typically 3½-year duration) is offered at these same institutions as well as at 2 of the 8 University Colleges in Denmark. The institutions typically offer engineering degrees in several cities.

Through the decades, numerous changes in engineering education have taken place (Froyd, et al., 2012). For several decades, a few engineering programs in Denmark have applied a problem-based learning approach, specifically at Aalborg University and at VIA University College. Recently, several of the engineering programs in Denmark have embraced the CDIO initiative (Crawley, 2014). The CDIO approach aims to produce well-rounded engineers who understand how to Conceive, Design, Implement and Operate complex products, processes and systems. The main goals of CDIO are to educate students who 1) master deep knowledge of technical fundamentals, 2) lead innovative creation and operation and 3) understand the importance and impact of research and technological development on society.

Engineering research

Examples of practical engineering accomplishments such as the pyramids, aqueducts and the steam engine have been apparent throughout history. Engineering research at academic institutions as we know it today, however, was only developed in the 1900's. In addition to engineering research in academia, engineering research today may also be carried out by government agencies or by private businesses.

The OECD Frascatti manual (OECD, 2015) provides a general definition of the term research. The manual states "research and experimental development (R&D) comprise creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge". In addition, the manual states that the research must be novel, creative, uncertain, systematic, transferable and/or reproducible.

This definition - along with the five criteria – may seem daunting to the individual charged with carrying out the research. Nowhere in the Manual does it state that it is adequate for the research to be novel only to the researcher - or that the increase in the stock of knowledge may be related to the researcher's own stock of knowledge. This means that research, by definition, has a global perspective. Therefore, institutions or individuals attempting to carry out research without giving full attention to this challenging work are not likely to be successful. In other words, research cannot be simply a means to provide students with better education or provide staff with professional development opportunities but must have value unto itself.

The research/education-relationship

The relationship between research and education was strengthened in the early 1800s at German universities by combining both activities at the same institution. This change was led by the work of the philosopher Humboldt (Huet, 2018) and allows for a close relationship, often termed the teaching-research nexus (Neumann, 1996). Since its inception, however, the value of the research/education-relationship has been contested (Prince, et at., 2007) and it might be suggested that the relationship is of great value for certain courses and of no value for others.

Today, a requirement for providing so-called "research-based education" may be exemplified through national education regulations. Although Danish Universities have a long-standing research/education-relationship, a requirement for research-based education has only recently been imposed on the Danish University Colleges. In Denmark, the current executive order for university colleges (Ministry for Education and Research, 2018) states (translated from Danish):

"The degree programs at the university colleges must be based on research and development knowledge from relevant fields as well as knowledge of praxis in those locations at which the programs are aimed."

Legislation – and the literature in general – is often remiss, however, in specific definitions of the term research-based education and especially in describing methods for implementation of research-based education (Sørensen, et al., 2017).

A framework for understanding undergraduate research is shown in Figure 1 below (modified from Healey et al, 2014). Here, four categories of the relationship between students and research are identified. The figure emphasizes that students may become producers of knowledge and not just be consumers of knowledge.
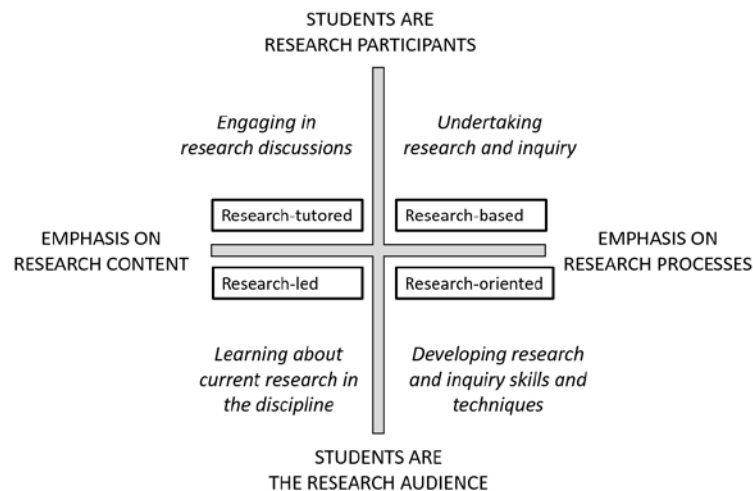
Figure 1. The nature of undergraduate research and inquiry
(modified from Healey et al., 2014)

The above figure classifies four ways in which students may interact with research. All four ways are valid and valuable and education should apply all of them (Healey et al., 2014).

The CDIO syllabus is a list of knowledge, skills, and attitudes desired of engineering graduates (Crawley et al., 2014). The syllabus embraces all four ways of students/research-interaction. Part 1 of the syllabus focusses mainly on research content, e.g. Part 1.2 (Core Engineering Fundamental Knowledge). To ensure the CDIO learning outcomes in Part 1, the left side of Figure 1 should be emphasized. Part 2 of the CDIO syllabus focusses on research processes and problems through learning outcomes regarding personal and professional skills and attitudes. Examples include Part 2.1 (Analytical Reasoning and Problem Solving - also called "engineering thinking") and Part 2.2 (Knowledge Discovery). At the third level of detail in the CDIO syllabus, other examples include Part 2.1.1 (Problem Identification and Formulation), Part 2.4.4 (Critical Thinking) and Part 2.2.1 (Hypothesis Formulation). These learning outcomes are ensured through an emphasis on activities placed at the right side of Figure 1.

Purpose

The purpose of this article is to develop a conceptual model for research-based education by understanding the various channels through which interaction between engineering education and engineering research can take place.

Method

This study develops a model for research-based education through a case. By utilizing an explicit case it is expected that the model will provide greater practical value. The VIA University College Engineering Department was chosen as the case because it is in a period of significant change with respect to research and because of the authors' intimate knowledge

of the Department. This article first describes several aspects of the Department. The aspects described are the institutional organization, the engineering programs offered, the identity of the staff and students as well as the engineering research and development activities. Then the article develops a conceptual model for research-based education seen from the point of view of a Danish University College Engineering Department. Finally, the article discusses research-based education in light of the model.

CASE STUDY – VIA ENGINEERING

Organization of the institution

To promote a good interaction between research and education in an educational institution, it is important to consider how the institution's organization affects this interaction. In general, research and education may be mixed together in departments in individual fields or they may be separated in two silos since excellence in research and didactic competences is not always found in the same individual staff member. Since the immediate goals of research and education are different, antagonism between these two parties can appear.

The term "interaction" is used frequently in this article. This is to emphasize that the quality of research, as well as the quality of the education, may be improved through close cooperation, rather than advantages flowing unidirectionally from the one party to the other. In other words, both parties can benefit.

At VIA University College, engineering research and engineering educational activities are organized in two silos, each with its own director with staff responsibilities. In this way, the dichotomy between researching and teaching is embraced rather than ignored.

VIA Engineering educational program

The Engineering Department at VIA University College includes seven different engineering disciplines; Global Business, Material Science, Civil, Software, Mechanical, Production and Climate & Supply. Most of these disciplines are provided in Danish as well as in English. There are approximately 1400 students and 110 teachers in the various VIA Engineering programs.

The teaching approach at VIA Engineering is entrenched in problem-based and project-based learning. Students learn through work on realistic engineering problems and projects in close cooperation with companies. Students learn engineering skills and competences through active participation in the classroom and there is a close relationship between the teachers and the students.

The teaching staff is dominated by staff without a PhD degree. In 2015, the University Colleges prepared an action plan with a goal of raising the number of teachers with PhD-degrees to 50%. The great majority of the professional staff are employed as full-time teachers and are not required to undertake research. The authors' experience suggests that this staff, in general, is dominated by an educator identity, with some occupational (practicing engineer) identity mixed in and with very little or no researcher identity. This means that staff identity is in alignment with the staff function.

The student body at VIA Engineering is composed of 62% international students. Some of the students come to VIA with a craftsman background, but the majority come with a high-school degree. Virtually all students can be assumed to have first-hand knowledge or special interest in knowledge of praxis. Since there is not a cut-off level for grades, any student with a high

school degree may be accepted. This results in a student body with a wide variety of academic competencies.

VIA Engineering research and development program

In 2017, the Engineering Department of VIA University College had approximately 11 staff (full-time equivalents) employed in research on 31 research and development projects with external financing. This resulted in 35 publications and 16 conference appearances. The efforts mentioned here were assisted by 3 PhD-students. No postdocs were involved.

The typical researcher in the Engineering Department uses 80% of his/her time doing research and 20% teaching. However, a small number of teachers used approximately 10% of their time doing research. The authors' experience suggests that this staff, in general, is dominated by a researcher identity.

The research group carries out applied research in the following focus areas: geothermal energy, geology and groundwater, climate solutions, drinking water, wastewater, corrosion and materials, circular economy, indoor climate and comfort, digital building and augmented/virtual reality. Due to the relatively small size of the research team, it is only able to engage in subject matter from one or two of the engineering disciplines. This means that many of the engineering disciplines are not supported by research in a directly relevant field.

A MODEL FOR RESEARCH/EDUCATION-INTERACTION

In the context of a University College, a conceptual model for visualizing potential interactions between engineering research and engineering education was developed. The model - shown in Figure 2 - shows research and educational activities as two separate silos, with different staff identities and different outcomes. Between the silos, various methods of interaction between the silos are illustrated as numbered arrows. Advantages and disadvantages of each of the numbered interactions are described below.
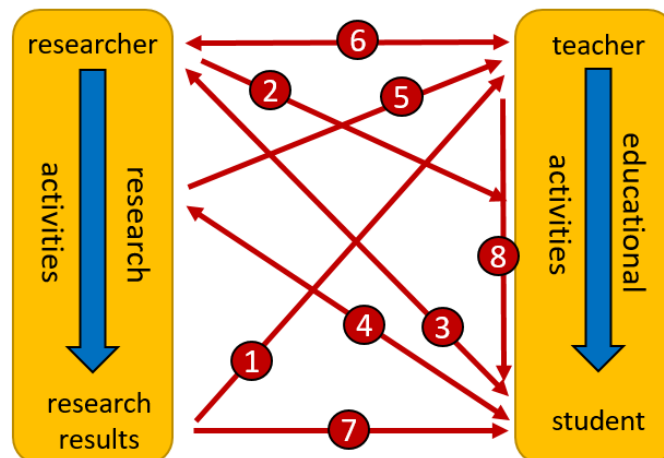

Figure 2. Conceptual model for research/education-interaction at VIA University College.

1. The product approach

A typical understanding of the role of research in education is that research contributes to education by producing results that are then fed into the educational system through the teacher (lower left quadrant of Figure 1). This product approach supports the CDIO syllabus by implementing learning aim 1.2 Core engineering fundamental knowledge.

Here, the research results that are utilized in educational activities include the results produced by the institution's own researchers as well as results drawn the global pool of engineering research. When considering the institution's own research results, this approach has a severe drawback in that the learning objectives for the student in terms of knowledge and skills are not in alignment with the research results. In general, the curriculum taught at engineering programs at University Colleges is broad-based and simplified, while research results are typically narrow in scope and highly complex. Therefore, this product approach may be referred to as the classical misunderstanding when referring to the institution's own research. The product approach is more suited when using the global pool of research. Here, the teacher must sift through the world's literature to identify parts that are relevant in scope and complexity.

2. Researcher-Teacher

At some instances, the active researcher may also be the teacher. This is an excellent way to impart a structured, inquiry-based scientific method to the students since the knowledge, skills and attitudes of the researcher can be "person-borne" to the students. This is one way to meet the CDIO aim of students gaining competences such as 2.1 Analytic reasoning and problem solving as well as 2.4.4 critical thinking.

At University Colleges in Denmark, the ratio of researchers to teachers is quite small, however, which creates a major challenge for this approach. As seen in Figure 3, the number of courses that can be taught by the active researchers at VIA Engineering is less than 1% of all engineering courses, even if the researchers spend 90% of their time teaching (which entails the risk of lower quality research) and carry a heavy teaching load of 20 ECTS points per semester. In addition, researchers are generally not qualified to teach in all engineering fields and can only support one or two of the most closely related engineering disciplines. It is not expected that the researcher/teacher ratio at VIA Engineering will increase drastically in the near future, as an increase would likely require increased governmental funding.
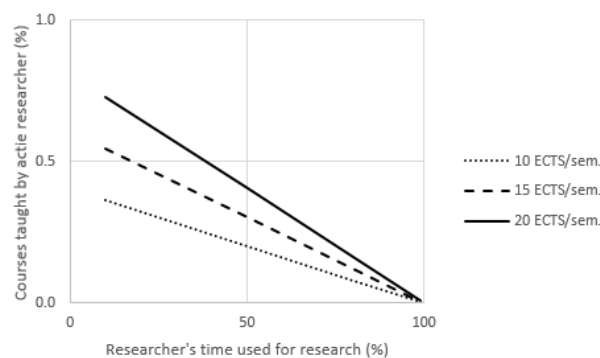

Figure 3. Potential for person-borne teaching by active researchers.

The typical teaching load of a VIA Engineering staff member using 80% of their time as a researcher is approximately one course every semester or one course every other semester. In addition, supervision of one or more semester projects may be included in the teaching load.

In some cases, the teacher does not have to be a researcher employed at the institution in question. For example, students may be invited to participate in a conference which includes platform presentations, posters and possibilities for the students to network with recognized researchers from outside the institution. This approach has been used with success at VIA Engineering and appears to produce a profound effect on the learning as well as the motivation of the participating students.

3. The Humboldtian Exchange

The research-education interaction is a two-way street in which the researchers, as well as the students, can benefit. The German philosopher Humboldt suggests that research and education should take place side-by-side – the so-called "Humboldtian model of higher education" (Andersen, 2004) in order to create opportunities for exchange of knowledge, skills and attitudes. Therefore, the interaction arrow in Figure 2 points in both direction.

In one direction, researchers benefit from the students. This is because students strive eagerly in all directions, as opposed to experienced researchers, who are more one-sided (Andersen, 2004). This keeps the researcher on his toes. In addition, students require researchers to deconstruct their research objectives and procedures and to sharpen their communicative skills. Even if only a small portion of the student body is in contact with a researcher, this contact can be an advantage to the researcher.

In the other direction, students gain insight into research processes through discussions with researchers. This supports students in the CDIO aim regarding engineering thinking and critical thinking competences. This approach also suffers from a scaling-up challenge. The student/researcher-ratio is naturally very large, reducing the breadth of the impact.

4. Student participation in research

In this approach to research-education interaction, the student takes an active role in the production of research results, either in connection with a course or as hired help. This closely resembles the "research-based" category of the research-student relationship defined by Healey (top right quadrant of Figure 1). It provides the student with valuable hands-on experience, changing the student from a receiver of research knowledge (audience) to a co-producer (participant). This approach supports many CDIO competences in terms of personal and professional skills and attributes. It develops the ability to identify problems, create problem formulations and hypotheses, undertake qualitative analysis, as well as to find solutions and recommendations. The advantage of students learning how to learn through inquiry is that this is a transferable skill and is a higher-order thinking at "extended abstract" level of SOLO taxonomy.

The success of student research depends highly on a creative environment where the students learn by inquiry. This is a process approach where the scientific way of thinking is in focus as opposed to a product approach where the research results for a specific subject matter is in focus.

Figure 2 shows that this approach has a double-headed arrow since the research carried out by the student has at least the potential to be an advantage to the research efforts of the researcher. At VIA Engineering, student research efforts have in several cases, for example, provided results which allowed the researcher to write a more qualified funding application.

This approach requires the existence of projects that are relevant to the student's field and work hours from a supervisor. The approach is often thought to be even more suitable for master's degree students than bachelor's degree students and is naturally the basis for research carried out by PhD students.

5. Teacher involvement in research

At University Colleges, teachers without research training may be included by the staff employed as active researchers in research activities. In this way, teachers gain insights that may be useful in their teaching activities in which research processes and problems are emphasized as already mentioned in approach 2.

Similar to the student research approach, hands-on research experience provides teachers with opportunities for participating in an inquiry-based learning environment, for becoming familiar with cutting-edge results, for practicing written communication skills, etc. For teaching staff to support the CDIO syllabus it is necessary for teachers to possess competences such as problem formulation and critical thinking themselves.

This approach of teacher involvement in research projects has the added advantage of providing cohesiveness between staff groups where research and education are organized in separate silos. This approach also helps researchers avoid the "ivory tower" syndrome and learn about the educational challenges facing teachers – and may even become inspired to write a needed textbook or the like.

6. Cooperative dialogue

In instances where the teacher and the researcher are two different people, opportunities for dialogue are provided by working together on common projects outside of the field of research. Examples of such cooperation that the authors have been involved in at VIA Engineering include designing new courses, preparing guidelines for student project work and testing various didactic methods. Each party can learn from the other, creating a win-win situation. This approach is relevant for developing interpersonal skills such as teamwork and communication in the CDIO syllabus. It is easier to support these competences among students if the teaching staff also possess these competences. A challenge for this method is aligning scheduling demands between the researcher's project and the teacher's educational activities.

In addition to formal cooperation, informal meetings between the teacher and the researcher can provide mutual inspiration. For example, one of the authors recently experienced that a teacher identified a potential solution to a troubling research problem during a 15-minute discussion over lunch. A physical framework that encourages informal meetings (such as a common area for coffee breaks) is therefore seen as an advantage.

7. Student literature searches

The student does not need to be limited by the researcher and teachers at the local educational institution but may use search engines to search the literature from the entire world for relevant research results. This approach suggests that engineering educations should be built on disciplinary knowledge and reasoning. The fact that students have access to worldwide research makes this approach possible to be used by all students. The CDIO syllabus emphasizes the importance of engineering students of critical thinking and prioritizing among endless amounts of research.

8. Teacher development

Due to the low active researcher - teacher ratio at VIA Engineering, it is essential to have a teaching staff with some level of research competences, even though they do not carry out research in their daily work. To support students with competences as stated in the CDIO syllabus, such competencies such as critical thinking, problem identification and problem formulation, should be possessed by the teachers.

As teachers are often hired directly from an engineering profession, they might not always possess these competences. Consequently, it is essential to build up these competences through supplementary education and opportunities to participate or get insight into research projects driven by the research department.

DISCUSSION AND CONCLUSIONS

As seen in the model in Figure 2, research and education can interact through multiple approaches. In practice, the interaction may also be a mix of above-mentioned approaches. To be of value, these approaches must be prioritized, and selected approaches must be implemented. Which approaches should be prioritized depends highly on the individual institution, including its organization and the identity of the staff and the student body.

In Figure 4, the various approaches in research-education interaction model are subjectively rated as highly suitable (green), partially suitable (yellow) and less suitable (red) for the three parameters, breadth, depth and ease of implementation. Impact breadth is a measure of how many students at the educational institution are likely to participate in the approach. Impact depth is a measure of how profoundly the students are affected, i.e. how much the students learn through participating in the approach. Finally, ease of implementation reflects the cost and effort required to operationalize the approach. It should be noted that additional parameters could be rated to assist in the prioritization of the different approaches.

	Approach	Impact breadth	Impact depth	Ease of implementation
1a	The product approach, local	red	green	red
1b	The product approach, global	green	yellow	yellow
2	Researcher-teacher	red	green	green
3a	The Humboldt exchange, researcher	green	green	yellow
3b	The Humboldt exchange, student	red	green	yellow
4	Student participation in research	red	green	yellow
5	Teacher involvement	red	yellow	yellow
6	Cooperative dialog, teachers & researchers	yellow	yellow	yellow
7	Student literature searches	green	yellow	green
8	Teacher development	green	yellow	yellow

Figure 4. Characteristics of the various approaches for research-based education.

It appears that none of the listed approaches has a perfect score of three green parameters. Each approach is unique with respect to impact breadth, impact depth and ease of implementation. It does, however, appear that obtaining an acceptable impact breadth is especially challenging. In this situation, it would seem appropriate to test multiple approaches.

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A NEW ADAPTIVE E-LEARNING CONCEPT FOR MULTIDISCIPLINARY LEARNING ENVIRONMENTS

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ABSTRACT

Engineering is a broad multidisciplinary discipline, also reflected in the increase of the variety of students in a single academic course in terms of foreknowledge and of interests and skills. Adaptive learning is a powerful tool to achieve tailored education in a multidisciplinary learning environment. Students with a diverse background and even with different levels can work together in a similar learning environment. Without the support of e-learning concepts and online tools, this method is however very time consuming and ineffective for the lecturer.
E-learning modules are typically passive, not directly guiding the students. The new concept presented here, actively helps the student to develop their own learning route, based on their needs and interest, yet meeting the course's learning objectives. The overall concept is based on a plenary core set of lectures embedded in a flexible shell of adaptive e-learning modules. These modules are cross-linked allowing the student to step from one topic branch to another, depending on the need or interest identified by a brief end-of-module assessment and earlier information collected by the system.
A basic version of the web-based application to guide students through the network of e-learning modules is tested and showed positive results in terms of student appreciation yet not directly in terms of performance. The latter is the most relevant from a didactic point of view, while the success of the concept heavily relies on positive student appreciation. The outcome of these first test used as input for the development of the final application.

KEYWORDS

Adaptive Learning, Multidisciplinary, Blended learning, Engineering, Web-based tool, ICT, Standards: 1, 5, 8.

INTRODUCTION

The ever-changing and developing society constantly requires professions that did not exist twenty years ago. Students have to become professionals capable of steering their own career development and capable of controlling their own learning process, now and in their future profession. Multidisciplinarity is a relevant key challenge in the Science, Technology, Engineering and Mathematics (STEM) disciplines. The multidisciplinary character answers to the needs of the industry: multidisciplinary engineers are demanded to solve the challenges the industry currently and in the future faces. These challenges range from design to end-of-life related, and from highly technical to – for example – more logistic problems.

Multilevel education is relevant as well: students enter courses or educational programs with different levels of foreknowledge and intended or required output level. The term multilevel broadens the "Personalized Learning" concept by including a variation in student foreknowledge level, e.g. MSc, Post-MSc and PhD.

These two elements are in particular relevant for the Mechanical Engineering master specialization Maintenance Engineering and Operations (MEO), offered by the faculty of Engineering Technology (ET) of the University of Twente (UT). MEO crosses borders between departments in and even between faculties: the research group Industrial Engineering and Business Information Systems (IEBIS) of the Behavioural, Management and Social science (BMS) faculty, also contributes to the track.

The influx of students in the MEO courses exhibits a high diversity: they are following a master track in Mechanical Engineering (ME), Industrial Design Engineering (IDE) or Industrial Engineering (IE), have a BSc degree in one of these directions or in Advanced Technology (AT) or Electrical Engineering (EE). In addition, an increase in influx from post-master students (PD-Eng – a 2 year post-MSc program – and PhD) is observed, requiring flexibility in the exit level. New educational methods are deemed necessary to accommodate all this.

The key challenge is how to offer a flexible program, allowing students to make choices (Personalized Learning or Student Centred Learning (Richmond, 2014)), yet also to guide them through the selection process, while assuring the learning goals of the course are met. None of the currently existing educational models meets these requirements, thus a research project is initiated. Its objective is to adjust and morph existing techniques, combining and integrate them with state of the art supportive techniques, such as offered by ICT.

The novel concept is based on a blend of plenary lectures, a flexible shell of adaptive e-learning modules and an interactive guidance and selection tool. Using adaptive e-learning modules is recognized as a powerful tool to overcome the challenges identified (Kamardeen, 2014, Marković, Jovanović, Jovanović, Jevremović, & Popović, 2013). The students have the possibility to compose their own, individual program of learning modules, satisfying both their needs and interest. Shifting responsibilities in the learning process to students, leading to a more active engagement of the students, is shown by Freeman et al. (2014) to have a positive effect in particular in STEM disciplines. The students should, however, be guided in their selection, recognizing what is relevant to them. Boelens, De Wever, & Voet (2017) point out that self-regulation is necessary, yet for some students, difficult skill. Although online lectures, e-learning and e-teaching methods, both static and adaptive have been implemented (Kamardeen, 2014, Marković et al., 2013), the extent to which they are blended with plenary lectures is limited (Boelens et al., 2017). Modules are implemented as separate entities of the course, while a strong linking between the modules is envisioned here.

The navigation through the network of e-learning modules requires:

- a well-defined structure relying on a decision tree (Song, Singleton, Hill, & Koh 2004);
- input based on the student's selection of modules and on the student's level of understanding of those modules. This information can be acquired prior to following an e-learning module, or in an adaptive way during participation in a module. Learning analytics is an important means (Jovanović, Gašević, Dawson, Pardo, & Mirriahi 2017);
- the incorporation of feedback mechanisms, to inform students and lecturers on the performance and to inform the students on the suggestions for other modules to follow. The feedback currently greatly depends on the lecturer's skills and available time to answer to questions in fora on applications such as Blackboard (Rovai & Jordan, 2004).

The novelty of the proposed blended learning concept is the supporting guiding system for the students to navigate through and select modules. This sets the method apart from the more standard application, based on a series of not interconnected (micro-)lectures and no or limited feedback, let alone guidance. As the first step in this research, a network of learning modules is built, including guidance and basic feedback for the students, for the first year BSc course Statics of the Mechanical Engineering and Industrial Design Engineering programs of the University of Twente. The learning modules were provided to the students who failed the first test and were preparing for the re-take. The objective of is to investigate the appreciation of the students of the concept and the effect in terms of understanding of the course topics. The results are evaluated by individual feedback of the students on the use and usefulness of the basic adaptive learning tool developed and by examination of the exam results. The results will be used as input for further development and implementation of the tool.

THE ADAPTIVE BLENDED LEARNING TOOL

Adopted Methodology for creating the Tool

The Tool has been created using three main methodological steps. Firstly, following Cloutier, Hugo & Sellens (2011), the core Intended Learning Outcomes (ILO) were identified. The ILOs represent the backbone of the proposed method. However, the additional (sub-)ILOs that are defined (see Figure 1), are not considered optional but may be met at a certain, pre-specified minimum level. Here, a distinction can be made between multidisciplinary courses, for which the concept is initially developed, and mono-disciplinary courses, see also Table 1. In a multidisciplinary course, a basic level of knowledge is expected in all fields, while specialization in a certain direction requires the student to master ILOs of that discipline. The additional ILOs for the mono-disciplinary courses are more supportive of reaching the core ILOs. The objective is to enhance the fundamental knowledge of a specific topic by providing more learning material.

Secondly, the different levels of lecturing in relations with the ILOs were analysed. The core level ILOs are lectured in a more direct way, with the minimum distance between student and lecturer, while the ILOs of the other levels are taught in a more distant manner through video lectures and/or pen-casts or similar options.

Finally, the tool was evaluated with the support of questionnaires for mainly investigating general perception, general use, level of difficulty of the questions, instruction videos, learning effect and appreciation.

Structure of the Tool

The tools are based on the ILOs that students need to acquire: topics that are mastered by the student do not need to be followed. The underlying mechanisms to guide the students through the network (Figure 1) are very similar for the mono- and multidisciplinary versions. Logical, conditional statements are used to guide the students. Such a conditional statement can, for example, be either "if you are interested in discipline X, then you may also be interested in discipline Y" or "If you do not understand topic X, then you may also not understand topic Y", in case of a multidisciplinary or mono-disciplinary course respectively.

It is therefore of utmost importance to define the ILOs both accurately and in a hierarchical way. It is important to recognize that some disciplines or topics are more important to master completely than others. Consultation with colleague lecturers of the same or linked master specializations (e.g. MEO) or learning lines (e.g. Mechanics or Mathematics) is strongly advised if not essential.

For the course of Structural Health and Condition Monitoring, it is evident that the students must have a fundamental understanding of the concept of monitoring. On the other hand, the way the monitoring is executed, the algorithms are used, the sensors are used, are all in the domain of (sub) specialization. For the mono-disciplinary courses, it is important to identify from which concepts a fundamental understanding is essential. Making a Free Body Diagram (FBD) is an essential starting point. Making one of a composed structure, or from a section of the structure are less general examples. Some students will need more support before they are able to apply the general concept of making an FBD to these more specific cases.
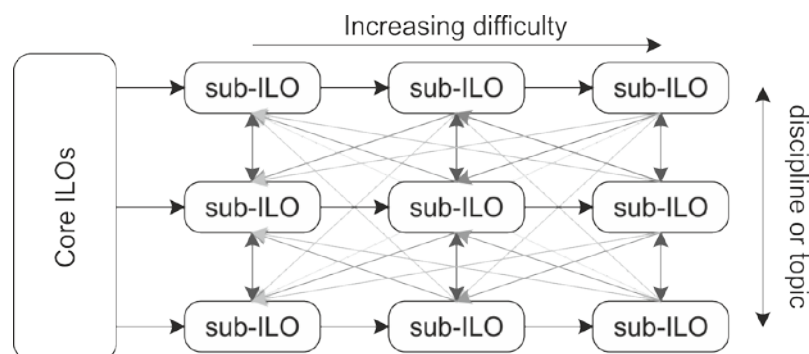
Figure 1. Network of core and related sub ILOs. Horizontal lines: modules treating a certain discipline or topic. Students are guided over the network (arrows).

Table 1. The differences in modules for multidisciplinary and mono-disciplinary courses.

ILO	Multidisciplinary	Mono-disciplinary
Core	General knowledge and insights related to the course content, overarching various disciplines.	Basic knowledge of the course, as a bare minimum, sufficient for above average student to meet the ILOs
Sub	Specializations in different disciplines, partly elective.	Topics addressed in more detail and with increasing complexity or completeness.
	Student must reach a preset minimum level in each discipline, depending on the required output level.	Student follows as many levels as necessary to gain sufficient understanding of the topic to meet the ILOs
	Student must reach a preset minimum level in the direction of specialization.	

This blended form is deemed necessary to optimize the effectiveness of the learning process (Asarta & Schmidt, 2017). This effectiveness includes student appreciation, as a higher appreciation results in a higher commitment of the students and an increased effort by them (Padhi, Rajasekhara Babu, Jha, & Joshi, 2019). This also stimulates peer review; giving, receiving and processing feedback from peers is a valuable learning mechanism (Boud, Cohen, & Sampson, 2014).

The layers with the sub-ILOs are typically organized in an e-learning setting, using e.g. video lectures and pen-casts. This provides the necessary flexibility for the students, as well as guidance in their choices (Boelens et al., 2017). The challenging aspect is to identify the needs of the student, without the direct interaction of the lecturer. In a passive mode, the students provide information on their foreknowledge. Active methods involve queries that the students must make.

In the particular example discussed in this paper, the background of the students is known in a more or less passive way: the students using the adaptive learning tool all failed the first test and are preparing for a re-take. This is still a diverse group, but in general, their knowledge level and skills are below average. Typically, the averaged mark and pass rate, as well as the highest mark are lower than that of the first exam.

Development of the Tool

The basic adaptive blended learning tool is developed for the course Statics, a first year, first term course of the BSc programs of Mechanical Engineering (ME) and Industrial Design Engineering (IDE) at the University of Twente. The students of the two programs follow the same course, be it lectured at different hours during the week and by different lectures. However, all materials (book, exercises, lectures slides) are the same. The written exam is also the same for both groups and made jointly by the lecturers. The part of the lectures can be considered as the core of the course (see Figure 2).
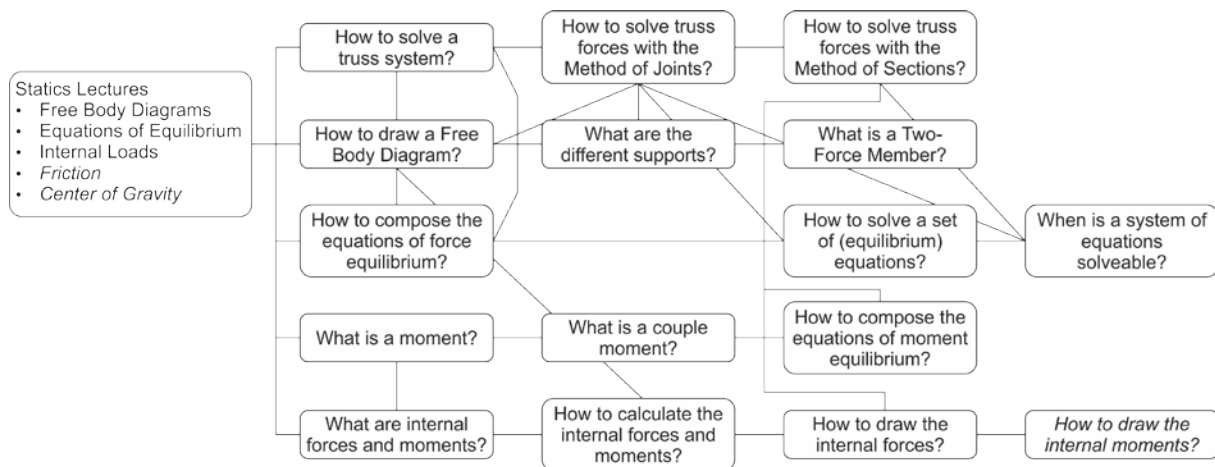
Figure 2. Learning modules (pen-casts) for the course Statics. The lines indicate the connections between the different modules. The italic parts are not yet developed.

The first exam was taken as a starting point (which is why there is a module on solving truss systems), as the prime focus of the tool was to prepare the students for the exam. This does not imply that only exam questions are treated in the tool, but it rather makes it a top-down than a bottom-up approach: the questions of the exam are used to highlight and clarify the general concepts of Statics. A pen-cast is made for each topic, using an iPad and the software Explain Everything. These pen-casts are subsequently stored as a video file (mp4) and uploaded to Vimeo. The settings are set such that only someone with a direct link can find the video.

A pdf document is made with a series of multiple choice questions. In some cases, the student is asked to first watch an instruction video (external link to a pencast uploaded to Vimeo), but in the majority of cases, the student has to answer the test questions immediately. The student can then view the answer (internal link in the document) and compare it to the answer given. These answers provide brief information about why a certain answer is either correct or wrong and suggest specific instruction videos (external link to Vimeo location). The structure is visualized in Figure 3.

The given structure requires a thorough design of the questions: specific errors must be implemented, without making the answer very obvious. One option is to base the errors on the errors students make during the written exam. The idea is that the students will make the same mistake here, even though the correct answer is also listed. A construction in which this works quite effectively is to ask the student to e.g. sketch a so-called Free Body Diagram (FBD) of a certain structure. Then, the students are asked to compare their answer to a set of FBDs and the conditional logic starts: "If your FBD corresponds best with answer *X*, then [feedback *Y* is given] and it is advised to watch instruction video *Z*". In some cases, multiple instruction videos can be advised, although it is best to keep this number limited.
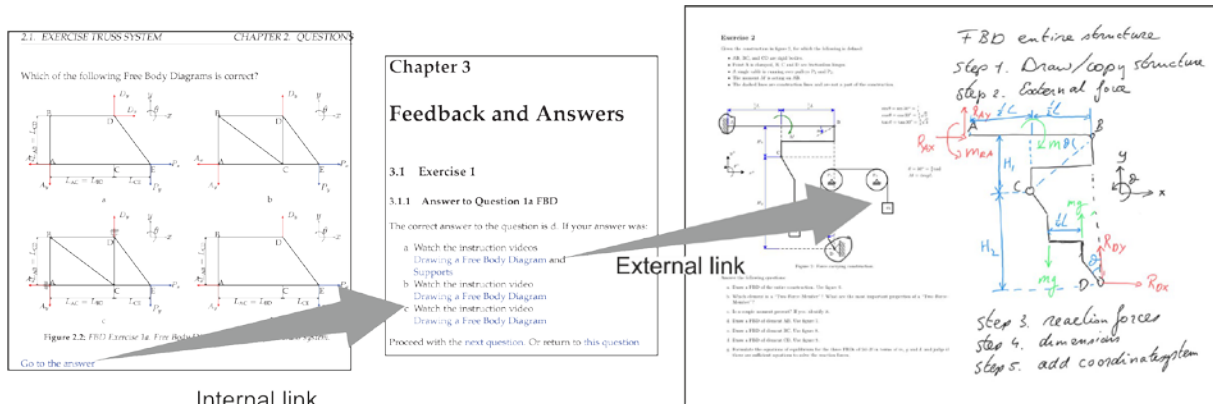
Figure 3. Document structure from question via an internal link to the answers and via an external link to a pencast (mp4 uploaded to Vimeo).

Another form that is used is a list of statements from which more than one is correct. Again, the questions should be formulated carefully. Some questions are deliberately very much alike, such that the student must really know what is true and what is not true. Alternatively, a statement is repeated later in the list, with a different formulation, to check the consistency of the answers of the student. An example of a list of questions, on the properties of a truss system and the analysis of these systems, is:

"Which of the following statements is true (multiple answers possible)
   a. One can choose the direction of the forces in the trusses arbitrarily.
   b. A truss system consists of Two Force Members only.
   c. A truss system consists of Two Force Members only, apart from the elements that are connected to supports.
   d. The method of joints is easier than the method of sections.
   e. The method of sections can only be used if the forces in a limited number of trusses is asked.
   f. An arbitrary number of trusses can be cut to create sections.
   g. The method of joints does not require moment equilibrium.
   h. A single coordinate system must be used for all FBDs when using the method of joints.
   i. Each force in a truss is a vector, hence there are two unknowns: the two components of the two orthogonal directions *x* and *y*."

Statements b and c are very similar and test the details of the knowledge of the students. Both statements g and i link to statement b, as they are consequences of the truss consisting of so-called Two Force Members. Answering these questions wrongly, indicates the students have an insufficient overview of the consequences of certain principles in the theory. For example, if they did not include answer g as a correct answer, then they are advised to follow the instruction video on what a moment is, but in addition to the instruction video on Two Force Members, as it is addressed there why no moment equilibrium is required.

The entire process requires some discipline from the students. To stimulate correct use of the document, it starts with an instruction, not only explaining how the document works, but also how it should be and should *not* be used.

RESULTS AND DISCUSSION

A Google form-based questionnaire was sent to the students, to investigate their experience with the tool and the effectiveness of it. Unfortunately, the number of respondents is low (11 out of 114), which is a common problem with digitally sent questionnaires. Students receive a large number of questionnaires, making them less willing to complete yet another one. As said, the questions were organized in different categories: General perception; general use, level of difficulty of the questions, instruction videos, learning effect and appreciation. These questions had to be rated (5 levels, from fully disagree to fully agree). Two open questions were added ("What aspects of the ABL tool were most useful or valuable?" and "How would you like to see the ABL tool to be improved?"), followed by an overall rating of the tool (score 1-10), an field for additional comments and additional, optional, information regarding the study program they follow and gender. The results are graphically represented by the radar plot in Figure 4, showing each category with a different background colour. The squares indicate the mean score for each question, while the size of the grey circles indicates the frequency of each score for each question.

All respondents were positive about the document and in particular the instruction videos. This last point is not entirely unexpected, as long and extensive instruction videos were already made, explaining how to answer the questions of a previous exam. These videos were well received and multiple requests for making more of these videos were received by the author. Extensive, written documents are also available for the students, explaining the answers to the exam questions in virtually as much detail. Key elements explaining the appreciation of the students for the pen-casts are the more dynamic and visual explanation compared to the static text, the possibility to pause and rewind the pen-cast and explicit visualization of how an answer is built up. These aspects are all included in the pen-casts of the adaptive blended learning tool.

The one low score in this category was for the question "Jumping back and forth in the document and to the videos is disturbing". A pdf with internal and external links is a rather basic form of an e-learning application, not particularly optimized for user-friendliness. According to Song et al. (2004), this is a key element in the student appreciation of an e-learning application, hence it is positive that the score is low in this question.
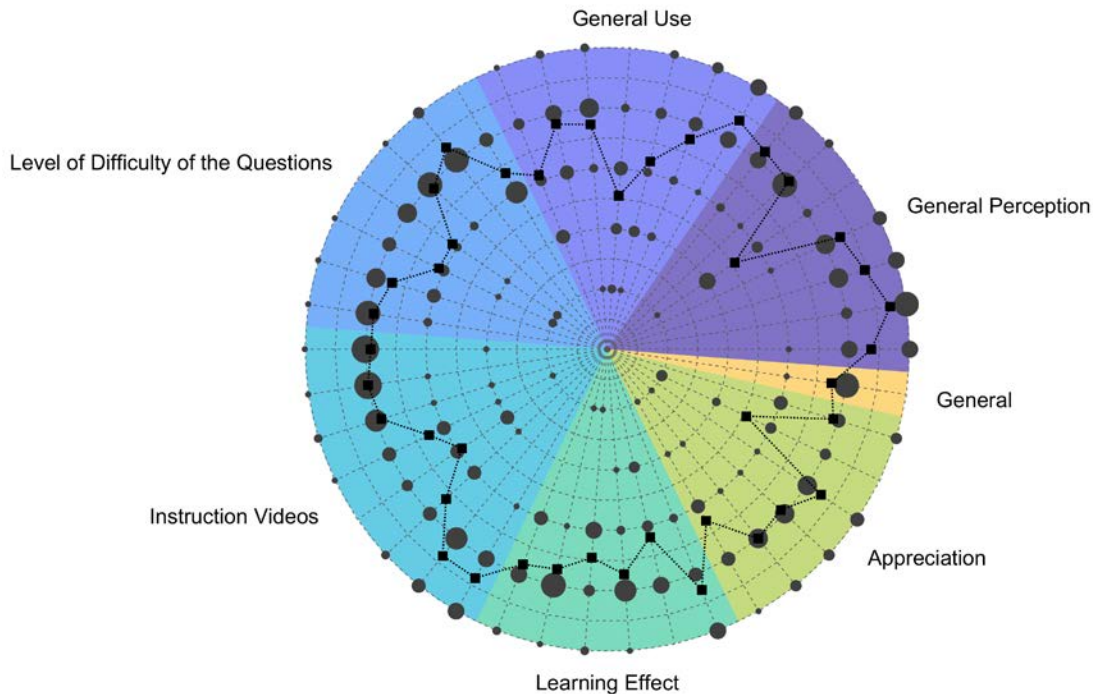
Figure 4. Radar plot of questionnaire results. The black squares indicate the mean, the size of the grey circle the number of times that score was given while the colours refer to the different categories of questions.

More variation and a lower score were observed for the questions in the category "general use" on reviewing videos. This kind of repetition can be useful, but a good score for skipping suggested videos if the student already mastered that topic hints to effective use of the tool: study time is spent on the topics the student do not master well.

The level of difficulty and the quality of the videos were both awarded with high scores, indicating a good level was found for teaching the course theory. However, lower scores are given for the questions relating the problem presented and discussed in the tool and the exam questions: students indicate that a better match with the exam questions would have been better and that the tool did not prepare them for the exam. At the same time, most respondents indicate they had the feeling their understanding of the course content was increased by using the tool. In a one-to-one setting with some of these students, the author noticed that indeed the level of understanding was significantly better than the mark for the first exam suggested, although it was not reflected in the mark for the re-take. This is partly attributed to the fact this exam was prepared by the ME lecturer of the course, who is new to educating first year students. The formulation of the exercises and balance of the test was different and consequently, the results are not a good measure for the effect of the adaptive tool on the performance. However, it did reveal that there is a gap between the student's perception of understanding and their actual understanding.

The underlying mechanism here may be the predominantly qualitative learning environment of the students. Starting at primary school, students are graded and the limit mark for passing becomes a target by itself while understanding the concepts of a course is less important (Yorke, 2003, Gikandi, Morrow, & Davis, 2011). In response to the issues with the re-take, oral

exams with some IDE students were scheduled. These oral exams showed a reasonable to good understanding of the students, but a limited ability to apply the knowledge in a more general way. This indicates a gap exists between possessing and applying knowledge. Formative assessment is an important concept to change the student's attitude and it is recommended to explore the possibilities to embed this in the tool to steer the students towards fundamental understanding and improve their ability to apply their knowledge.

Overall, the respondents mark the course highly (7.5 out of 10 on average). This is a clear sign that the method of learning is well appreciated, which is also confirmed by the scores in the appreciation category. The lower score is for the question of whether this tool can replace lectures. Together with the high score for the question whether the course can equally well be studied by using the written material, indicates that the students consider it an addition, which is in line with the intentions of the tool: it is complementary to the lectures.

It was suggested in the open comment section that open questions would be better than multiple choice questions. The choice for multiple choice was forced given the technical constraints and time limitations faced during the development of the tool. The fact that the correct answer is given, be it amidst incorrect answers, does allow for recognition rather than deduction or derivation of the answer. This can be mitigated by using multiple choice questions in a smart way. Some questions were shaped such that the student first had to answer a question (e.g. sketch an FBD), which is the nearest to an open question that the tool got. The right attitude is required from the student. It is therefore recommended to investigate how the adaptive learning tool was used to fully assess its effect on the output level of the students.

CONCLUSIONS AND FUTURE OUTLOOK

The following can be concluded:
- Students appreciate the concept of being guided to elements of the theory they understand less, giving them a feeling of better understanding;
- For this case, the students' perception of their level of understanding does not match their general level of understanding, while the tool aims to stimulate the latter;
- Multiple choice questions may allow for recognition rather than deduction and derivation, implying proper attention to the development of the questions is paramount.

The results obtained here will be further used in the tool to be developed. The next steps include the following aspects:
- Professionalization of the recording of the pen-casts
- Exploration of the use of formative assessment to stimulate general understanding;
- Exploring the possibilities to enrich the way questions are asked, to mitigate the possibility of answer recognition;
- Embedding of the tool in the digital learning environment;
- Implement the tool in a course.

ACKNOWLEDGEMENTS

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PROJECT-BASED LEARNING APPROACH IN A COLLABORATION BETWEEN ACADEMIA AND INDUSTRY

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ABSTRACT

The traditional disciplinary academic environment and learning practices do not provide a rich enough environment for deep learning of software development practices. Thus, to provide a richer learning environment, in the 2015/2016 school year, an interdisciplinary project-based learning (PBL) pilot approach was introduced where all the courses of the same semester focus on a complex software project provided by a software house. This paper describes the motivation, the concept and presents some qualitative results.

KEYWORDS

CDIO, PBL, Deep Learning, Standards: 3, 5, 7, 8, 9, 11.

INTRODUCTION

Market requirements for Software Engineering (SE) graduates have been changing at a very fast pace. One of the reasons for such is due to SE being a relatively young subject. In fact, many ICT programs pay little attention to the industrial software development best practices, focusing instead on programming languages, algorithms and trendy subjects like, for instance, Artificial Intelligence. Yet, the software is pervasive in modern society and there is a huge demand for software industry professionals, *i.e.,* Software Engineers. In this respect, Europe alone is demanding hundreds of thousands (Hüsing, 2015) of such professionals. Like any other engineering subject, learning SE requires some practice in a real or simulated environment. CDIO is a natural choice for the design, implementation and operation of a SE program.

The Informatics Engineering programs at Instituto Superior de Engenharia do Porto (ISEP) have over 10 years' experience in the application of CDIO. Both the Bologna 1st cycle (LEI) and the master (2nd cycle) have an EUR-ACE accreditation. Moreover, the master was also accredited by ABET in 2017 and both are highly regarded programs by the industry. LEI is the

largest Computer Science / Informatics Engineering program in Portugal with over 200 graduates per year, which are sought after by both national and international companies.

Even so, LEI's program management recognized that the traditional academic environment and learning practices do not provide a rich enough environment for deep learning of SE practices. Following CDIO standard 5, LEI has a 4-week long design-implement course in each semester, providing students with a short team-based product/system-oriented development experiences designed and operated by faculty. Moreover, an iterative approach is used, as it is now common in the industry, but the short time-span doesn't allow for more than 2 or 3 iterations with limited scope. It's too short, too fast, so that it doesn't foster reflective observation the way it should. It was evident that some of the outcomes were not going further than the "apply" level (Bloom level 3).

It would be interesting to provide a learning environment where the students could face the kind of requirements they face in professional practice and, very important, that they had the opportunity (time) to face and learn with the consequences of their choices. Thus, to provide this richer learning environment, in the 2015/2016 school year, an interdisciplinary project-based learning (PBL) pilot approach was introduced where all the courses of the same semester rely on a single complex software project provided by a software house. All students' activities and assessment should be in the scope of the development of this project. Internally, this pilot is called CDIO Integrated Learning (CDIO-IL).

CONTEXT

In order to better understand the motivation behind the CDIO-IL approach, it is important to introduce the reader to the professional software development area, which is a fairly new branch of engineering. Until the 70s, computers were very expensive centralized machines with limited capacity. They were used in science and in big business to solve specific tasks so that the number of professionals programming computers was small and many of them had another background (e.g. Math, Engineering, Business).

During the seventies and eighties, there was a boom in cheap computing, especially with the introduction of IBM PC clones running MS-DOS. For the first time, millions of PCs were produced yearly and introduced to small businesses and home users. The need for software developers rose accordingly, resulting in the worldwide creation of specialized higher education programs with names such as Computer Science (CS) and Computer Engineering (ACM, 2019). Later, Software Engineering. Even so, computers were mostly disconnected from each other or connected only in local networks. Software was composed of large standalone applications that were commonly distributed in a physical form. Cooperative software development was managed as a centralized hierarchical activity. As such, higher education programs focused on standalone applications programming and individual programming practices.

The advent of the commercial Internet and the World Wide Web in the nineties, changed the way how software is developed and distributed and how computers are used, i.e. connected. Almost all software is made collaboratively by teams, many of them encompassing different continents. Software also becomes increasingly interdependent, i.e. relying on services provided by other software to achieve its mission. The centralized hierarchical approach no longer can be applied in such a distributed and decentralized environment in continuous evolution. The weekly build no longer applies.

One current trend in software development is Continuous Integration that Fowler (2006) defines as "[…] a software development practice where members of a team integrate their work frequently, usually each person integrates at least daily - leading to multiple integrations per day. Each integration is verified by an automated build (including tests) to detect integration errors as quickly as possible".

This kind of environment requires software developers to have good "classical" design and programming skills, but also requires them to have practice in coordinating development with other team elements. "Competence" and "practice" are the key success elements here, as this agile development methodology is not viable without those throughout the whole team. To stress this, one well known agile methodology is actually named "scrum" (Suntherland, 2014) after the scrummage in rugby, which requires the cooperation of all players.

Higher education programs in the computing area must prepare the students to work in this collaborative/cooperative, complex and demanding environment. IT engineering programs can gain a lot from adopting the CDIO framework (Costa et al., 2012), as it goes much further than pure technical requirements and promotes a much broader view of the engineering world's requirements (e.g. sections 3 and 4 of the CDIO Syllabus). Furthermore, in IT programs it is easier to fully implement the CDIO framework, as software development doesn't have the same physical, time and cost limitations than other engineering subjects (Martins et al., 2013).

Edström & Kolmos (2012) present an introduction to PBL and CDIO, comparing the two approaches and concluding that "[…] CDIO and PBL can be productively combined. There is no need to make a choice between the two approaches, for an institution that plans to create an innovative engineering curriculum equipping the graduates for engineering practice, problem solving and innovation." Furthermore, the authors state that PBL can be particularly useful in the CDIO design-implement courses.

Design-implement courses in LEI

LEI is a Bologna 1st cycle program with 6 semesters, being the last semester mostly dedicated to the capstone project/internship (18 ECTS). The first 5 semesters have 16 weeks of classes: 12 weeks for traditional disciplinary courses and 4 for a design-build course (LAPR1 to LAPR5). At the end of each semester, there are 4 weeks exclusively for projects assessment and exams. The structure was adopted in 2007 and was inspired in a computing program at DTU (Denmark).

LEI is structured in two learning processes:
- Software Engineering, aiming at providing software development skills (Figure 1);
- Networks and computer systems.

The LAPR2 to LAPR5 design-build courses aim at introducing and practicing the continuous integration (CI) methodology and teamwork using an iterative and incremental approach. The technical requirements of the projects are fully aligned with the disciplinary subjects learned during the first 12 weeks of the semester. These courses are a key component of LEI, as they allow students to practice and enhance their skills in larger projects. Nevertheless, we believe that 4 weeks is too short to fully simulate an agile/iterative development approach. Also, in such a short period it is not possible to fully explore real-life conditions like evolving architecture, evolving requirements, etc. Based on this, the LEI's program management team decide to explore the possibility of the LAPR courses to become a semester-long complex projects

strongly interwind with the semester's disciplinary courses, i.e. a "mix of Aalborg style PBL and CDIO disciplinary approach" (Edström & Kolmos, 2012). This possibility is described in the remaining paper.
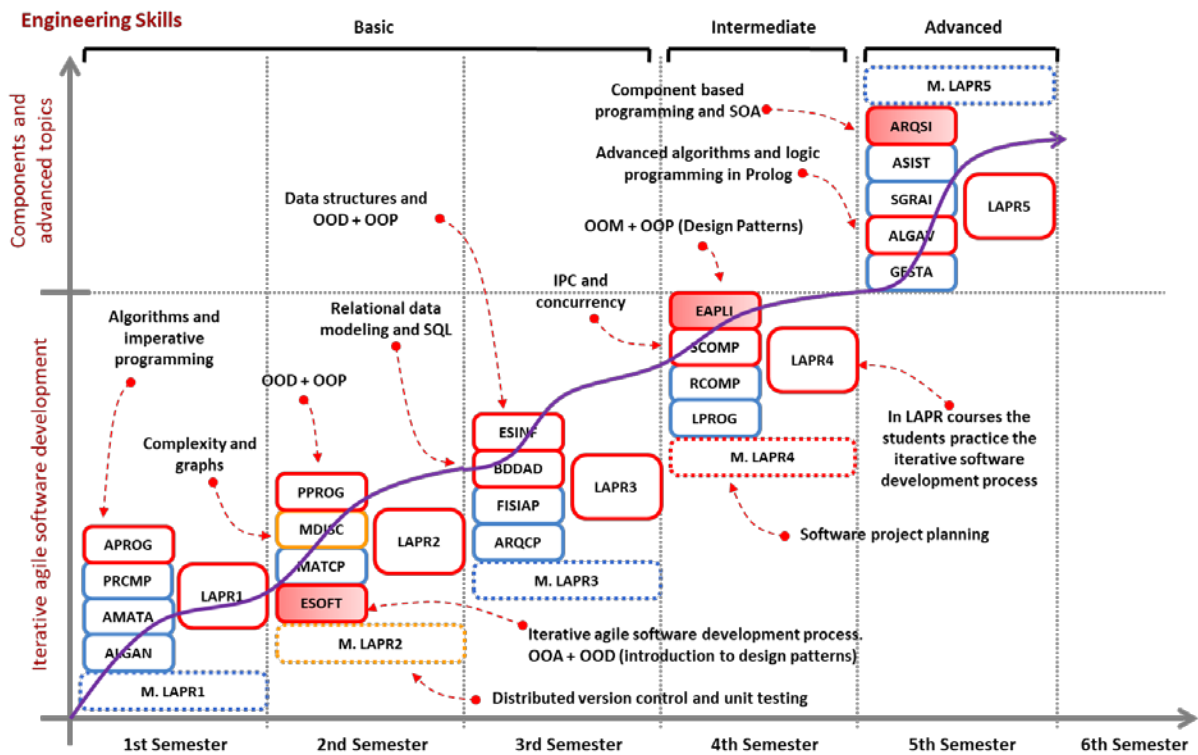

Figure 1 – Software Engineering learning process

DESIGN CONSIDERATIONS OF THE CDIO INTEGRATED LEARNING APPROACH

The introduction of the so-called CDIO Integrated Learning (CDIO-IL) approach aimed at providing students with a richer learning environment without a major structural change to the program. LEI has no elective courses, but students may choose to enroll in fewer courses than they are allowed, thus taking more time to graduate. The strong coupling between assignments from all courses of the semester makes this approach ill-suited for students that are not enrolled in all these courses. Also, there is a sizable number of students that have failed one or two courses, so that they are enrolled in one semester, but have also courses from previous semesters. The CDIO-IL was regarded as an elective track for a limited number of students and the pilot aimed at assessing if the integrated and the pure disciplinary approaches could coexist in the same program.

The disciplinary component versus PBL

LEI has 5 or 6 courses per semester, split by 4 or 5 disciplinary courses and a LAPR design-build course as depicted in Figure 1. There is pedagogical consensus in the program that resulted in the definition of common rules and pedagogical patterns that should be used by all courses. This avoids personal drifts and enforces consistency (Martins et al, 2016). School-wide pedagogical rules try to promote continuous assessment and projects, but most courses do have final exams. In some of LEI's Math and Management courses, the final exam may

have a weight of over 50%. However, on all other disciplinary courses, final exams have a weight between 30% and 50% of the course grade.

The initial idea was that the final assessment through an exam would be the same for all tracks. This is relevant for accreditation purposes, as it reduces variation within the program. As such, the learning process would have to include a relevant component focusing on outcome assessment by written exam (Bloom level 3, max). There is a paradox here: one wants to promote deep learning in CDIO-IL and, nevertheless, decide to use the same assessment tool for all students, namely a tool that, by nature, is not suitable to assess higher levels of learning. It was a dangerous compromise, as the common exam would necessarily fail one of the tracks.

The continuous assessment component of all courses in the semester would be assessed in the context of an interdisciplinary project. The project is implemented in a scrum-like approach so that the semester is divided in 2-weeks sprints. For each sprint, project requirements are given as a set of user stories, and all teams must implement and demonstrate them at the end of the sprint in a special class called "sprint review". The division of work in the team is the whole responsibility of the team itself, i.e. they are self-managed teams as prescribed by scrum.

The sprint review is an important moment because it includes the students, all teachers and the Product Owner, i.e. the internal client of the project. At this class, the students present and demonstrate their work and are provided live feedback. Further technical feedback is given during regular classes, as well as individual and group assessment. The sprint review tries to echo what happens in the industry and is a major contribution to the students' communication, teamwork and business skills. It is a key differentiator from the disciplinary track.

The CDIO-IL approach requires careful design and planning of the project's user stories, as they are the semester assignments and drive all students' work and learning. One can state that the CDIO-IL learning process is user story driven. Therefore, the user stories are the result of a collaborative effort of the teaching staff and the Product Owner. Courses and project's requirements are taken into account and a set of user stories are selected for the next sprint, the so-called Sprint Backlog. This is a major deviation from the scrum, where the sprint backlog is defined by the development team, but without it, the project management of multiple teams would be unmanageable. Individual courses lose relevance in this interdisciplinary approach (otherwise it won't work at all), but there are an increasing breadth and depth of the courses' subjects and practices in the project implementation.

The general overview of the approach is presented in Figure 2. The project is formally included in the semester's LAPR course, which also includes all application activities related to the other courses of the semester. Pure disciplinary content is dealt with the respective course. Each course's grade results from the final assessment by written exam and the course's application component in the project.
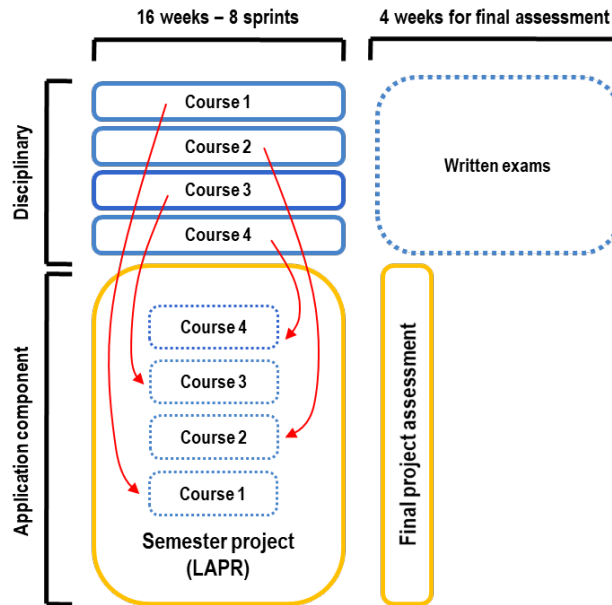
Figure 2 – CDIO-IL overview

The industry component

On one hand, developing software for academic purposes tend to be slightly different from developing professional software houses. Academic software projects are frequently started at the beginning of the semester and are "disposed" when the assessment takes place. Students barely feel the weight of producing low quality software, because they do not feel the burden and the long-run cost of maintaining it. On the other-hand, industry software houses know the long-run weight and cost of maintaining low quality software. Yet, these two realities barely meet during academic years.

For the CDIO-IL approach, in each semester, a local industry software-house is invited to host and promote a software project that could potentially become a fully commercial product. Because software-house collaborators are given access to the software project code, they inspect students code in order to advise them how to do better, according to industry standards, and students start learning that producing higher quality software is actually something that is not only perceived but pursued by software-houses.

Furthermore, students and software-houses become committed in the process. While students know they are being watched for what they produce and therefore tend to show their better skills in order to impress, software-houses also gain in doing some free content recycling and sometimes disposing of bad habits that have accumulated during the years.

In spite of the project being proposed by the software house, this is done in close collaboration with the teaching staff, which are also responsible for writing and scheduling the user stories. This is paramount as the interests of the software house may not be fully aligned with the requirements and the planning of the courses. It is important to keep the software house engaged in the project, but the learning process is the top priority. We have found that most problems can be solved with a little imagination in user story writing.

IMPLEMENTATION - THE CDIO-IL PILOT

In the 2015/2016 school year, CDIO-IL pilot class was deployed in the 3rd semester (2nd year, 1st semester) with a maximum of 32 students. It was proposed that these students should be enrolled in the pilot for 3 semesters. In the last semester, they would have the capstone project/internship, which is out of the scope of this approach. This class would share lectures with the other classes, as well as final assessment by exam on most courses, but lab classes would have to be adapted to the PBL approach: 50% would focus on the regular exercises of the disciplinary track, and the other 50% would focus on the project development.

The semester's project management was achieved by using an agile scrum-like methodology. The semester was structured in two-weeks sprints, where an element from a software house and a faculty member act as co-Product Owners (PO). The project would last 2 semesters and it was to be developed in parallel by the 4 teams, i.e. the user stories were the same for all teams. For the 3rd semester of the pilot, another project from another company would be used, as it must be aligned with the semester's requirements.

The CDIO-IL class was given an exclusive room that would be available to the class 24/24, 7 days a week. Each group would work on an island and have a 3-meter whiteboard, as depicted in Figure 3. Furthermore, we asked some companies to donate high quality puffs with their logos, in order to create a lighter and informal environment.

Figure 3 – CDIO-IL classroom

Starting with 32 students, 8 abandoned the pilot in the first week. These 8 students were good students and very competitive and they wanted to create a team between themselves. This was regarded as a danger for healthy teamwork. So, 4 teams of 6 students were created.

At the end of the first semester, 10 more students abandoned the pilot because they were not happy with their results in the exams. They liked the approach, in spite of the heavy workload and the challenges, but they felt that it didn't prepare them well for the final exams. So, in the

2nd semester of the pilot, there was only a large team of 14 students working as the development team.

In the 3rd semester of the pilot, some of the students that had left the pilot at the end of the 1st semester applied to reenter the pilot and a few more were also added to test if there was a substantial gap in the skills of students from the two tracks. The pilot was run with 3 groups of 8 students.

In the 2016/2017 school year, another CDIO-IL pilot class was deployed, this time in the 4th semester (2nd year, 2nd semester) with a maximum of 28 students and a duration of two semesters. The pilot's rules were basically the same, except for some refinements related to balancing disciplinary and PBL components in lab classes. It was clearly defined that all assessment in lab classes had to be related to user stories. Quizzes, lab tests, etc., were not allowed. This resulted from some teaching staff's resistance to the PBL approach.

Finally, in the 2017/2018 school year, another CDIO-IL pilot class was deployed, also in the 4th semester (2nd year, 2nd semester) with a maximum of 28 students and a duration of two semesters. The pilot's rules changed considerably, in an effort to align the final assessment with the PBL learning process in the project development. Therefore, final written exams were replaced by individual discussion/reflection on the courses' subjects and the project. This was a departure from the initial objective of the pilot, i.e. test if the disciplinary and CDIO-IL approach could exist in the same program. In fact, this 3rd pilot was more akin to experiment with a new independent CDIO-IL based program.

The 1st semester of the 3rd pilot run as planned and it was probably the "smoothest", in the sense that there was a very strong alignment between the courses and the project. It was possible to explore most areas of disciplinary knowledge in the project, almost every time going much deeper. The fact that one of the key courses in the semester (EAPLI) also decided to switch the final written exam for a final individual discussion/reflection in the disciplinary track may have had a positive impact in the pilot.

Unfortunately, the independent final assessment of the 3rd pilot was deemed by the school management "too different from the disciplinary track" so that it could be a risk to the program's current accreditations (national and EUR-ACE). Also, LEI's management team changed, and the new management opted to try to align the second semester of the 3rd pilot with the disciplinary track: the project would be the design-build experience of the semester (LAPR course), running the whole semester (16 weeks instead of 4), and the students would be integrated in the disciplinary track in the other courses of the semester.

RESULTS

The CDIO Integrated Learning (CDIO-IL) approach poses substantial operational and organizational challenges, but the feedback from companies who hosted these students in their capstone project/internship was extremely positive. The students of the 3rd pilot have yet to have their internships. Most of the students earned very good marks in their capstone project/internship, well above the program's average. Just a couple of them failed to reach the program's average, but more than half a dozen reached the typical top mark of 19/20 (20/20 is a rarity, about 0.2% of the students). It must be stressed that the students enrolled in the 3 pilots were not selected by their grades, but by their will to participate. Therefore, the typical

averaged grade before enrolling in the pilot was just 0.5 to 1 point in 20 above the overall average grade of all other students.

Regarding the impact of the approach on final exams' grades, one could say it was neutral. Their grades were in line with their counterparts. This led to some frustration in the students, as they felt that their hard work during the semester didn't pay off in the exams. It is not an unexpected result as exams require a specific set of skills, more often memorization and speed. The students in the disciplinary track train the whole semester the kind of small exercises that show up in exams. It is already very positive that CDIO-IL students can match their performance.

Regarding project work, most students gave their best and went much further than their colleges. They worked hard and enthusiastically, and we believe the external companies' participation was a decisive factor. The companies seem to be much more effective at motivating students than faculty and the students loved to have frequent contact with the companies. Also, companies tried to recognize the students' effort by providing summer internships, etc. For example, the team with the best project in one of the semesters was offered a trip to the retail summit in London (September 2018).

CONCLUSION

This paper presents a brief description of the application of a methodology that tries to extend the CDIO disciplinary approach with the use of PBL in a semester-long design build project course. Over three years, three pilots were deployed with some variations in the methodology, especially in the assessment.

The approach seems to have a very positive results regarding the students' software development competence and skills, teamwork and other key professional skills like knowing how to interact with a client. The technical quality of the work done and the students' maturity also has improved. There was no evidence of improvement in exams' results, which is also within expectations.

On the other hand, it resulted more difficult than expected to implement the pilots. Faculty's mindset was the biggest hurdle and it took some time to change it. The complexity and effort of creating the project user stories should not be undervalued. It requires a lot of cooperation between teachers and the company. In the end, there must be a teacher acting as co-Product Owner that is responsible for integrating all requirements and writing the user stories. This co-PO must have a very good knowledge of all courses in the semester.

One key objective of the pilots was to assess if it was possible to have two different approaches simultaneously in the same program so that the students could choose the one that suits them best. Modern program accreditation is outcome-based, so the dual-track approach is not a problem if one can assure that all students meet the required set of outcomes. Nevertheless, it is possible that auditors may find it a bit odd. It can be a risk. On the other hand, the coexistence of the two tracks was the biggest problem for teachers, some of them finding it difficult to manage two very different sets of students.

The experience of the pilots was very valuable. We are using the CDIO-IL approach in a post-graduation intensive program which aims to requalify graduates from other areas to software development. The results of the first edition were very good and we are currently in the second

edition with 51 students. A new 1st cycle completely based on the "pure" PBL version of the CDIO-IL approach is also being planned. Another quite interesting side effect of the application of this approach is that we have been asked by a large software company to help them redesign their internal training programs. This is very relevant, as in the software area there is the perception that academia is well behind industry regarding software development practices.

Finally, and not least important, this approach has contributed to the enhancement of faculty professional competence (Standard 9). This is a difficult subject in most schools adopting CDIO because professional competence enhancement is seldom aligned with career advancement. In this case, the teaching staff involved faced the same engineering challenges as the students and had to practice and improve their CDIO competences. Sometimes one doesn't introduce more engineering practice because of the potential lack of engineering skills by faculty, but probably it should be the other way around: introduce engineering practice that faculty will adapt.

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AN IVR ENGINEERING EDUCATION LABORATORY ACCOMMODATING CDIO STANDARDS

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ABSTRACT

This paper presents the development of an educational immersive virtual reality (IVR) program considering both technological and pedagogical affordances of such learning environments. The CDIO Standards have been used as guidelines to ensure desirable outcomes of IVR for an engineering course. A learning model has been followed to use VR characteristics and learning affordances in teaching basic principles. Different game modes, considered as learning activities, are incorporated to benefit from experiential and spatial knowledge representation and to create a learning experience that fulfils intended learning outcomes (ILOs) (defined by CDIO Standard 2 and Bloom's learning taxonomy) associated with the particular course moment. The evaluation of IVR laboratory highlights the effectiveness of the approach in achieving ILOs provided that pedagogical models have been followed to create powerful modes of learning.

KEYWORDS

Immersive Virtual Reality, Virtual Learning Environment, Standards 2, 6, 8 and 11.

INTRODUCTION

Active teaching forms where the most perceptive channels (sight, hearing, smelling, etc.) are involved and attention to different information sources can alter freely, are often preferred by students. One active teaching approach that has been considered as an important element of universities curricular since the early stages of development is laboratory work. This activity educates scientists and engineers through practices of theories and knowledge in various ways. Nowadays many experimental based labs are being replaced by computer-based labs and the trend is growing rapidly. This is primarily due to that computer-based labs not only offer practices of knowledge and theories but also give another level of experimentation including improved visualization, sense of presence, no time and space limit, and risk-free experiments for certain disciplines such as aerospace and medicine. In this era, a technology, which has grown in importance over the last decade, is virtual reality (VR) (Gartner, Inc., 2017; The Goldman Sachs Group, Inc., 2016). While the technic was originally developed for the computer game market, it started to build appeal for the educational sector, which is together with the healthcare sector already today the third largest customer group of VR tools (Karl, et

al., 2018). Like other forms of teaching, the use of VR for educational purposes in courses and programs demands pedagogics considerations such as a specification of learning objectives, alignment to course intended learning outcomes and assessment. This paper reports the development of an educational VR program in an engineering course and highlights the pedagogical considerations including the use of CDIO Standards as guidelines. The VR program was developed for an introductory course in *Gas Turbine Engines*, offered on the master level at Linköping University.

BACKGROUND

Virtual reality as an educational tool

A lab activity offers a learning environment that students can either apply already gained theoretical knowledge on a practical problem (giving learned knowledge a meaning), and/or to discover new facts, concepts, and principles for themselves. In such a case the teachers and lab assistants role is to guide students towards achieving certain goals. Laboratories or supervised practise including VR plays an important role in educational programs within engineering, medicine, or social science. Freina and Ott (2015) name four motivations for the use of VR in education: "time problems", "physical inaccessibility", "limits due to a dangerous situation" and "ethic problems". In addition, acquiring and operating instructional laboratories are today often connected to heavy costs. However, they all boil down to the same basic idea, namely that VR makes it possible to experience and learn from situations that in one way or another cannot be easily accessed physically (Freina & Ott, 2015). These motivations rely on characteristics of this technology, which according to Sherman and Craig (2003) consists of four key elements: a virtual world, immersion, sensory feedback and interactivity. The use of lab as a constructivist educational approach in virtual worlds creates a learning environment which is capable of responding and interacting with students' movements and inputs which allows them to experience a mediated sense of presence (Chien, You-Send, & Hsieh-Lung, 1997). This is referred to as virtual learning environment (VLE).

VLEs can be experienced by applying different information and communication technologies (ICT). The visual immersion and situation awareness inside a virtual environment is commonly experienced through a computer screen which simply can be desktop based (desktop virtual reality) or, when using more sophisticated equipment for immersive 3D experiences, a cave automatic virtual environment (CAVE) alternatively a head-mounted display (HMD) based system (Freina & Ott, 2015). By applying a position tracking system, which translates in real time the student's physical position and movements into direct feedback inside the VR, it is possible to interact, change the field of view (FOV) or walk around within the virtual world.

The hardware's quality, ergonomics and intuitive design play an essential role in providing a high level of sensory feedback and interactivity which in turn forms a main fundament for a high immersivity. Dalgarno and Lee (2010) point in the same direction identifying the representation fidelity and the learner interaction as the biggest factor that will contribute to a higher degree of immersion.

The terminology "immersion" can be simplified explained as the feeling of self-location within the virtual environment (Lau & Lee, 2015). Freina and Ott (2015) note that the term immersion is often being used in the meaning of "spatial immersion", as in the perception of being physically present in the virtual world. Slater (2003) stresses in his study that immersion is not the same as "presence" and that these terms should be kept separate. Immersion, Slater

(2003) argues, is an objective term for the way the virtual world is presented to the user, as in the number of different sensory displays or the simulations' fidelity to the user's movements, whereas presence is the user's perception of the immersion. Shortly, the feeling of presence is a human reaction to immersion. Moreover, apart from the already mentioned *sensory immersion,* which is best experienced by help of HMDs, other immersive aspects (Dede, 2009) like *actional immersion,* referring to be immersed in the task, *narrative immersion,* as induced by intoxicating real or fictional stories, and *social immersion* (Krämer, 2017)*,* considering social aspects between the students or the students and the teacher, are important when aiming for a high learning outcome. Fowler (2014) follows Salter's definition of immersion and presence and draws the conclusion that immersion provides a bridging concept between the technological, psychological and pedagogical experience of learning in three-dimensional virtual environments. This makes immersion an important factor to take into consideration whenever choosing or designing VLEs.

Educational VR challenges and methods of resolution

Of all the research and work done in the field of VR related VLE's there seems to be a shortage of papers that have had a clear pedagogical underpinning (Fowler, 2014; Mikropoulos & Natsis, 2011). According to a review of educational virtual environment design studies by Mikropoulos and Natsis (2011), few of the examined studies had a clear pedagogical foundation to motivate VLE design decisions. Although studies have suggested learning models that integrate the characteristics of virtual learning environment to their learning affordance (see Dalgarno & Lee, 2010), it is apparent that even such models miss the pedagogical aspects such as intended learning outcomes (ILO) and objectives. However, even if it does not exist yet one model that includes all pedagogical frameworks or taxonomy for VR related VLEs, it is possible to find models that can help to analyse the suitability of an ICT, to integrate pedagogics during a VLE design, and to evaluate a VR based learning activity.

Pantelidis (2009) and Fowler (2014) suggest frameworks for developers of VLEs, which considers both technical as well as pedagogical aspects. Pantelidis (2009) model recommends in ten steps how to approach, evaluate and develop a VLE. The model requests considerations of the VLE's learning objectives, the advantages of using VR to reach a specified learning goal, the right VR equipment/environment, and suggesting a VLE development cycle. Fowler (2014) presents a Design for Learning (DfL) approach, which combines Dalgarno and Lee (2010) model for developing three-dimensional VLEs with Mayes and Fowler (1999) concept of pedagogical immersion. The DfL framework provides three VLE design requirements: "learning stages", "learning objectives" and "learning activities". By basing the design approach on Fowler and Mayes (1999) three learning stages (1) conceptualization, (2) construction and (3) dialogue, learning objectives (or outcomes) can be determined, such as "exposing learners to new concepts, theories and facts" (conceptualisation), or "reflecting critically" (dialogue). To reach these learning objectives different learning activities must be defined and carried out, for example, "receiving information" or "self-assessment of level of competence". Depending on the case, the practitioner then has to determine which approach will be chosen to reach the specific requirements. The whole design process can be documented in a learning specification, for example in the form of a storyboard, a table or a formal learning specification (Fowler, 2014).

Designers of a VLE can also get guidance from the game industry and related research. This counts in special for educational games. Erhel and Jamet (2015) define digital game-based learning (DGBL) as an activity where the player receives educational goals through an educational computer game (ECG). The learning benefits of digital games to nongame

conditions and the influence of simulations and virtual environment on a higher cognitive level have been addressed among others by Clark, Tanner-Smith and Killingsworth (2016), and Merchant, Goetz, Cifuentes, Keeney-Kennicutt and Davis (2014).

Designers should also be aware of the psychological limitations of the student. It exists a risk that the amount of visual information in VLEs easily overshoot the perceptivity of the student and by that learning decrease. To avoid this risk, the cognitive load theory (CLT) with its universal set of principles for managing cognitive loads and ensuring efficient learning, can be consulted. Based on the theory it is important to decrease the student's extraneous cognitive loads often introduced due to unnecessary audio or visual stimulation (Liu, Bhagat, Gao, Chang, & Huang, 2017).

REALISATION

Development of an IVR laboratory for an engineering course

The VR based laboratory, subject of this study, is part of an introductory course for gas turbine engineering (TMMV12) at Linköping University which inheres a number of teaching and learning activities including lectures, labs, assignments and self-study. The objective of the course is to teach students, within a 160 hours of total study time (6 ECTS credits), the fundamentals of gas turbine and jet engine performance, deeper their understanding of the different sub-components functionality, and discuss different design problems from a fundamental thermodynamic, fluid mechanic and aerodynamic perspective.

As part of the educational digitalization process, ongoing at Linköping University, and a feasibility study of Smart Pedagogy (assessment of the pedagogical and technological affordances of different ICT approaches, see (Daniela, 2019, Pantelidis, 2009)), VR deemed to be a beneficial digital learning tool for the above-mentioned course. Therefore, four HTC Vive systems with a resolution of 1080 x 1200 pixels per eye and a 110-degree field of view were acquired. The used computers had an Intel® Xenon® CPU E5-1650 V3, 32 GB RAM and a NVIDIA® GeForce® GTX 970 graphic card. The laboratory was performed in an educational VR arcade (Figure 2(b)), newly established at Linköping University, with four independent working spaces separated by lightproof curtains. This allows four students to join the laboratory at the same time conducting the lab after a short introduction to the VR equipment. Each individual can finalize the task independently within approximately 30 min. While the students are in the VR, a lab assistant monitored the students' progress from the outside following their actions on the desktop screens and provided pedagogical and technical help if necessary.

The VR lab intended learning outcomes are based on Blooms Taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956) and CDIO Standard 2 focusing in general on individual experimentation as well as knowledge discovery by applying engineering reasoning, system thinking and problem-solving. In more detail, ILOs were defined as to identify the type of engine and its different parts, to understand the operating phases of a gas turbine, to list different thermodynamics station and numbering procedure, and to reflect about advantages and disadvantages of the given engine's design. Then, the laboratories ILOs were translated into specific tasks formulated as questions. In addition, the students' preferred learning styles and needs including learners attributes (age, origin, academic year, etc.), prerequisite requirements (both course content knowledge and VR related) preferences (reading, instructions, group work, analog/digital, etc.) and motivations (grades, knowledge gain, play, etc.) have been analysed. Subsequently, it was looked after already available VR application,

which could suite the laboratory ILOs as well as student needs and provide sufficient pedagogic to the same time. Due to the lack of VR applications that fulfil the current specific course requirements as well as pedagogical needs, it has been developed internally.

The conceptual design of the app development started with an ideation phase including a brainstorming, which resulted in a suitable basic program layout including three learning modes: 1. Lab Mode, 2. Examination Mode, and 3. Exploration Mode. In the next step was the previous specified ILOs translated into VR learning activities by utilizing Fowlers (2014) DfL approach. Since the application should have characteristics of an ECG, relevant aspects of the DGBL approach were extracted from the literature and drawn into a list of "must", "should" and "could". That list was further developed into a table with a list of goals and later broken down into different ECG design and implementation requirements. The basic concept was subsequently compared with the CDIO Syllabus 2.0 (CDIO, 2019), and if necessary, completed, in order to ensure that the basics of Standard 2, 6, 8, and 11 were from the beginning included in the ECG design.

In the concept realization phase, the abovementioned modes were defined. After ordering exercises and tasks, flowcharts for different lessons were created. These flowcharts lay the foundation for the storyboards, which specified in greater detail the user interaction with the program, as well as the most basic environmental setups. The main model of the application, the DGEN 380 turbofan jet engine developed by Price Induction, was directly imported in Unreal Engine 4 as 3D computer-aided design (CAD) object. The company provided original CAD model however was too rich in details and had to be decreased in its complexity such that it fits the pedagogical needs of the VR laboratory.

From the beginning of the conceptual phase until the introduction of the application in the classroom, the programs were iteratively testified to improve the learning modes pedagogics and didactics by resolving the technological design and functional issues.

Classroom experiences applying an IVR laboratory

The current beta version of the developed educational VR application has three modes (Figure 1): 1. Lab Mode, 2. Exploration Mode and 3. Examination Mode, which enables the use of different pedagogical approaches. The Lab Mode is designed with clear instructions and tasks to develop students' knowledge step by step. The Exploration Mode offers a more open learning approach where the student can freely discover different aspects of the jet engine design. These two modes use feedback and flexible experimentation for learning that was positively commented during the development phase; students' statement: "liked the lab mode, but especially the exploration mode". While the later mode may have pedagogical benefits, the lab mode is more efficient from time management on finalizing a particular task following some instructions, about 30 min to finish. Both modes aim to engage students' active learning (CDIO Standard 8) and promote hands-on learning by placing them virtually in a realistic engineering environment (CDIO Standard 6) in which a complex mechanical system, here a jet engine, can be analysed and manipulated. In accordance with CDIO Standard 11, the Examination Mode seeks an individual knowledge level and task completion through an assessment and provides feedback to both teacher and students with students' pre- and post-laboratory knowledge, which is valuable due to uneven knowledge background. Moreover, such information can also be inputs for further task development, the level of complexity or, in terms of ECG, creation of more challenging games.

The right sensory design is of high importance for the learning outcome and degree of immersion, see (Saleeb & Dafoulas, 2011), which has been reflected through the design of different environments. The lab environment (Figure 2 (a)) relates strongly in form and colour to the architectural design of the university (Figure 2 (b)), known for students, to decrease the risk of mental overload. This will prevent experiencing a new environment by the students and helps in focusing on learning. For the Exploration Mode (Figure 2 (c) and (d)), the students were placed inside an aircraft workshop/hangar. The idea is that they can go around, see the engine in both aircraft installed and uninstalled conditions and explore parts and functions in their "natural" context. The students who used the scenery were all positive about the hangar environment expressing it was "cool" and "impressive".
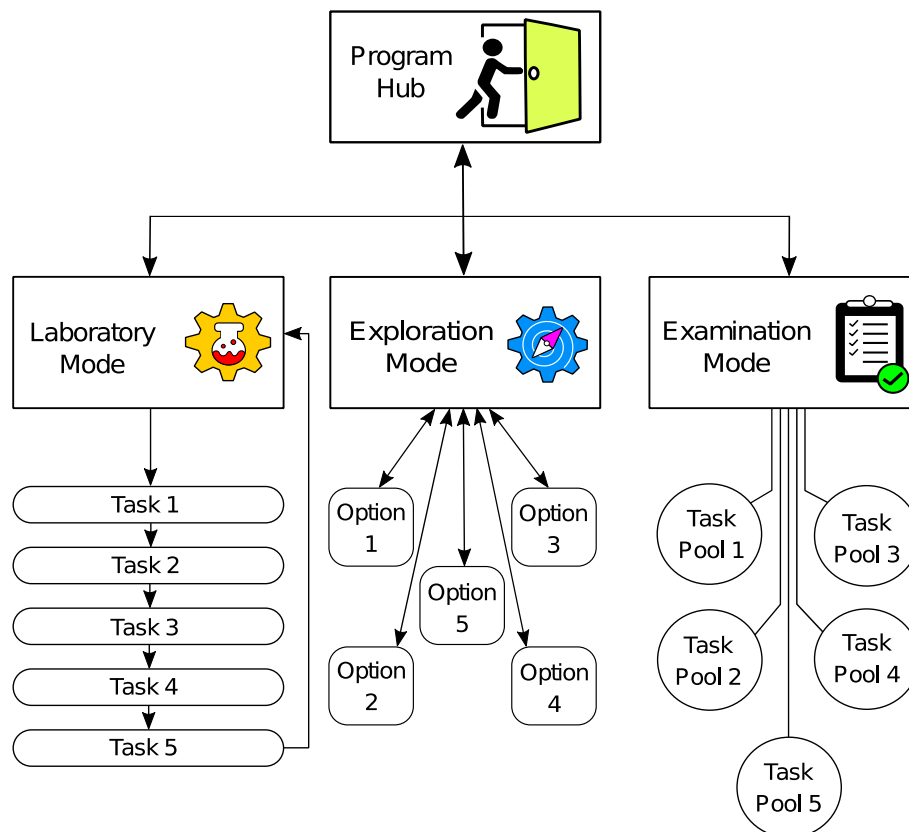
Figure 1. Program structure of the VR laboratory application. The Laboratory Mode includes different tasks, which are solved one after another. The Exploration Mode offers different task options from which the student can choose. The Examination mode provides task pools for individual student knowledge assessment.

Cognitive overload in the lab mode was also prevented by introducing the jet engine parts first as simple labels and later systematically by a realistic presentation of the object. In the actual version of the application, engine parts have different colours aiming to support the student indirectly with information about which parts are related to each other. Although a more realistic material representation could be beneficial (commented also by students), the degree in which this should be implemented is correlated to defined ILOs and human's perceptual abilities. For instance, due to human's visual perception limitations, rotations of certain engine parts, like the fan, were significantly reduced so the students can reflect on movements of components, direction, etc.
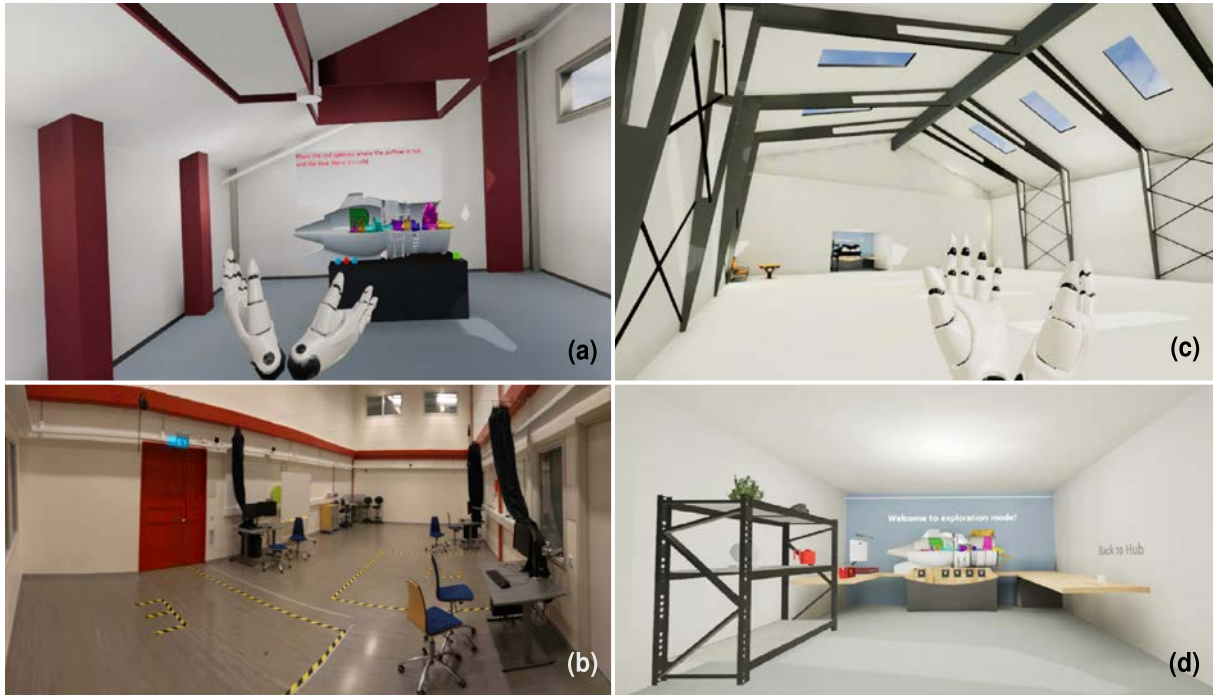
Figure 2. To minimize cognitive overload and hold student focused the VLE of the Laboratory Mode (a) equals the design of the universities architecture (b). In contrast, the Exploration Mode VLE is a more context related environment placing the students in an aircraft hangar (c) with integrated jet engine workshop (d).

Another example was related to readability of text and instructions where students experienced some level of difficulties due to the blurry or fast movement of text. The first issue, blurry text, is probably related to technological limitations such as the relatively low resolution of the VR goggles. When using the glasses intensively, longer time intervals, the readability was sometimes decreased by slightly fogged lances, caused by human perspirations. To overcome the problem of readability text size and contrast was increased as well as functions for self-determined text speed and to read-out are planned for the next update. The recently tested HTC Vive Pro system also shows improvements in readability due to the enhanced resolution.
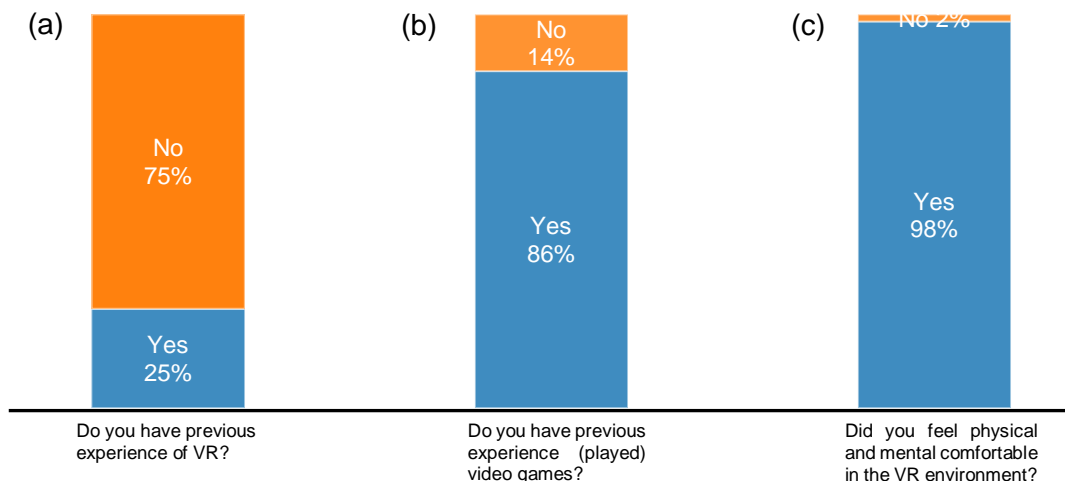
Figure 3. Students' response regarding to VR experience, video games and comfort in VR environment.

In a survey, conducted directly after the VR lab, 98% of the 110 students, which so far joined the IVR laboratory, responded that they felt physical and mentally comfortable in the VR environment (Figure 3 (c)). Problems reported in other papers (Davis, Nesbitt, & Nalivaiko, 2014) related to "cybersickness" causing dizziness of the user were not expired by the students. However, this is most likely since students in this VLE did not experience any fast-visual changes, which could affect their balance system negative. The positive mental comfort is also reflected in the question: Could you focus on the learning task or did you experience any disturbances? 86% of the students reported no problems (Figure 4 (b)), most likely due to sensory design consideration, 13% had some difficulties to focus, while only 1% could not focus at all. The named reasons for the students' difficulties reach from already mentioned readability problems, over unclear task formulation and small disturbing bugs in the program, to issues with the hardware (loose HMD or confusion with the controllers' button functions). In answer to the question of how intuitive it was to work in the virtual reality lab (Figure 4 (a)), 41% of the students reported no problems at all while 55% indicated minor difficulties and 4% more severe problems. One of the major issues mentioned by the students, also observed by the teacher, was to teleport within the VLE to reach objects, which were outside the area where the student could physically reach them.
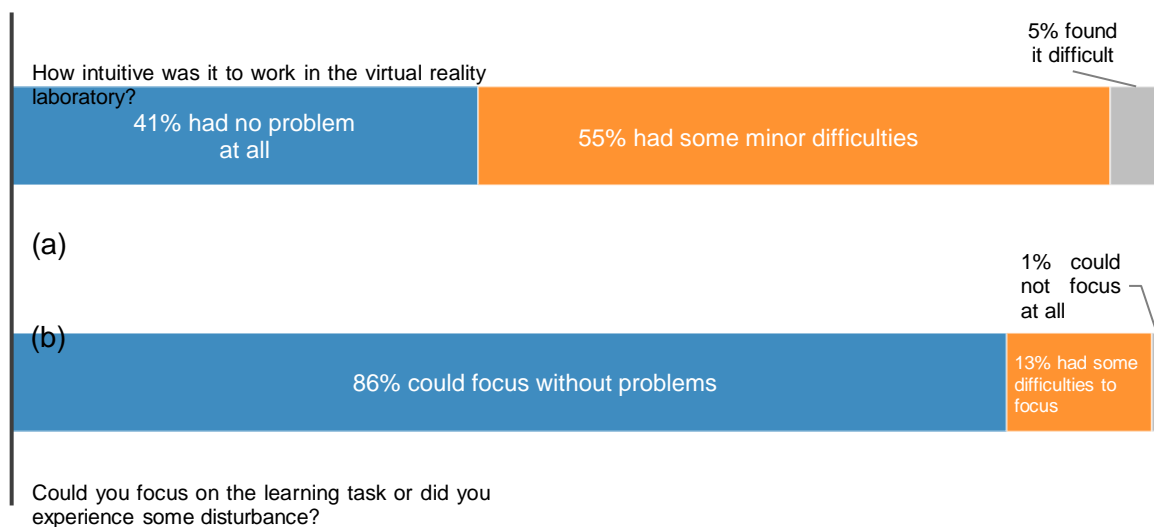
Figure 4. The intuitiveness of the VR program and sensory design effect on focus in actual learning has been positively commented.

Moving through the VLE by teleporting needs synchronously coordination of the VR nonvisible controller buttons and relocation of the VLE's internal virtual operational area. A possible solution for the future could be to present the controllers inside the VLE as how they look in real instead of illustrating them as hands by simultaneous simplification of the teleportation function. However, despite the high number of students who never experienced IVR before coming to the lab, 75% (Figure 3 (a)), and some minor problems was the overall feedback positive. A student summarized this with: "… I think the present issues in the VLE did not really disturbed the learning. I think I will remember more from what was thought because of the unusual teaching tool and method." The teacher observed also that students who indicated (Figure 3 (b)) no previous video game experience in the survey (14%) struggled more with the controllers, were less agile in their movements, and tried less thing out in the VLE, than students who played videogames before.

To evaluate the achievement of VR specific ILOs and students' perception of these ILOs, an additional survey was conducted at the end of the course. The students had to relate different ILOs to four learning activities included in the course. Note that the survey contains ILOs that were not intended particularly for VR lab to evaluate students' attention on designed activities for specific ILOs, (see categories (e) and (f) in Figure 5). The results show clearly students' appreciation in the contribution of VR lab to achieve ILOs (a)-to-(d) (highest contribution from VR). It is also evident from the figure that ILOs (e) and (f) have nearly zero contribution from the VR lab, as anticipated (not intended for VR lab). For all the presented ILOs, the percentage response rate of High (very effective) or Low (not effective) is quite significant when it comes to VR, i.e. lower variability in response for VR compared to other activities. An interesting observation is also that the mechanical lab in which students had the possibility to observe a real gas turbine is still after VR lab in facilitating students to achieve these ILOs.
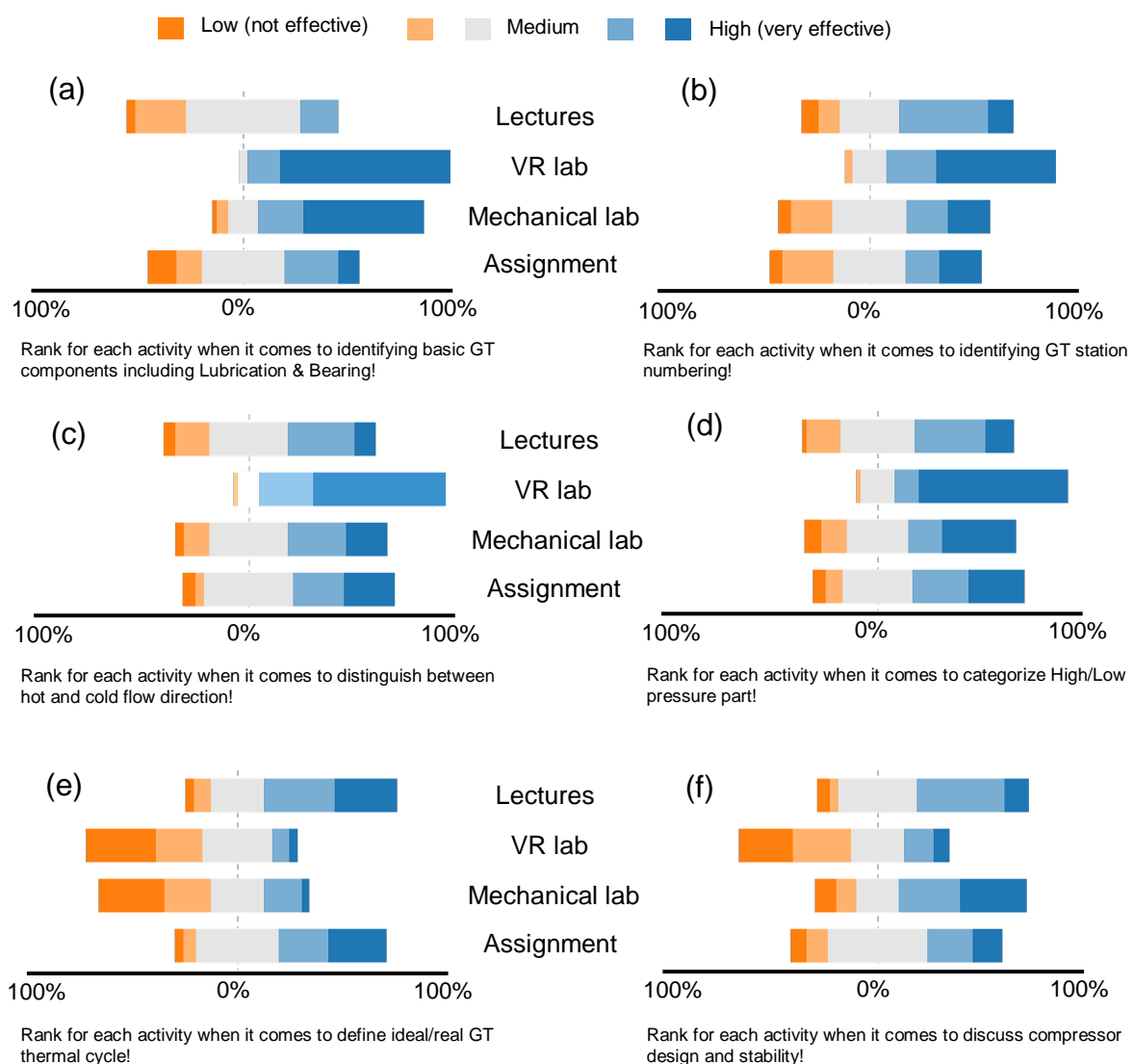
Figure 5. The results of survey with response rate of 61% (51 answers out of 84) about students' perception on achieving different ILOs through different activities. ILOs (a)-to-(d) were intended to be persuaded through VR lab, whereas categories (e) and (f) were intended for assignment and relevant lectures.

Even if the presented application is still a beta version and further improvements are necessary, both surveys and the students' feedback indicate satisfactory achievements using the chosen method to develop a VR laboratory from a technical and pedagogical point of view. Placing the students learning, the physical and psychological needs and limitations, as well as motivation in the canter of the VR application development process provides from the beginning a good foundation for achieving ILOs. Thereby, the frameworks presented in the literature can provide good guidelines for the development of a VR based laboratory even if some frameworks are from a practical standpoint too theoretical and/or too general.

CONCLUSION

A VR-based laboratory used in an engineering program, the basics in gas turbine has been developed considering the joint benefits of IVR technology and pedagogical frameworks to achieve specific ILOs. Earlier studies and experiences from this work show that IVR not only offers an affordable possibility to create and operate an instructive laboratory, but also it provides a supportive tool for active learning (which improve students' practical skills, a real-world context experience and a complex system learning through engagement). In addition, a pedagogic supported IVR laboratory covers CDIO Standards such as Standard 2, 6, 8, and 11. Concurrently, the standards also can provide a theoretical base for the design of an IVR laboratory. Summing up, an IVR based laboratory has a high potential to be a game changer in the university's practical education if, and only if, modern pedagogy and didactics are from the beginning considered and implemented. Technologies as IVR can only support a teacher not replace him.

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TOWARD EARLY INTERVENTION: MODEL OF ACADEMIC PERFORMANCE IN A CDIO CURRICULUM

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ABSTRACT

After three years of implementation of the CDIO initiative in the electronics engineering program at the Pontificia Universidad Javeriana, the curriculum management has focused the operation of the program on monitoring students who, from the point of view of the assessment of learning, generate important information to the program evaluation. The performance of the students is an important marker that indicates the efficiency of the program and represents the level of success of the reform according to the CDIO methodology. The structure of the curriculum and the gradualness of the integrated competences, reflect a program transition behavior that is aligned with the student development model of the university. Three transitions were identified: first year, second and third year, and advanced students. These transitions show different behaviors and needs that, in the institutional context of risk prevention, involve the identification of realities that require early monitoring and intervention.

In order to implement, the student development model, the university generates a risk prevention program that takes into account individual, psychosocial, academic and financial factors. Based on this model, a system of early alerts is created. This system includes intervention and monitoring processes. The initiative is complemented by a student accompaniment program (PAE + N, by its initials in Spanish), which is being developed initially in the School of Engineering. Under this context, it is necessary to design and implement models to identify patterns associated with academic performance and transitions of undergraduate students. This project is developed with the aim of detecting problems which can be intervened by making use of the entire offer of accompaniment from the university (advisors, workshops, psychological counseling, etc.). These patterns are detected using variables available in the University's information ecosystem, using analytical techniques and artificial intelligence.

In this paper, the identification methodology for risk patterns is shown. Additionally, some of the alerts that are in development are described including the analysis of their incidence as efficiency indicators of the CDIO program. The results of this project will allow reforms to the courses, the program, the teaching methodologies, learning and assessment, as well as the programs of the accompaniment of students in all transitions.

ANTECEDENTS

The School of Engineering of the Pontificia Universidad Javeriana (PUJ) has conceived, designed and implemented in four undergraduate programs (civil, electronics, industrial and systems) under the CDIO philosophy. This curricular process developed in a continuous improvement scheme allowed the assurance of the CDIO standards. In particular, standard 12 "Program Evaluation", has been developed establishing a model to verify the effectiveness of the program (Brodeur, 2005). This model has the base of qualification of the assurance of learnings. In this sense, standard 11 (assessment) feeds the evaluation model of the program, positioning the measurement of student performance in each of the courses, as a marker of program success. From the point of view of the integrated curriculum, gradualness in the competences allows to identify different moments in the student's formation (Crawley, 2014). Each moment is associated to the level of advancement in its curricular route and all the variables included in the training process such as personal issues, socioeconomic context and behaviors associated with the transition of the secondary school, among others. A general research in PUJ, determined six continuous and separable student states. Each state is outlined by their own elements and this structure let PUJ propose a model of student development for the whole university (MSD) as shown in Figure 1.

This model locates students in transitions (Jaramillo, 2018). We can explain a transition as the state describing the student's progress profile. "High School Student" corresponds to high school students who can be candidates for engineering programs. The "Applicant" refers to a transit condition in which selected candidates for each program participate in a basic skills assessment activity. This process identified weaknesses and strengths for the subsequent intervention.

The transition of the "First Year" characterizes the adaptation time to the university system, the integration into an institutional culture, the reaffirmation to the disciplinary vocation and the approach of the project of life as professional projection. For MSD, this transition is critical because of the high levels of drop out and it is determinant for academic development (McKenzie, 2014), (McKenzie, 2016), (McKenzie, 2017), since it includes the basis for a good performance in the curricular lines.

The transition "2-3 Years", coincides with the completion of the fundamental core of engineering, this stage determines the selection of the specialization line and the projection of the professional project. The transition "4-5 Years", is considered as the period in which students have a variety of subjects associated with the specialization lines and includes the capstone project, which is the most significant design and construction experience in the programs (Crawley, 2011). Finally, the transition "Graduate", in which the student becomes alumni of the program, it is a potential candidate for graduate programs and becomes a stakeholder for the evaluation of the program (Brodeur, 2005).
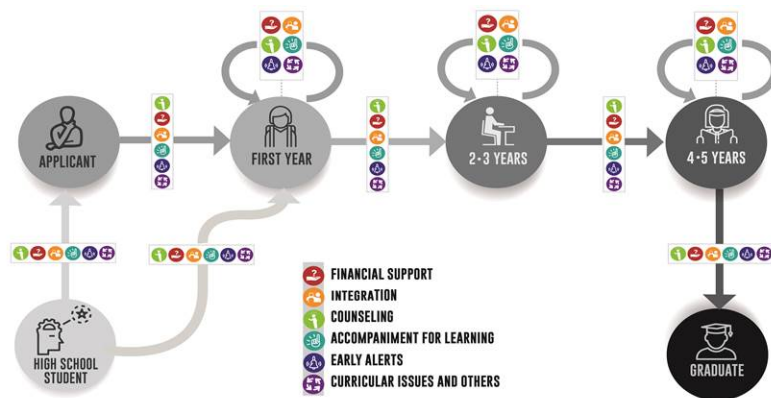
*Figure 1. Student development model. (Jaramillo, 2018)*

The conditions for a student to pass from one transition to another, are facilitated by institutional processes aimed to provide tools and strategies strengthening transit in the academic program (Torres, 2012). Tools and strategies are oriented to six dimensions of accompaniment (Jaramillo, 2018): "Financial Support", as its name implies, are programs aimed at solving difficulties in the payment of tuition or maintenance, for example, scholarships and financing. "Integration" refers to all activities related to the adaptation to the institutional culture and to fostering a sense of belonging, including the induction week for new students and a Peer Mentoring Program (Moody, 2015). "Counseling", is a program of support and follow-up directed by professors to guide the students in everyday situations of the university life. "Learning Accompaniment" includes strategies designed to strengthen skills needed in the development of curriculum competencies including personalized tutoring, study workspaces and a basic skill workshop (BSW) which is focused on ensuring success in areas related to mathematics and sciences (Lightbody, 2015), (Lightbody, 2016). Culture of "early warning", is related to the culture of risk management oriented to prevention rather than treatment, the main component of this strategy is a system of early alerts, intervention and follow-up (SEAIF). Finally, the other strategies that link outreach units, psychological counseling, spiritual counseling, among others, complement the previous dimensions forming a large institutional program for risk prevention. In particular, the school of engineering materializes these strategies in a pilot program called PAE+ N (González, 2018). Since 2017, this program has been implementing and integrating all the aforementioned strategies, evaluating their effectiveness in the support of transitions and promoting a culture of prevention of student risk (Ministry of National Education, 2015), (Ministry of National Education, 2016).

Here it is important to highlight SEAIF as a project of early detection of risk. The system is designed to identify hazards associated with the individual, socioeconomic, academic and institutional issues. These four categories coincide with the types of risk proposed by the Ministry of National Education for priority attention in higher education institutions (Ministry of National Education, 2013). The alerts generated by SEAIF come from two sources, the academic community and the university information ecosystem. We can classify two types of alerts, the first ones that are generated by logical inference, that is, a combination of variables or by a direct declaration of a member of the community and the second ones are those of prediction of patterns of behavior. For example, teachers are key stakeholders in the generation of logical inference alerts as they inform about students with low academic performance, non-attendance, and even personal problems, among other risks. From this point, an intervention and follow-up protocol is activated, which attempts to mitigate the identified risks. For prediction alerts, a project has been generated in parallel to the development of the system. This project looks for prototypes for the recognition of patterns based on the

information resident in the university information ecosystem. This project is led by the lab for student success, S2 Lab 4.0, where analytical and artificial intelligence techniques are used to detect these patterns. The following chapters show one of the prototypes of the laboratory, the methodology used and the intervention protocol of the generated alert.

PERFORMANCE DIAGNOSIS

In the PUJ, the student regulation establishes an average minimum accumulated, in order to be consistent with the mission of educating comprehensive and academically excellent professionals. In this context, students are assessed from 0 to 5 and the curricula respond to an academic credit structure. In this sense, the accumulated average is weighted according to the amount of credits and the final note of the matter (GWA, graded weighted average).

The minimum GWA required to consider a student in a normal academic situation is 3.4 or when the average of the academic period is less than 2.5. PUJ is characterized by a culture of student accompaniment and risk management (Torres, 2012), (Jaramillo, 2018). At this point, we define a student at risk when he is very close to this minimum GWA or below. A student may be in 4 academic states as shown in Figure 2. The "normal" state represents a GWA greater than or equal to 3.4. The "First academic probation" state represents the first semester in which the student with a GWA less than 3.4 initiates the improvement plan to reach a GWA equal to or greater than 3.4. The "Second academic probation" State is presented when a student does not exceed the GWA condition less than 3.4 after having been in "first academic probation". Finally, the "excluded" state is reached when the student does not exceed the minimum GWA for two consecutive semesters. In the School of Engineering of the PUJ the prevalence of "First academic probation", during the periods 1630 to 1810 (second semester of 2016 until the first semester of 2018), can be differentiated in each one of the programs as shown in Figure 3.
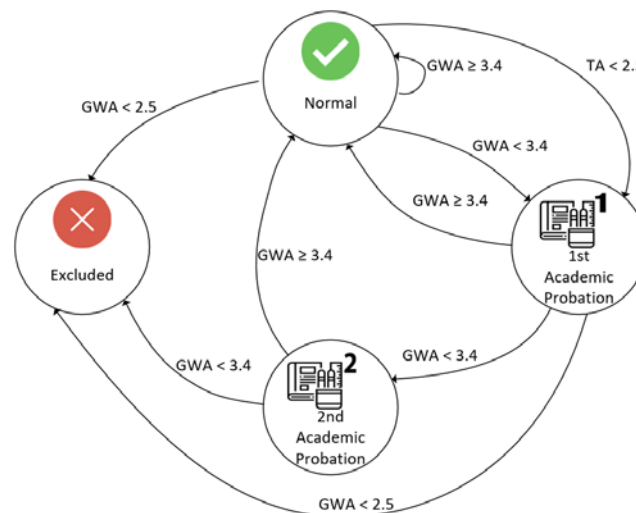
GWA: Grade weighted average
TA: Term average

Figure 2. Academic probation model

Although the percentage of academic probation may not be considered significant for the university, the responsibility to train professionals for the country and to accompany the student in its life project makes this population more important for PUJ. A qualitative and quantitative

analysis of the behavior of this population makes it possible to identify some patterns. For example, students who take the first 4 semesters of the program have a greater tendency to enter the state of academic probation, this explained by the conditions of adaptation (McKenzie, 2016), the paradigm shift between the levels of schooling (high school-university), deficient fundamentals in mathematics and critical reading (Ministry of National Education, 2006). Additionally, since the amount of credits taken has a direct effect on the GWA, in the first semesters we observe that poor performance in the academic term significantly affects the GWA. The opposite case occurs in the advanced semesters in which, due to the accumulation of credits, the performance in an academic term may not affect the GWA.

However, in the first semesters to overcome the academic probation, presents a minor challenge for the students, given the inertia of the GWA and depends directly on the decision of the courses to enroll. We can define the inertia of the GWA as the relationship between the academic credits accumulated and the variability of this average according to the performance of the academic term. In this sense, the performance of a student who is in the first semesters of the program will affect his GWA since the accumulated credits and the academic load of the semester are comparable. As the student advances, the proportion of credits taken is higher than the academic load of the semester and for this reason, inertia decreases.
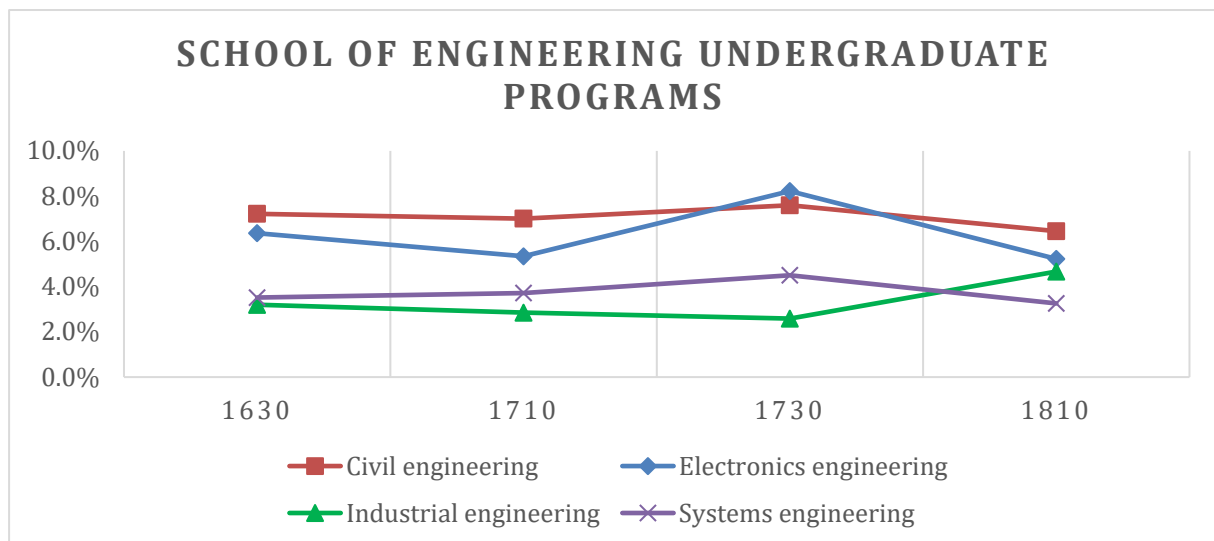

Figure 3. Prevalence in School of Engineering undergraduate programs

A low performance in the academic term occurs when students who have difficulties in the basic sciences and in the curricular core, face an academic term in which the majority of credits corresponds to the aforementioned areas. However, students with these same characteristics have a better result, if the load of credits of the semester is balanced between the curricular core and free choice courses (elective courses focused on the integral education).

At this point, we have noticed that a balance between the curricular core courses and the free choice courses have an impact on the weighted average of the semester. Timely intervention will advise the student to make the best decision of which courses to join up. For this reason, we have designed strategies that include academic behavior predictions to be able to make accompaniment, intervention and opportune follow-up to students.

The understanding of the phenomenon of academic performance includes a directly related to the problem variable categorization. Although there are many determinant factors in the

performance of a student (Wilson, 2017), the prediction proposed in this paper, is limited to purely academic variables without including individual elements related to physical and mental health, motivation, social and economic conditions, among others.

In this context, we can intuitively identify as possible academic variables, related to the phenomenon of performance: the average of the semester, GWA, load in academic credits, accumulated credits, performance in curricular areas, morbidity in particular courses, history of notes by courses, difficulty of the semester associated to the type of course, and perishable variables like the classification of the high school according to elements of quality and performance in state quality tests. The purpose of this work is a primary exploration of variables, which allows us to achieve the intervention and monitoring of the population. We established a methodology from the identification of the hypothesis to the approach of strategies of diversified accompaniment, including a review of resources (counselors, information systems, support material, among others).

METHODOLOGY
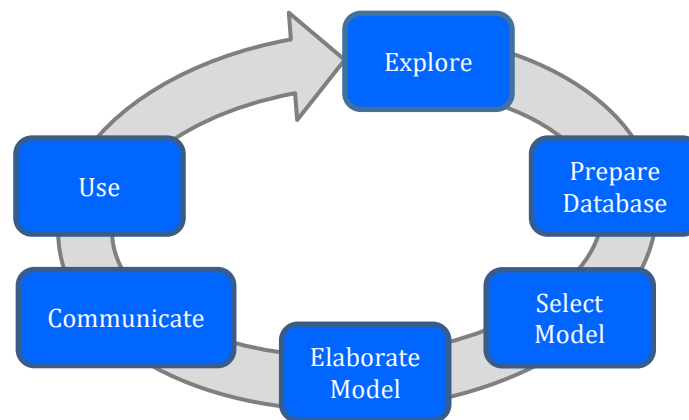
Figure 4. Methodology cycle

The proposed methodology follows the cycle of Figure 4, which describes a process of data analysis focused on the defense of a hypothesis to later use the conclusions and return them to the context to produce an improvement. In this way, the research question that motivates this work arises in the stage of exploration of the cycle. That question is focused on investigating the possibility of predicting first academic probation even before the student course the academic term. The prediction is based on academic history, advance and the intention to enroll in particular courses. This is how the following question is raised: is it possible to predict first academic probation using academic variables? With this question we can generate several scenarios:

> For students who are predicted to enter in the first academic probation, a balance in the type of courses (core - free choice) will reduce the risk of entering in this state in the academic term.

> The understanding of a student's performance can be measured on the basis of the relationship between approved credits and taken credits. This relationship allows us to characterize the student according to its potential for approval.

The effect of the inertia of the GWA can be controlled using the balance between the load in credits and the balance between the types of courses enrolled in the academic term.

In the stage of preparation of the cycle, the data necessary for the validation of the hypotheses are collected. The necessary data are in the PUJ ecosystem, specifically in the university information bases. The system includes monitoring the advancement of students and integrates enrollment modules, grade book, counseling and socio-demographic databases. However, the consistency, coherence, and completeness of all information should be reviewed.

The databases contain a great amount of information that includes GWA, average of all academic terms, notes of each course, professors, evaluation of professors, geolocation of the student´s home, among others. These bases describe the evolution of student performance over time and are it is determined by an environment under controlled conditions, in the context of a curriculum and its characteristics (approval threshold in the grade, contents, competencies, among others). Given the large number of variables, in the planning stage of the model, we decided to revise which variables are sufficient for a first exercise of prediction and test hypothesis. For this work, we use a simplification heuristic in which we choose three variables that are considered important and with a high potential to be a predictor: GWA, load in credits and approval rate.

The GWA is an indispensable marker in the prediction of the academic risk and its weighted nature allows to extract indirect relations on descriptors of the phenomenon. In addition, according to our hypothesis, the load to be taken and the potential for approval are predictors of the student's performance during the semester. The three variables selected, can be intuitively related as risk descriptors of the phenomenon. A first academic probation prediction using these variables requires combination, approximation and training techniques. A technique that attempts to define the relationship between variables, in different ways and with different weights, is the Artificial Neural networks (ANN). An ANN uses phenomena modeling. These phenomena evolve over time and under this condition, ANN uses a technique of learning based on labeled data to weigh about the characteristics and obtain an exit that approaches the true behavior of each phenomenon. For this reason, the model selected for the test of the hypothesis in the first approximation is the ANN. For the implementation, ANN was developed in MATLAB and some parameters of the technique were varied, to find the best structure and combination of them, using a verification protocol. The network has as output a list of students that the technique predicts will enter academic probation.

The above procedure was carried out for the four programs of the School of Engineering. We used the classifiers for the prediction of the academic term of the second semester of 2018. The results were delivered to the respective heads of the program. The program heads validated the results delivered from an expert assessment by reviewing each of the cases and assigning a potential risk to each one. With this validation were identified four levels of risk: critical, priority, moderate and mild. Students at the critical level are whose GWA is at the limit of the minimum demanded and those who have a poor performance in the current academic term will change the state to first academic probation imminently.

A characteristic pattern of this population is a non-satisfactory performance in the core courses, which results in a delay in the advance route that will block the possibility of enrolling courses of the same. In addition, such performance will lead to a low charge for limited options in core courses. Finally, we have found that some of these students have iterated between the normal state and first academic probation. Students who have poor performance in core courses but

their GWA is far from the required limit, are considered at priority risk, in. They are students who in advancing the core courses face greater complexity of the subjects. This reality can mean poor performance and hence a decrease in GWA. On the other hand, students who have many accumulated credits (low inertia of the GWA), present a performance in the average population of the program and have downward trend in the core courses are classified as moderate risk. Finally, people who are not going to be in academic probation but have a tendency to decrease their performance are at a slight risk.

The intervention with the students is designed to mitigate the level of risk, in this sense we identify that the behavior of the population depends on the average grade necessary to obtain the minimum GWA required, the performance in the core courses and the student transition. As previously mentioned, for the School of Engineering, transitions correspond to first year, second and third year, and fourth and fifth year. For this process, the temperature map strategy is used. The map describes the relationship between the probability of occurrence of an event and its impact. Figure 5 shows a two-dimensional temperature map, in which the y-axis corresponds to the impact and is expressed in terms of the balance between the tuple amount of credits in the core and the load of the semester. In the ' x ' axis are the mentioned tuples to describe the behavior of the population.
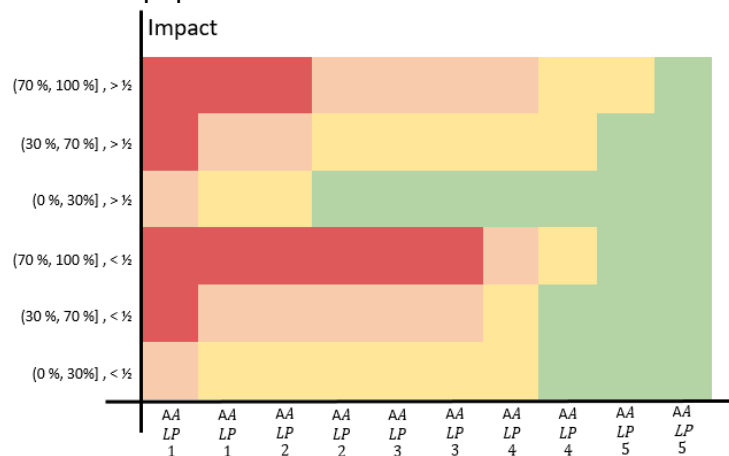

Figure 5. Temperature map

For example, a student who has a GWA close to the required minimum (AA), a low performance in the core (LP), which is in the first year, and whose intention of enrollment is to take between 70% to 100% of the core, with more than half load is at a critical risk. For this reason, the intervention is focused on making a variation in the location of the student in the temperature map in the elements of the tuples with variability, i.e. the axis of impact. The construction of the temperature map is the result of the expert validation of the program heads who assigned a risk value to each of the student profile-impact combinations.

The intervention strategies include the counseling in which they suggest changes in the intent of enrollment: load, subjects and balance. On the other hand, students are referred to various types of accompaniment depending on the level of risk: personalized tutorials, classrooms of study guided by teachers, psychologic counseling and follow-up to the process by counselors.

CONCLUSIONS

In this first simplified test, we can conclude that it is possible to make a prediction of academic performance before the student is in the academic period, based on their history, academic advancement, and on an intention to enroll in courses. Although the first approximation was simplified, it allowed early intervention to students who were classified at risk, giving them tools to make the right decisions and mitigate the risk in which they were. Evaluation models based on the assessment of student learning, not only allow to regulate the curriculum by identifying improvements in course programs, CDIO competencies, curricular integration and the structure of the program (Crawley, 2007), (Al-Atabi, 2013), but also, these models allow to monitor the performance of the students from the individual point of view and the possible generalized behavior of the population. From the understanding of the phenomenon of academic performance, it can be made an intervention to each one of the factors (curriculum-individual), responding to fulfilled facts. From the point of view of the student, said facts correspond to courses enrolled and taken, the result in the performance of them, overload of credits in the semester, imbalance between the complexity of the courses, among others.

From the perspective of the curriculum, these factors correspond to learning outcomes (Crawley, 2014), resources, assigned teachers (Brodeur, 2005), the relationship between the allocation of credits and contents of the courses. This intervention will have a direct impact on the future population of the program without having a direct effect on the population studied, i.e. in a treatment scheme and not prevention. By including prediction alerts, performing the non-fulfilled intervention allows a direct impact on the population by anticipating behaviors and preventing incorrect decision making. On the other hand, the prediction of patterns of behavior, allows to quantify resources in advance in such a way that the institution can anticipate a number of advisers, mentors, tutors, classrooms and to initiate the processes of accompaniment even since the inscription of courses. The anticipated understanding of the population that initiates an academic term allows an institution to make changes in the curriculum from the point of view of the methodology, activities and evaluation strategies, and gives to the professors, elements of judgement allowing a classroom-focused accompaniment. For the particular case of the alert chosen answering the question, "is it possible to predict first academic probation using the academic variables?", we concluded that it is possible because one of the factors that affect the academic performance is the individual, and this element is mapped directly from the selected variables. In addition, this first exploration allows establishing a clear path of study for future works. For example, S2 Lab 4.0 proposes to add for the case of the prediction of first academic proofing, several variables that explain with greater detail the phenomenon. The new variables proposed include curricular factors such as professors, complexity of the courses, morbidity of the courses, complexity of the academic term, among others. S2 Lab 4.0 also proposes to include other alerts associated with the prediction of loss of courses, tuition fees, prediction during the semester, delays in progress IB and learning difficulties.

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CHALLENGES IN THE IMPLEMENTATION OF A CDIO CURRICULUM FOR A PROGRAM IN ELECTRONICS ENGINNEERING

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ABSTRACT

The electronics-engineering program at the Pontificia Universidad Javeriana has been implementing, over the last three years, a reform based on the CDIO philosophy. The program has its focus on the solution of real problems with electronics engineering. This philosophy involves different challenges at the level of implementation. Then, it is necessary to look for standardizing, improving and optimizing curricular processes. In addition, this transformation implies operational risks, which are inherent in having several curricula simultaneously. Indeed, each one has different approaches to learning-teaching methodologies. These risks are mainly the faculty overload and its resistance to change, taking into account the development plan and expectations of each of the professors within the institution.

Additionally, the reform implies administrative strategies that guide the implementation and operation stages. This leads to the training of professors in the design of course programs, review of the coherence between the competences and the disciplinary lines, and the evaluation of the program for continuous improvement. All the elements of curricular management plus the need for training in the learning-teaching and assessment methodologies, constitute a new dimension in the CDIO standards 9 and 10.

The management processes, aligned with the philosophy of the university, have required reaching a consensus on what and how to develop the subjects and competencies to ensure learning and high quality of teaching within the framework of the institutional mission. All efforts have demanded professors to incorporate new tasks into their work routines. This generates even tense work environments within the group.

This paper describes the process of implementation and operation of the new curriculum. It begins with a general description of the new program and a comparison with the old one. Then it shows the methodology that has been followed for implementation over the three years and ends with recommendations that reveal the perception by the professor's body about the process.

KEYWORDS

Standards: 3,4,5,7,9,10.

ANTECEDENTS

The main challenges of the implementation of the CDIO methodology to the engineering education lies in integrating the professional, personal and interpersonal skills in the learning process. This paradigm seeks to keep in the curriculum the disciplinary content and teaching of technical and scientific knowledge (Andersson & Andersson, 2010), responding to the needs of the country and industry.

One way to address these challenges is to consider the implementation of professional, personal, and communication skills within engineering teaching methods. The incorporation of these methods is based on the choice of teaching methodologies with the objective of creating the context in which the students of engineering learn the knowledge of their careers and open spaces for the interrelation with the professors and their classroom classmates to facilitate the learning of professional and personal skills. Other topics to consider are the nature of professional skills and competencies in the field of engineering and how these skills develop within classrooms. In the case of CDIO philosophy, this approach is manifested, for example, by a greater integration of the different subjects of the program and active and experiential learning through design and implementation projects.

The strategies for the implementation of the CDIO methodology are based on:
- Curricular reform in order to ensure students have the opportunities to develop knowledge, qualities and attitudes to conceive and design and implement complex systems and products that meet a particular needs or requirements. (Berggren et al., 2003)
- Improvement of the level of education for the deep understanding of technical and complex information.
- Experimental learning environments making use of joint and collaborative laboratories and workspaces
- Efficient methods of evaluation to determine the quality and improvement of the learning processes, in order to maintain standards and quality.

For the methodology of curricular design under the philosophy CDIO must be taken into account 4 stages, these are carried out within the classrooms and by means of cases of study evaluates their viability: the stage of **conception**, which includes defining the necessity and the technology, considering the strategies, regulations and requirements of the final product. The second stage, **design**, focuses on the approach of architecture that responds to requirements based on plans, drawings, algorithms and describes what you want to implement. **Implementation stage**, this stage refers to the transformation of design into a product, including manufacturing, coding, testing and validation. Finally, **operation** stage, which generates the life cycle of the product which includes installation, maintenance and removal (Berggren et al., 2003). All these stages in order to develop concepts, architectures and methodologies within the academic field and classrooms of students.

THE NEW CURRICULUM VS. THE PREVIOUS CURRICULUM OF ELECTRONICS ENGINEERING FOR THE PONTIFICIA UNIVERISDAD JAVERIANA

Engineering education aims to provide students with sufficient disciplinary knowledge of science and engineering principles so that they can become successful engineers (Andersson & Andersson, 2010). The program of Electronics Engineering includes basic sciences as mathematics and physics, and is orientated the conception, design, integration and development of technology, in multiple areas of the industry and the daily life, to give solutions applied to practical problems.

Among these multiple areas developed in the Electronics Engineering program at Pontificia Universidad Javeriana (PUJ) are: telecommunications, power electronics and renewable energies, industrial control and automation, signal processing, robotics, digital and computer systems, microelectronics, biomedical and many others. All this through the design of digital electronic circuits, analog and system integration.

Overview of the previous program

The curricular approach of the previous program of Electronics Engineering at PUJ has a traditional approach, in which the teaching of disciplinary knowledge is the main and only objective measurable and evaluable (Christensen et al., 2006). Professional and personal skills are expected to be developed implicitly and do not consent, while students devote their time to problem-solving, project development and solution design.

The curricular structure of the previous program includes 56 articulated courses following the institutional policies and the disciplinary, integral and flexible guidelines of the program. It has a total of 174 academic credits. The fundamental core component represents 74.8% of the plan, including the lines of mathematics, physics, engineering, and institutions subjects. The 15.5% of the academic credits are assigned to the emphasis of the discipline and 9.7% correspond to subjects of free choice.

As mentioned above, the objective of the program is to train professionals capable of providing electronic solutions to the problems of the context. In this sense, the curriculum proposes 7 disciplinary work units that contain a group of courses dedicated to each specific area: physics, mathematics, signal processing, analogue systems, digital systems and emphasis. The line distribution is shown in Figure 1.

Figure 1. List of lines for the old plan of studies of the Electronics Engineering program of the Pontificia Universidad Javeriana

The old Electronics Engineering curriculum was founded in the first two years as a strong component in basic science and mathematics, with the aim of developing solution-oriented and problem-formulation skills. From sophomore year students, they face more specific problems oriented to electrical circuits and signal analysis. After year three, the program introduces students to components in analogue and digital electronics and a component of emphasis to deepen the subjects of greatest interest of each student.

Overview of the new program

The curricular structure of the new Electronics Engineering program was developed as a result of a continuous reflection of the program, meeting the requirements of the context (industry, professional associations, graduates, students and professors). A 5-year structure was designed with courses in charge of the development of students' skills, as well as the knowledge and skills necessary for their professional practice. (Gonzalez, Patino, Garcia, & Roldán, 2018).

This curricular structure includes 51 courses articulated following the institutional policies and the disciplinary, integral and flexible guidelines of the program. It has a total of 160 academic credits. The core component represents 68% of the plan, including the lines of mathematics, physics, engineering, and institutional courses. 17% of the academic credits are assigned to the emphasis of the discipline and 14% correspond to subjects of free choice. In addition, the new curriculum presents particular characteristics compatible with the context guidelines offered by the CDIO philosophy (Gonzalez et al., 2018) (Gonzalez, Hurtado, Fadul, Sánchez, & Viveros, 2016).

An overview of the curriculum can be addressed from the overall goal of training electronics engineers. As mentioned above, the objective of the program is to educate professionals capable of providing electronic solutions to the problems of the real context. In this sense, the curriculum proposes 6 disciplinary work units, that contain a group of courses dedicated to each specific area: physics, mathematics, signal processing, analogue systems, digital systems and CDIO Project unit. The line distribution is shown in Figure 2 (González, A., 2017).

Figure 2. List of competencies for the new curriculum of the program of electronic engineering of the Pontificia Universidad Javeriana

Unlike the previous program, this raises disciplinary learning that begins continuously since the first semester. It is addressed from the construction of a fund related to the cycle of identification and formulation of problems. In this sense, the solutions are technological and the object of design corresponds to an electronic system. From the first year of training, students face knowledge of the context and their problems. The CDIO methodology is selected because this initiative allows to develop the knowledge in engineering and to improve the relevance of the education for the work life (Kontio, 2014).

It is important to emphasize that we focus on gradual learning of personal, interpersonal skills. The integration of these competencies requires a curricular design based on learning outcomes that combine technical and disciplinary skills, as well as general skills (communication, teamwork, etc.). Therefore, the viability of an integrated curriculum is generated in the choice of some topics, which are really essential for the student's training, especially in the areas of mathematics, physics and Engineering (Fai, SK, 2011), (Jamison, A., 2014). These specific concepts of the discipline

are called nuclear competencies and allow the construction of integrated training results with general skills and focused on personal and professional skills. The course programs are then characterized by including a group of learning outcomes, the activities associated with each outcome, and the learning assessment rubrics that feed the program's evaluation model.

In addition to curricula, efforts are also focused on faculty, so that they can teach a curriculum with personal and interpersonal skills and building skills of products, processes and systems, integrated with disciplinary knowledge, as described in standards 3, 4, 5 and 7. Then, professors as a collective, have to be proficient in those skills ("Estándares CDIO v.2," 2010). Engineering professors are often experts in research and in the knowledge base of their respective disciplines, but they also tend to have rather limited experience in the exercise of engineering in the industrial and commercial context. Therefore, the university offers courses from the Teaching, Learning and Evaluation Center (CAE+E) to give teachers support and necessary tools to take on the intellectual and personal challenges within their classes. Among the most representative courses, we find: Planning and management of the teaching, resources for the learning: analogues and digitals tools, methods and instruments of evaluation: analytical, planning and management processes workshop, approaches of evaluation for the learning workshop, among others.

METHODS AND CHALLENGES OF IMPLEMENTING THE NEW PROGRAM

As already mentioned, the current program seeks to have as a basis, the solution of problems directly related to electronics engineering under the philosophy CDIO. This philosophy entails different challenges at the level of implementation by faculty, in which we must seek to standardize, improve and optimize processes.

To take on the challenges associated with the implementation, several steps were followed:
1. Introduce the CDIO methodology to faculty and administrators.
2. Help faculty become familiar with CDIO's methodology.
3. Plan the organization, hierarchy and structure of the relevant topics in each line of the program.
4. Reform in the teaching paradigm: Active learning based on problem-solving, by projects, by experiences and collaborative.
5. Plan the interconnection of learning lines.
6. Understand the structure of the course programs from the CDIO perspective: technical knowledge or disciplinary is one of the basic pillars because it provides fundamental knowledge of engineering, knowledge in basic sciences (mathematics and physics).

In the following figure, we can observe the process that has been made for the creation of the course programs based on the CDIO philosophy and with the guidelines of the academic Vice-presidency. Figure 3 shows the iterative process (represented in a closed loop of control) that was carried out until reaching the creation of the course programs and the reforms of all the courses of the plan of studies in Electronics Engineering at PUJ.

The new program references were the academic excellence and the general academic guidelines at PUJ. These two elements allow an integral formation characteristic of our graduates, in which the knowledge is fundamental but one does not leave aside the personal, ethical and social aspects.
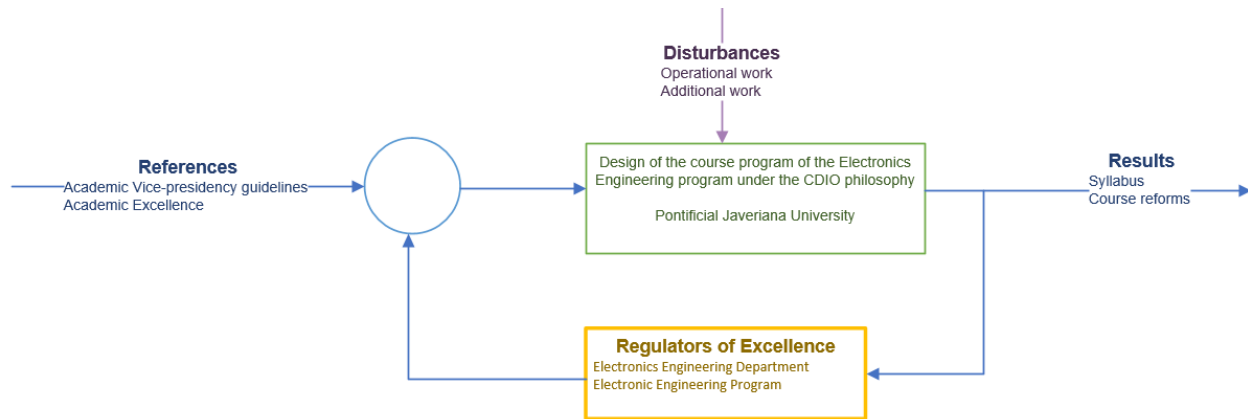
Disturbances
Operational work
Additional work

References
Academic Vice-presidency guidelines
Academic Excellence

Design of the course program of the Electronics Engineering program under the CDIO philosophy

Pontificial Javeriana University

Results
Syllabus
Course reforms

Regulators of Excellence
Electronics Engineering Department
Electronic Engineering Program

Figure 3. Implementation of the new curriculum of the program of electronic engineering of the Pontificia Universidad Javeriana

In the implementation process, there were some drawbacks or disturbances (represented with purple color). Among them are the operational risks that were one of the hardest to handle. These are inherent to having two curriculums simultaneously, with different approaches to learning-teaching methodologies. This issue mainly generated the workload in the faculty and therefore the resistance to change. Faculty had to design the course programs, in parallel to teach, to carry out research and to maintain the professional development plan within the institution.

In figure 3 the block "regulators of excellence", is understood as a set of entities that claim programs of the courses are carried out according to the quality expectations, maintaining the curricular contents and the curricular limits within each one of the courses. Additionally, the Program of Electronics Engineering and the Department of Electronics generated spaces for learning and conflict management within the work teams. All processes support the management of laboratory spaces to be more efficient and articulated with the contents and learning objectives of each new course. Spaces of mentoring and advising were created, and their purpose is supplying gaps of knowledge of the students and to support them in their integral formation.

As a result of this iterative process, the new course programs and the corresponding reforms were obtained (Figure 4). The curricular models and designs are based on an organized list of learning outcomes identified as critical in the education of new engineers. In addition to the guidelines, we take into account the identity and ethics as a value of our institution. Finally, surveys were carried out to faculty, students, alumni and industrial representatives to validate the importance of the skills and contents.

PONTIFICIA UNIVERSIDAD JAVERIANA
FACULTAD DE INGENIERIA
ELECTRONICS DEPARTMENT

Pontificia Universidad
JAVERIANA
Bogotá

Course Name	Specify the name of the course
Academic Credits	4
Course ID :	xxxx
Level	Haga clic aquí para escribir texto.

1   DESCRIPTION
2   DISCIPLINARY COMPETENCES
3   NO DISCIPLINARY COMPETENCES
4   TEACHING GOALS
5   LEARNING OUTCOMES
6   LEARNING OUTCOMES RUBRIC

Objective 1: Describe the first objective to reach in this course					
Performance indicator	0%	25%	50%	75%	100%
	The student did not reach the goal	The student reached the learning goal by 25%	The student reached the learning goal by 50%	The student reached the learning goal by 75%	The student reached the learning objective

7   PEDAGOGICAL STRATEGIES
8   EVALUATION ACTIVITIES
9   COURSE PROGRAM

Figure 4. Course programs template

In addition, the curricular reform involves administrative strategies guiding the program implementation and the operation. Those strategies lead to train faculty in the design of course programs, review of the coherence between competencies and disciplinary lines, and the evaluation of the program focus on continuous improvement. All the elements of the curricular management mentioned above, together with the need for training in the methodologies of learning-teaching and assessment, constitute a new dimension in the standards 9 and 10 of CDIO.

RESULTS

At present, the course programs of the new program for Electronics Engineering of PUJ are fully developed. In order to measure the perspective of faculty on the development of the new course programs and the reform process, a survey was designed. 17 professors of 24 who were part of the process, responded to the survey, this is 70% of the population.

In the first part of the survey, faculty are asked about the general process. Starting with how many of them had read the manuals for the construction of the course programs. 35% of the professors reported having performed a full manual reading, 47% read the manual partially and the remaining 18% read did not read the manual (Figure 5).
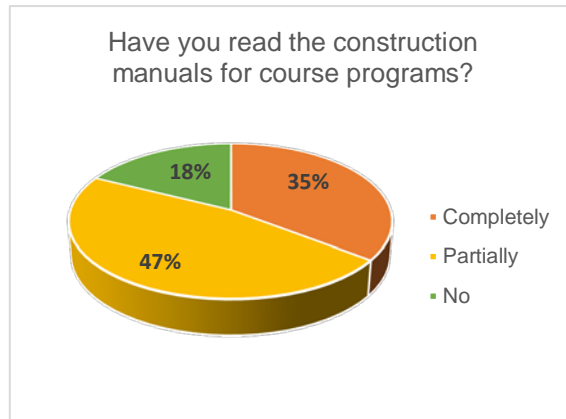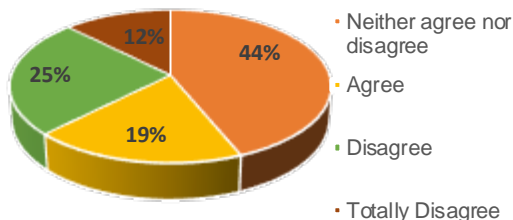
Figure 5.Question 1: Have you read the construction manuals for course programs?

The following two questions were focused on clearness in the process of implementation the course programs and the sections that it should contain. For the question if there was clarity in the process of creating the course programs, 44% of them are neither agreeable nor disagree; 25% consider that there was not enough clarity; 19% perceive the process as clear, while the remaining 12% show that there was nothing clear in this process (Figure 6 a). As, for the question, if there was clarity in the sections that the program should contain, 41% of the professors consider that, if there was clarity, 30% are not in agreement or disagree, the remaining 29% consider that there was no any clarity (Figure 7 b).

Figure 8. a) Question 2. Do you consider that there was clarity of the processes of the construction of the course programs? b) Question 3: Do you consider that there was clarity in the sections that should contain a course programs?

In addition, they are asked about the perception of the implementation process of the course programs. When asked about the efficiency of the process (Figure 7 b); 35% of professors consider the process as efficient while 65% consider it, inefficient or little efficient (Figure 7 a). To the question Do you consider that there were re-processes in the construction of the course program? 94% of the professors answered yes.
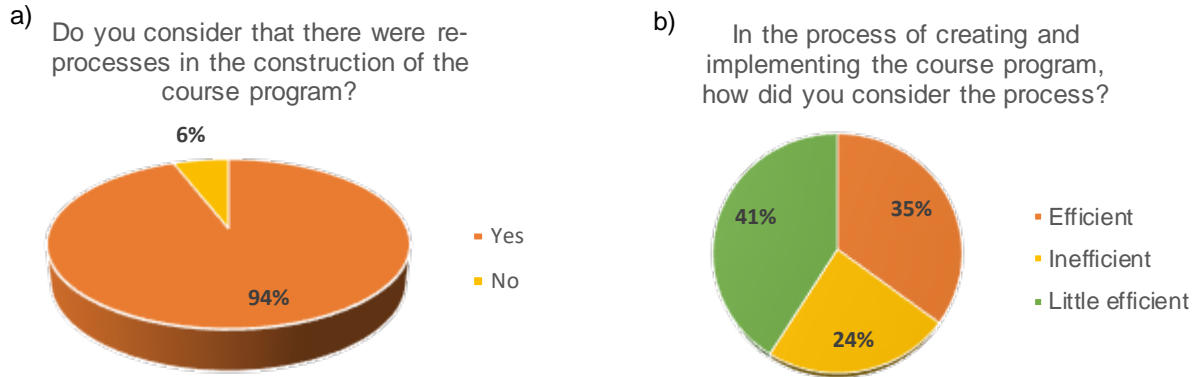
Figure 9.a) Question 4. Do you consider that there were re-processes in the construction of the course program? Question 5: In the process of creating and implementing the course program, how did you consider the process?

Within the evaluation process, it was also important to know whether the response time to the questions generated by faculty, during the implementation was appropriate and how much was that response time. Most teachers consider the response time to be appropriate (77%). 23% consider that this time was not appropriate (Figure 8 a). Response times are distributed as: a few hours (6%), one day (6%), between two days (47%), between one week (35%) and between a month and three months (6%) (Figure 8 b).
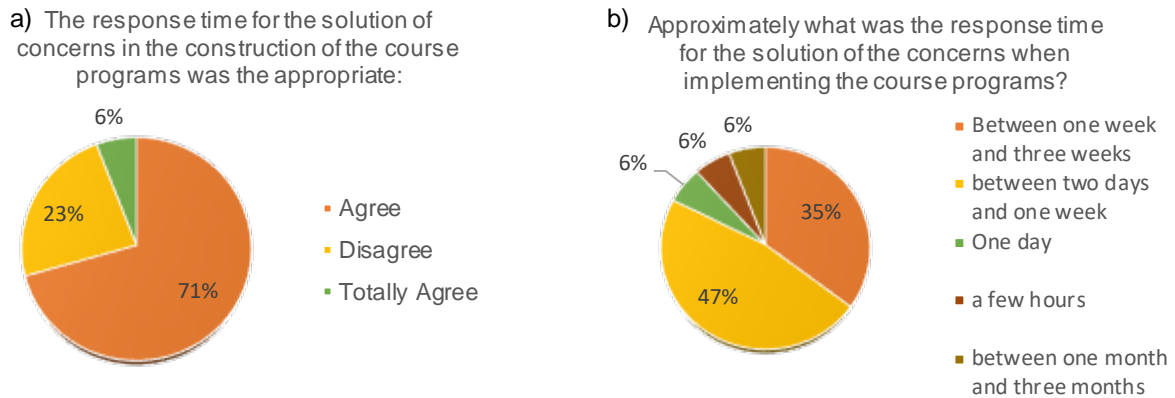
Figure 10. Question6: The response time for the solution of concerns in the construction of the course programs was the appropriate. b) Question 7: Approximately what was the response time for the solution of the concerns when implementing the course program?

We also evaluate which of the sections of the course programs are the most inconvenient to the professors. As can be seen in Figure 12, the section that most problematic section is "Outcome assessment rubric"; 10 of the 17 professors who conducted the survey think that. The learning outcomes and teaching goals section also generate some kind of difficulty.
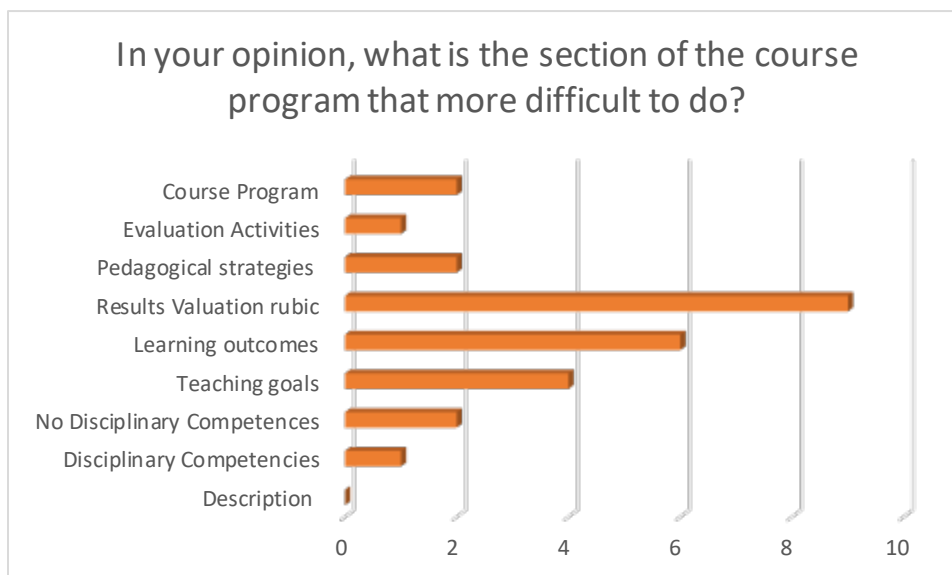
Figure 11. Question 8: in your opinion, what is the section of the course program that more difficult to do?

We made other questions to determine what were the strengths and weaknesses of the construction of the course programs under the philosophy of CDIO. We find that faculty believe that the greatest strengths of the process are: The generation of academic spaces to discuss relevant aspects of the program between professors, there was a previous work in front of the thematic contents of the subjects, the process was structured, it allowed to establish a homogeneous process generating course programs updated and homogeneity in the courses' subjects. As for the weaknesses observed in the process: lack of time, assignment of many tasks by the Electronics Department, the specific terms of each part of the course programs were a little confusing, too many sections and little clarity in process, content and lack of organization and planning.

PROPOSAL: IMPROVEMENT TO STANDARD 10.

Based on the experience of the construction and implementation of the course programs, we can identify a set of good practices in the design and implementation stages of a curricular reform under the perspective of the CDIO initiative. First of all, it is important to raise a structure of working groups that are responsible for disciplinary lines. These groups will be based on the integrity of the contents and their articulation with general skills to be developed gradually. During the implementation and even the operation and evaluation of the new program, these groups will be responsible for ensuring the articulation between lines, including training areas belonging to other schools. In particular, for engineering education, an example of these areas corresponds to sciences (physics and mathematics). At this point, we recommend to include in the work structure, groups responsible for the fundamental basic science lines. The work of these groups is to accompany School of Sciences, in the redesign of the courses and the integration of skills in them. A second element for the success of the implementation of a new CDIO program is the effectiveness and efficiency of the processes, mostly operational. At this point, it is of vital importance the traceability of meetings, agreements and decisions and the follow-up to the documentation. Then, it is necessary a methodology of project management that includes among others, control of changes and versions, schedules of activities and advance indicators. The

management tools above allow saving time, knowing the progress of the process, avoiding the reprocesses and obtaining a program designed from high quality parameters.

The third element is associated with the paradigm of change management. In this sense, faculty and in general the actors involved in the reform of the program must understand the objective and the reason of it (define). The management group is responsible for motivating the commitment of faculty and keeping it informed of the progress of the curricular reform project (communicate and engage), translating the expectations of the reform in indicators of the day to day of each professor (detail) and to develop the implementation, operation and evaluation processes offering the necessary methodological and technological tools (training). On the other hand, it is essential for the process, to ensure the sustainability of the reform (assurance) and to seek the necessary alliances within the university to support the complexity associated with this process and mitigate the resistance to change. For the particular case of PUJ, we look for Learning, Teaching and Evaluation Center (CAE+E) and the academic Vice-presidency are aligned with the CDIO philosophy, in such a way that their offer of training of professors and accompaniment to curricular processes is by demand and based on the needs of the School of Engineering and its processes associated with the reforms. However, all the efforts of an engineering school that seeks continuous improvement, redefinition of its programs and that welcomes an innovative philosophy like the one proposed by the CDIO initiative, must have support from the structure of the institution (policies and investment). In this sense, the administrative management of resources (time, budget, internal services) and institutional processes must be efficient and effective in order not to hinder strategic reform projects and in general the culture of continually rethinking engineering education. Finally, we suggest that a curricular reform project should follow an operational model of implementation to avoid the overhead of work in faculty. Below, we describe an improvement to the standard 10 which includes the above elements.

Implementation proposal: Improvement to standard 10

Our proposal to improve standard 10, includes understanding the reality of faculty from the point of view of their daily functions, the additional activities inherent in the operation of a curricular reform and the design of detail of the program including the courses from a CDIO perspective. Figure (10).
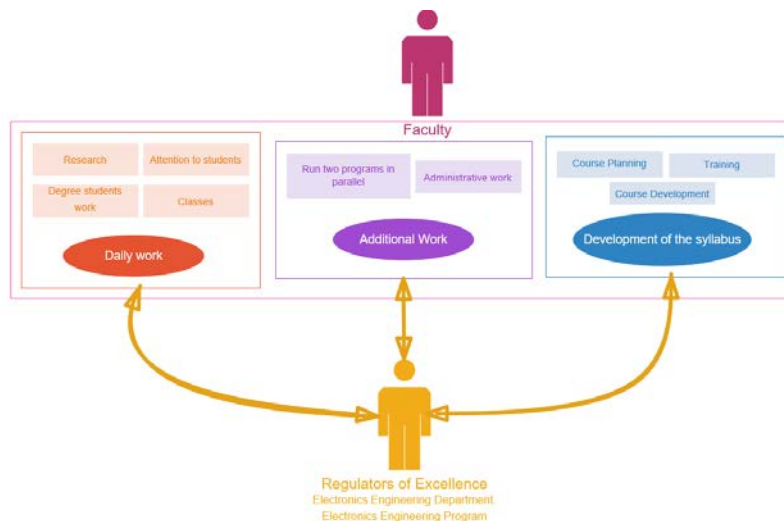

Figure 12. Faculty Work load

We will use the Business model canvas (BMC model) to summarize our proposal. The BMC model is a graphic representation of several variables that show the values of an organization

(Electronics Department). Usually, MBC model is used as a strategy tool for developing changes in a process (Electronics Program) or an organization (Electronics Department -Faculty). This tool includes the analyses of the state of the art of a situation of an existing process. BMC model defines nine categories as the building blocks of an organization or a process: Key partners, Key activities, Key resources, Value propositions, Customer relationships, Channels, Customer segments, Cost structure, Revenue streams.
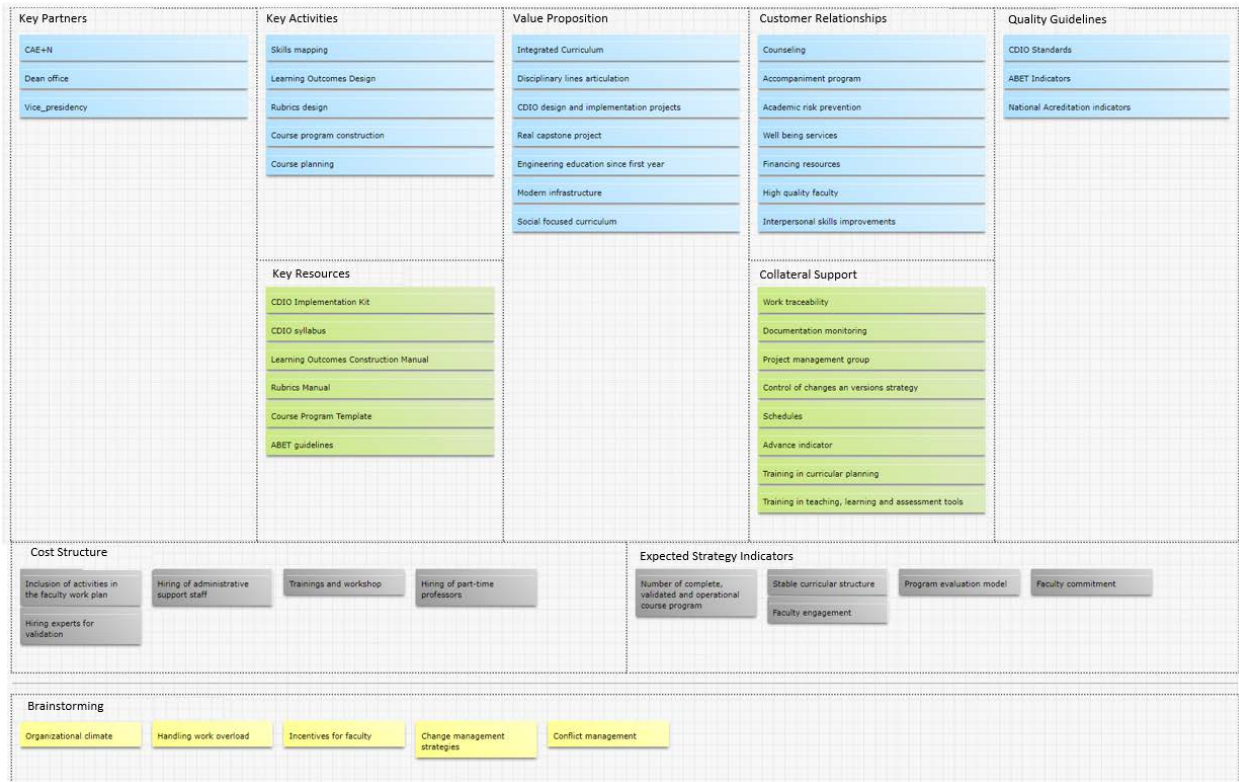
Figure 13. Business model canvas (BMC model) to summarize our proposal

We have adapted the BMC model for the case of a curricular reform and in this way, we have modified some categories to be consistent with an academic process. Then, we have replaced the Channels by Collateral Support, the Market Segments by Quality Guidelines and the Revenue Streams as the Expected Strategic Indicators. In addition, we include a brainstorming space to report some items that are not categorized in the BMC model categories. Figure 11 shows the resulting BMC as an initial proposal for the improvement of the CDIO standard 10.

CONCLUSIONS

This article showed the process used at the Pontificia Universidad Javeriana to implement the CDIO methodology and its challenges in the Electronics Engineering program. The most frequent challenges were overloading the work of the faculty and administrative staff by having two simultaneous study programs. This situation has generated resistance to change and situations of delay in the different activities related to the implementation.

Our work is oriented to articulate all the elements of each category of the BMC model to carry out efficient and effective improvement processes that do not resent the attitude of the faculty and instead can consider the reform as a project of professional growth.

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FOSTERING DESIGN COMMUNICATION SKILLS: A CDIO INSPIRED INNOVATION ENGINEERING COURSE

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ABSTRACT

In the context of junior level courses in Industrial and Systems and computing Engineering of the Engineering Faculty of Universidad de los Andes, projects are developed seeking to strengthen the students' observation, engineering design, communication and team working skills. Throughout the semester, the students, in teams, **observe** a problem that they believe could be addressed through engineering. After that, based on their comprehension of the specific problem and specific user, they (1) **conceive** proposals, (2) **design** one of them and (3) **implement** it. Between each stage, the teams get feedback from different stakeholders in order to focus and improve their proposal. Before the end of the semester, students participate in a fair (**LaMuestra**) to show their projects (based on a prototype) to entrepreneurs, alumni, students and professors from different disciplines. This approach has led to the **Innovation Week**, a set of public events to share our CDIO activities with our stakeholders. In this paper, we present a learning methodology for the student's teams to carry out the design of an engineering solution while been challenged to innovate and have a positive impact on society. The methodology and some results of its implementation illustrate the relevance of the **o**CDIO approach.

KEYWORDS

Communication skills, Design Skills, Innovation project-based course, Standards: 4,5,8

INTRODUCTION

In order to strengthen design, teamwork, communication and innovation skills, the Faculty of Engineering of Universidad de los Andes in Colombia has been creating spaces for project-based learning. There are mainly two courses that all students must follow:

Introduction to engineering (freshman course) and *Mid-career project* (junior course). In Introduction to engineering, students develop a project in working teams and share it with the community in a fair at the end of the semester (ExpoAndes). In the mid-career space, all students work in teams (sometimes interdisciplinary teams) in the designing of an engineering proposal to solve a specific problem. Specifically, the mid-career courses of Industrial Engineering and Systems and Computing Engineering lead to the development of projects with innovation components that allow students to explore new approaches and tools to guide their emphasis in the following semesters of their undergraduate studies. We present the current state of a 15 years old course with around 1000 alumni. The different actual spaces and tools are the result of our continuous evaluation process.

THE CHALLENGE

The engineer is faced with the need to observe contemporary problems and to work in teams on the understanding of how to create possible contributions to its solution, in order to conceive, design, implement and operate technically feasible and economically sustainable proposals. In this regard, the half-career space described in this paper seeks that through the teamwork in projects, the students can develop:

- the ability to design feasible models or prototypes, in the context of a real problem
- an understanding of the need to work with engineers from other disciplines
- the need to communicate to their peers their own engineering proposals and the value that an engineering design generates in society (Ramírez et al., 2010)
- the attitude for creating innovative proposals with the potential to have an impact on society (OECD, 2004)
- the ability to be more proactive in a highly competitive environment

This model explicitly reinforces the Observation stage, seeking to improve the conception of the intervention that is sought through the engineering project. In this sense, the scheme presented starts from a CDIO approach and executes an oCDIO approach (Hernández, Ramírez & Carvajal, 2010).

THEORETICAL FRAMEWORK

Engineering as a profession has been undergoing changes in its teaching-learning models with the aim of training engineers able to face the challenges of the discipline in the 21st century (Steiner et al., 2008). Moving from the knowledge transfer paradigm to the development of professional skills is one of the most significative changes (Hernández et al., 2004; Siller et al., 2009). Examples of these changes have been reviewed by different institutions, renowned in the global context, such as the National Academy of Engineering - NAE (Siller et al., 2009) and the Accreditation Board of Engineering and Technology - ABET, in the United States of America. In Latin America, the CDIO experience has been reinforced and adopted in several universities in the region and Colombia.

However, the teaching of these skills is hard, especially for faculties seeking to generate a balance between the need to include an increase technical content in the curricula (Siller et al., 2009), and the training of engineers with the necessary skills for the adequate application of these contents. Taking into account the challenges posed by NAE (National Academy of Engineering) and ABET (Accreditation Board of Engineering and Technology), the Faculty of Engineering of Universidad de los Andes in Colombia has proposed a curricular space to develop these skills altogether with students, professors and entrepreneurs framed in an oCDIO approach.

Research has explored the need to produce alternative methods for students to develop real designing skills. Gilbuena et al. (2015) suggest the use of videos and interviews; while Kittlesson and Southerland (2004) propose the use of other tools such as self-recordings.

The researchers of this paper propose: i) to emphasize the Observation stage and ii) to reinforce the design communication through the development of systematic discussions with different stakeholders. As a contribution to the CDIO framework, a first stage of Observation has been proposed and developed within the courses: this stage seeks to carry out a careful research process based on bibliographic reviews and creativity workshops that allow the students to explore the technological conditions that surround them and make a first user-centered focus on possible problems that can be addressed from different fields of engineering. This first stage of what is called oCDIO (Hernández et al., 2010) fosters the collection of pertinent and very useful information, to begin with the conception of ideas proposed by CDIO.

DESIGN COMMUNICATION IN ENGINEERING COURSES

The oCDIO stages

To enhance the design communication skills in both engineering courses the projects developed by the working teams must be discussed with different stakeholders. The groups develop the innovative projects in the context of the six engineering stages described above: Observe, Conceive, Design, Evaluate, Implement and Operate. For instance, the three-credit mid-career course asks students to work on teams of 4-5 persons to develop an engineering project with innovation and sustainability attributes.

The students begin by a stage of Observation of the proposed problematic. In this stage, they approach it investigating with the possible people concerned by the situation, exchanging ideas with experts and researchers, exploring findings, reviewing bibliography, among other activities. Once this preliminary observation has been made, the students conceive the formulation, contextualization and a possible solution to the observed reality; this conception requires a strong emphasis on the development of creativity and innovation exercises that allow the proposal(s) to be appropriate.

The stakeholders

Although of course the course is accompanied and guided by the *teachers*, *students* have the support and following of a board of *Entrepreneurs* as *mentors* of their projects, and *technology experts* associated with each project. Along 15 weeks of the projects, students

must face the challenge of communicating the design process they are carrying out to their *specific users* and stakeholders (Mentors, TechExperts, Teachers and Students):

- In the OBSERVATION stage, they must understand the problem in dept together with an expert in the problematic situation and the potential specific user.

- In the CONCEPTION AND DESIGN stages, they must develop a dialogue with the user (continuously) an entrepreneur and an expert in technologies or solutions with social impact.

- In the IMPLEMENTATION stage, students must face presenting their MVP (Minimum Viable Product) to the end users of the solution.

In this regard, the courses have been designed with a low theoretical content and a focus on practical and debating content. What has enriched the process the most is the successful communication that the students must develop with the different stakeholders in the several moments of the semester.

In figure 1 is showed one of the mentoring session.

Figure 1. Entrepreneur board

The process

Each team (25 teams of 4 students each semester) has an entrepreneur-mentor who supports them on the project management. The group of 25 Entrepreneur-Mentors, gathered together, form a jury board that gives formal feedback on the projects' development.

At each stage of the project, the set (specific problem, specific user, proposed solution) must be tested with the specific user, and with external experts in both the problem and the technology involved.

- During the first 6 weeks, an **oCD**IO phase is carried out mainly focused on observation, Conception and a first design stage. At the end, the resulting proposal is presented to the jury board, together with a first "Oz wizard" prototype, with evidence of user participation in its construction.
- After processing the feedback from the jury board, a second oC**DIO** phase begins and, with the advice of professors and other experts and the deepening of the problem understanding, the design of a Minimum Viable Product - MVP is refined and implemented in a proposal that is taken to user evaluation and to a second round with the jury board. Some adjustments are made considering the feedback received by the teams, and the MVP is taken to an audience of professionals (alumni & entrepreneurs) at a fair called *LaMuestra* (The Exhibition).

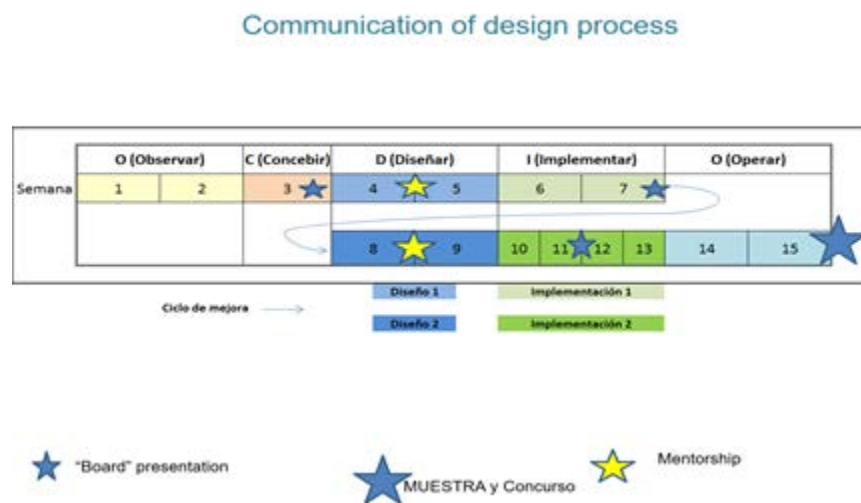In figure 2 is showed the process with the main communication points:

Figure 2. Communication of design process

The spaces devoted to communication during the process are:

-The four moments of validation with the specific user (twice in the Observation, Conception, Design and Implementation stages and once on the Operation one). These activities follow the guidelines proposed in "Running lean" (Maurya, 2012).

- An interview with the problem expert and one with the technology expert, following again the guidelines of "Running lean" (Maurya, 2012).
-Two presentations before the jury board in the Observation/Conception and Design/Implementation stages, consisting of: a jury of 5 members external to the University, a 7 minutes pitch, 3 minutes of feedback and an immediate verdict.

-Two videos that are published in the YouTube channel that is held for this purpose:

- The first takes place at the end of the first Design/Implementation iteration, presenting: problematic, user, proposal and preliminary engineering design. This video is addressed mainly to other engineering students of different disciplines at the junior level. Each student must analyze two projects from other disciplines and send feedback directly to the team responsible of the project:
  - A review of the project based on what was understood after having "explored" its video (maximum one page). This aims to the building of "mirrors" showing the result of their communication effort.
  - Three suggestions that could enrich the project. This furthers a reflection on the possibilities of contributing from their own discipline to the formulation and design of such engineering solutions.
- The second takes place at the end of the second Design/Implementation iteration, presenting: the project, its context and its MVP (Minimum Viable Prototype). This video is addressed to professionals and businessmen. These videos are part of the invitation to alumni and entrepreneurs to visit LaMuestra, an exhibition space in a fair format that takes place during the 15th week of the academic semester. Approximately 140 projects from different disciplines are exhibited and approximately 300 visitors external to the University are received.

-LaMuestra, where each team has a stand to present its project, supported by a poster and the display of the MVP. The public is mainly alumni and entrepreneurs community (aprox. 300). It takes place during the 15th week of the academic semester. Our 25 teams take part of LaMuestra with approx. 140 junior projects from different disciplines. In figure 3 is shown a set of student teams.

-A written report, or a paper to submit to an international congress of innovation in engineering, should be delivered by each team at the end of the term.

La Muestra

Figure 3. La Muestra- Final presentation

CONCLUSION AND FURTHER RESEARCH

An oCDIO space for carrying out engineering innovation projects in teams of students on their 3rd year (junior level) was presented. In this space, a special effort is made towards the development of communication skills, with emphasis on engineering design.

The presence and intervention of actors external to the traditional environment of the engineering school are highlighted. This effort to present the projects and listen to the reactions and suggestions of potential users, connaisseurs of the problem addressed, technology experts and entrepreneurs, has proved to be very enriching for all participants in this process. The use of different media (interviews, videos, pitch, fair, paper) expose students to communication challenges that they will face throughout their future as engineers. Also, an interesting aspect of this exercise is how students learn to listen to the reaction of the different stakeholders of their initiative, especially that of their peers, around the engineering proposals that are being elaborated in the projects.

An additional aspect to highlight is the point in the curriculum in which this exercise is carried out. This type of spaces usually has place towards the end of the career (Capstone project). This proposal, which has been implemented over the last ten years, is done at the junior level so that it can impact on the way students approach their last three semesters of undergraduate studies. Particularly the choice of electives and the orientation of the final engineering project.

A challenge in this process is a longitudinal evaluation of its impact, currently in implementation, both in the students' skills and the attitude towards innovation and communication in the first years of professional life.

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A PLAYGROUND FOR NOVICE ENGINEERS AND BEYOND

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ABSTRACT

The Innovation Playground is a living lab for co-creation accessible for all faculties and research programs situated in the main building of The Hague University of Applied Sciences (THUAS). It has shown to play an important role in building social, learning, and professional communities that reach beyond the intended purpose. Due to budget restrictions, the dedicated staffing and accompanying programming were eliminated. In this case, the fourth challenge on operational scheduling and staffing of the workspace, presented in the syllabus (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014) is encountered. To avoid throwing the baby out with the bathwater, this paper captures the value of the space and programming for its users and types of usage, primary and auxiliary. It answers the key question: what needs do the Innovation Playground fulfil for all its users? It focuses on uses beyond the educational and users beyond the engineering domain. Cases and spaces of multidisciplinary education beyond the technical domain are rare to find within the CDIO body of knowledge. The CDIO framework is optimized for engineering education, yet the value of these spaces for members across an institute (such as internal research partners and external network) is overlooked with this perspective. The syllabus touches upon the community building aspects as a result of the design-implementation projects (for students and faculty staff). The valuable activities, as expressed by its users, are teaching and learning modes that contribute to community building, such as advanced and simple design-implementation projects, collaborative design projects, extracurricular design projects, tinkering mode and self-guided learning (Young et al., 2005). For non-student users, this community building value is endorsed. Other intangible values for non-student users include a space to conduct and reflect on educational innovation, cross-disciplinary educational collaborations, and expanding networks within and outside of the institute to work with real-world clients.

KEYWORDS

Engineering Workspaces, Learning Environments, Relationships between Academia and Industry, Standards: 6.

INTRODUCTION

The Hague University of Applied Sciences (THUAS) has 25.000 students of about 100 nationalities and around 2000 employees. There are 44 bachelor-degree programs taught across 4 campuses. The faculty of Technology, Innovation & Society (TIS) has become a CDIO member for all its 12 bachelor-degree programs (Hallenga-Brink & Kok, 2016).

Inside the main building of THUAS there is a living lab for creativity and co-creation, called The Innovation Playground. Both the space and programming are intended and accessible for everyone. It has shown to play an important role in building social, learning, and professional communities that reach beyond the intended purpose. As a CDIO member, the technical faculty, (TIS) has multiple engineering workspaces in their section of the building. While spaces are in a more remote part of the building and not often visited by other disciplines, the Innovation Playground space, is situated in the central hall of the building. Right next to the entrance of the canteen, visited and visible to everyone in the university.

Since opening in May 2016, the Innovation Playground has gone through three strategic programming phases. This paper focuses on the second phase, where program directors were installed with the aim to foster innovation and collaboration throughout the university.

Aim

The aim of this paper is to analyze and reflect on the experiences of the Innovation Playground in its second strategic phase through the lens of CDIO Engineering workspaces. It answers the question: *what needs did the Innovation Playground fulfil for its users?*
This paper focuses on needs beyond the educational realm and users within and outside the engineering domain.

Firstly, the outcomes may benefit those who plan to effectively operate such interdisciplinary workspaces. Secondly, the results are of interest for technical faculties who are implementing or rebuilding their engineering workspaces. Finally, the outcomes may be useful for other institutes (within and outside the CDIO network) which aim to facilitate and foster creative multidisciplinary education and research initiatives that connect the technical realm with other domains.

Approach

An initial inventory was made on the current operations of the Innovation Playground, *through the lense of the CDIO Engineering workspaces*. Additionally, a grounded theory analysis was made based on 49 written testimonials about the Innovation Playground from a variety of users about how it added value to their work/study life.
Finally, an interview was held with the managing director of the Lighthouse, an organizational unit under which The Innovation Playground falls. The aim of the interview was to contextualize the strategic phases of which this staffing was part and to uncover the intentions and goals of these strategies.

The qualitative research method of 'grounded theory' (Charmaz, 2012) was adapted for the analysis of 49 testimonials. The following steps were conducted.
1. Aligning / triangulating analysis across researchers.
2. Open coding line by line with an emphasis of sticking closely to data. We looked for 'gerunds + noun' such as 'expressing belief'. "Gerunds build action right into the codes. Hence, coding in gerunds allows us to see processes that otherwise might remain invisible." (Charmaz, 2012)
3. a. Collecting codes into different needs (personal, educational, organizational).
   b. Finding narratives within the codes – writing memos (Birks & Mills, 2015).
   c. Categorisation of narratives
4. Communicating narrative.

Collecting codes and finding narratives, steps 3a, b and c, were iterative steps executed by all three researchers in order to reach a cohesive understanding of the documentation used for

internal communications. The approach taken deviates on this point from the grounded theory approach. Birks (2015) explains how a theory is built through successive data collection and analysis. *"Theoretical integrity is growing when the core categories reach theoretical sensitivity and saturation"*. The limited amount of data on the Innovation Playground prevented testing these categories on new data. Even though the iterative approach was used to form a narrative divided into core categories, it cannot be assumed that this resulted in a theory.

Previous CDIO proceedings have been consulted to compare the current operations to the existing body of knowledge. The outcomes will be compared in the discussion.

A limitation worth noting is the context that inspired the written testimonials. These testimonials were written after learning programming and accompanying staff for the Innovation Playground would be eliminated. There could be a variety of motives for writing a testimonial in this situation, but these intentions were not considered and only the contents of their testimonies were analyzed. Another limitation of the study is that it lacks perspective about the Innovation Playground from non-users.

THROUGH THE LENSE OF CDIO WORKSPACES

Standard 6 in the CDIO approach recommends that students "need to be immersed in workspaces that are organized around the Conceiving-Designing-Implementing-Operating" phases in order to "support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning". These workspaces are best supported through a Multimodal Learning Environment (MLE) (Crawley et al., 2014).

The following guidelines, with criteria for the development of these workspaces, have been summarized by Fortin (2008) as follows:
- The term MLE must integrate traditional student work areas, team-based project workspaces, computer-driven collaborative design rooms, manufacturing and prototyping laboratories, and facilities designed for extracurricular activities.
- CDIO workspaces are designed to support the entire curriculum.
- The new space must facilitate student learning of personal and interpersonal skills, group activities, social interaction, and both collocated and distributed team communication.
- The workspaces should be efficiently connected to other common student facilities, e.g. the library, storage facilities, machine shops, etc.
- An MLE can be built from scratch in a totally new building or can be an adaptation of existing physical layouts (redesign) or can be a combination of both (hybrid).

CDIO workspaces at THUAS

At the faculty TIS several MLEs can be identified that meet these needs and where advanced design-implement projects can be executed. Facilities such as project studios and living labs are at the students' disposal for authentic learning experiences, experimenting, and prototyping (Hallenga-Brink & Kok, 2016). As mentioned in the introduction, the Innovation Playground intended to function as an MLE for the entire THUAS, serving all faculties. These include the faculties: Business, Finance & Marketing; Public Management, Law & Safety; Health, Nutrition & Sport; IT & Design; Management & Organization; Social Work & Education; Technology, Innovation & Society; plus an Academy of Masters & Professional Courses, each ranging between 4 and 12 programs. Furthermore, THUAS has 27 research groups aggregated into 4 research platforms: The Next Economy; Good Governance for a Safe World; Connected Learning; and Quality of Life: People and Technology.

The Innovation Playground

The Lighthouse is the center for debate and culture at THUAS. This center offers programming and facilities near the central hall to support their goal to connect across programs and disciplines. Within this center the Innovation Playground fulfills two goals:

1. 'Classroom of the future', offering a space to teachers to experiment and setups and technologies to explore.
2. Bring together and showcase innovative forces, people, initiatives in a visible central place to foster links, associations and collaboration

The workspace has known three strategic phases of programming and staffing. Phase 1 (05/ 2016-12/2016) on opening it was staffed by 1 staff member, primarily with the operation of space in mind and adhering to the first goal. In phase 2 (01/2017-11-2018) the role of program coordinators evolved and became more in line with the second goal. Phase 3 (12/2018-ongoing) is characterized by having no program coordinators intended to create shared ownership and responsibility of coordination and activities. The description below is related to the second phase.

Manifesto of The Innovation Playground

We Play: Innovation starts with experimentation. Nothing is set in stone. Curiosity, openness, and failure approach are crucial for new discoveries. We shun dogmas and prefer to be daring and inquisitive. We welcome all things different and odd.

We Create: Innovation starts with an idea. When we bring that idea to life via the process of creation. We allow ourselves to discover, to be surprised, and to experiment. The process of creation makes an idea tangible and is therefore a prerequisite for Innovation.

We Show: Innovation starts with sharing. Sharing outcomes and methods furthers new insights and ensures progress for future projects. Although we promote intellectual ownership of projects, we support the Open Source / Creative Commons mentality.

We Unite: Innovation comes from diversity. We embrace all people and all ideas. Our activities are open for all. We believe that different viewpoints make for a broader design space and enables us to construct new perspectives and new possibilities.

We Matter: Innovation is substantial. It cannot be achieved in bite-sized portions. Ideas need dedication and focus to mature, grow and prosper. A meaningful result can only be achieved when no stone is left unturned and no question is left unasked. Therefore, time and attention are a necessity.

Written by Carmen Hutting & Chris Heydra,
program coordinators of the Innovation Playground

In January 2017, coordinators for the Innovation Playground were hired. The program coordinator's vision for the Innovation Playground aligned with the educational institution's vision, which focuses on world citizenship, internationalization, and networking. See also Hallenga & Kok (2016) for more background on this vision. The program coordinators' vision entailed a thematic approach for the MLE, which connected activities throughout the institute. Themes included: circularity, sound, food, and art. Their manifesto can be found below.

The space offers working spaces for 32-45 people on both higher and lower tables. The pitching corner can expand to seating for max 70 people. Most of the furniture is easy movable which allows for a flexible space, easily setup to the needs of the activity or usage mode. The wall on the bottom of the floorplan is made of glass, has large doors that can open and connects directly to the central hall of the university. The back walls are painted with chalkboard paint, to be used by anyone. Figure 1 and 2 below give an impression of the setup of the space. Table 1 describes more in detail what happens inside the space.
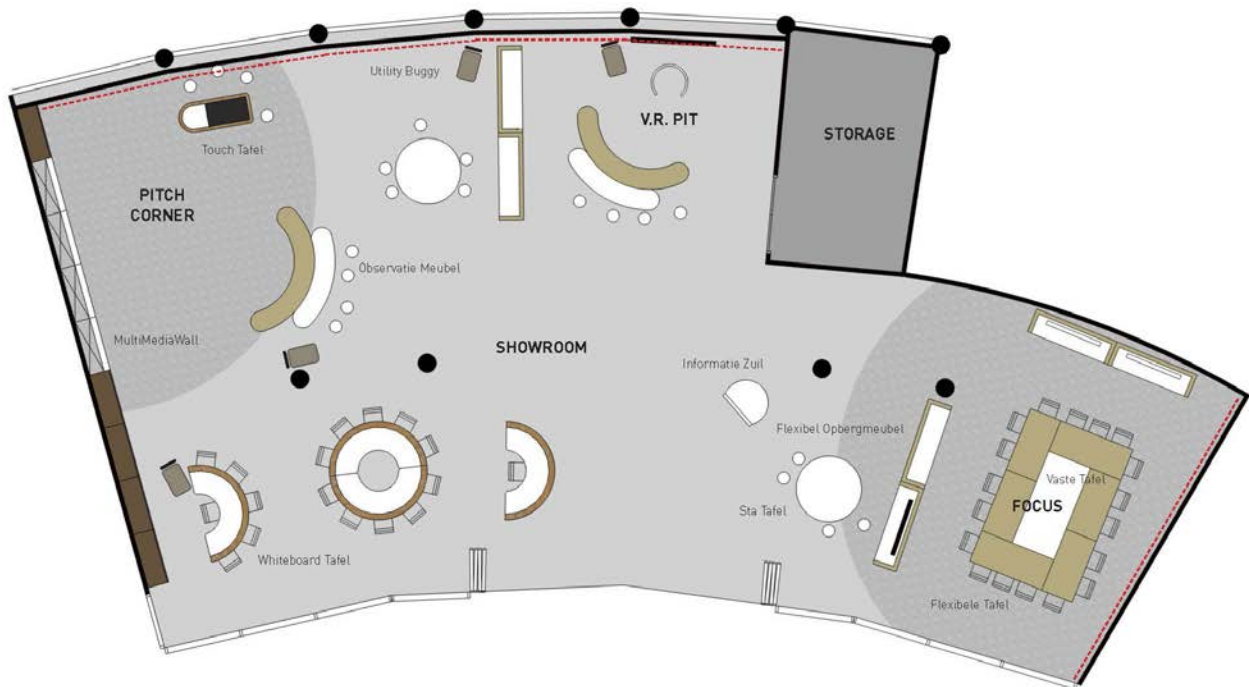
Figure 2: floorplan of the Innovation Playground

Figure 1: images of activities, focus area (l) and pitch corner (r)

Community building as central value

Table 1 shows how the detailed modes were present in the Innovation Playground. The community building detailed modes from the CDIO syllabus are highlighted.

Major modes	Detailed modes	Innovation Playground operations
Product and system designing and building	Advanced design-implement project	Not present
	Simple design-implement project	• 10 week long-curriculum specific projects. • Hackathons, pressure cooker workshops, etc.
	Collaborative design project	• Kick off of projects in this space • A commissioned interdisciplinary project within a theme was hosted every 10 weeks.
	Extracurricular design project	• Extracurricular activities, from 1 day up to 10 weeks. • *Playtime* was hosted once a week, a low threshold activity afternoon often kickstarted with a thematic lunch movie.
	Test & operate mode	• Technology to test and experiment: a VR pit, a green screen, ±4 cameras to operate, 2 movable screens and a video wall and table screen. • IoT building and programming hardware is present.
	Tinkering mode	• Creative office stationery, chalkboard walls, paper, and between 2-6 large Apple computers where present. • Students and staff used it as an extension of their habitats, bringing their practice to a shared collaborative space. • Students worked together to understand and experiment with IoT hardware. • Offering 32-45 spaces for working on high and low tables + benches. • A strict open door policy, where everyone can join everything.
	Linked Projects	• A commissioned project within the theme was hosted every 10 weeks. Several programs could be connected. Several courses within a program could be connected. Research programs were mostly not linked. • Workshops were often guided by IP staff. They actively suggested cross-links between projects and subjects.
Reinforcement of disciplinary knowledge	Class lab / experiment	• 2-3 curriculum-specific educational program projects ran parallel and shared the space throughout the week. Results of these projects were visible for all users.
	Teaching in labs	• Some courses were taught in this space or a lecture was situated here when opened up to a bigger audience.
	Self-directed learning	• Students and staff who came in to study their own disciplinary knowledge found motivation from the people and the space. • Initiatives for activities by teachers and students were supported by the staff and space. This varied from brainstorm sessions to movie nights to quire sessions.
	Lecture / presentation in labs	• A video wall and 2 movable screens made kickoffs and presentations common in the space. Presentations and workshops happened parallelly.
	Interactive electronic class mode	• In classes, students were asked to bring their own laptops.
	Distance learning mode	• A few 1 day projects were initiated that experimented with a live link to another location outside of THUAS.

Knowledge discovery	Undergraduate research project	Not present, internships were offered.
	Graduate research project	Not present
Auxiliary uses	Research design support	• There was a strong link with the research groups who hosted regular and incidental activities. Those with an interdisciplinary nature were welcome. • Research projects were kickstarted in this space. The flexible setup of the space gave ample room for interdisciplinary design and research workshops.
	Income generating mode	• The space was also rented out to internal and external parties – often outside of the regular opening hours – 10:00-17:00
	Outreach mode	• The space was located in the central hall of the main building and often visited by parties and external visitors, to showcase innovative projects. • Expos happened at the end of each semester where students showcased outcomes and products of projects • The program supported extra activities not aimed at university content, but did create awareness. For example a piano that anyone may play on at any time, jam sessions and (home made) beer tasting.

Table 1. Teaching and learning modes in the innovation playground

The CDIO syllabus explains how community building is an emergent mode that occurs when the major modes of use have drawn the students to the workspace, engaged them, and allowed them to interact (Crawley et al., 2014). The table additionally shows how detailed modes, such as 'Tinkering' and 'Self-directed learning' contributed to community building. The community building aspects are elaborated on in the section 'needs expressed by its users'

Reflection on challenges encountered

Taken from the challenges that Young et al. (2005) describe in their paper, the CDIO syllabus elaborates on four challenges experienced with engineering workspaces and stakeholder reactions. Below is described how these are encountered in the context of The Innovation Playground.

1. *The need for a workspace design driven by curriculum and usage modes.*

The location and programming were not curriculum driven. The thematic programming allowed for programs to fit their educational activities within the themed context. There was a limited number of programs who could benefit from a structural place in the programming, as can be seen from the *simple design-implement* and *class lab/experiment* modes in table 1. The workspace design was driven by the openness and flexibility to meet the needs of *all curricula*, not just one. This was a limitation because the space did not play a central role in any curriculum.

2. *Planning for flexibility in usage modes and evolution over time.*

Usage modes were well adhered to by offering flexibility in the space and allowing multiple activities to run simultaneously. The space and interior were intentionally designed to evolve over time and be flexible for a wide range of usage types. Large adjacent storage areas were used to adapt the space to its various needs. Material and machines were bought when the themes and

activities called for it. This allowed for natural growth in the material. As an example; throughout the theme 'sound' the number of instruments in the room steadily grew. A piano and guitar remained in the space several months after the theme had ended.

3. *Safety concerns and extended access, and operational issues.*

To support the operations of the Innovation Playground, students took on volunteer roles, became interns, and sometimes got paid jobs directly supporting the space. Regularly visiting students and staff were added to the key-list, which allowed them to access the space within the regular opening hours of the university (between 08:00 and 23:00).

4. *Operational scheduling and staffing of the workspace.*

As attractiveness of the space grew, scheduling activities became more difficult. There was tension between the Innovation Playground's own programming and the requests of curricula to use to space. Early on, a strict policy was established that only activities that matched the current theme were allowed to utilize the space. However, this resulted in too little involvement from all academic programs. A looser policy was later adopted which resulted in a crowded playground where not all curriculum requests could be fulfilled. It required diligent efforts by program coordinators to oversee the use of space, alongside academic instructors. While they managed the space usage, program coordinators also suggested relevant resources and helpful network connections to Innovation Playground users.

NEEDS EXPRESSED BY ITS USERS

Through the analysis of the testimonials, we were offered a unique inside perspective of frequent users of the playground, among them students, teachers, researchers, team leaders, program committees, and external partners. For the analysis, we used the qualitative research method of 'grounded theory' (Charmaz, 2012). The narrative below is the result of the final steps of analysis. The narrative can be read in the first column, an expression of each element can be found in the second column.

Innovation playground offers…	
a home space	*the need for a physical location that acts as a safe home base for both students and faculty, Dutch and internationals.*
to global citizens	*a firsthand experience into an open, explorative environment needed for driving curiosity in a globalized world.*
Who are looking for…	
human connection	*the need for a fertile environment for starting relationships and growing networks with colleagues and students, in and outside of faculties.*
belonging	*There is a need for a positive and engaged community that supports new endeavors, treats everyone equally (faculty, students, all studies) while still valuing individuality.*
personal development	*There is a need for a launching pad that inspires change and growth on a personal level.*
Who are experiencing…	
unique atmosphere	*Experimental, curious, playful, inviting, and comfortable. It makes for a unique environment for learning, where education can occur that does not have a place anywhere else in THUAS*

magic of discovery	*A mode in which you allow yourself to be surprised, driven by curiosity, and sparked by creativity. It takes form in venturing miraculous projects and doing innovative things.*
boundary crossing	*Venturing creatively and across boundaries into complex wicked problems.*
becoming a professional	*In an environment where all people are considered equal in their contribution, students feel invited to be part of the experience.*
Who are finding…	
educational test field	*a place where teachers have room to experiment with learning methods and forms with actual students.*
localizing expertise	*Involving people from within and outside of THUAS into educational and research activities/programs. Tapping into a network and experiencing their (and your own) willingness to contribute.*
fostering networks	*Bringing to life what it means to be a network university in a practical and purposeful way.*
Who are seeing…	
embodying vision	*There is a need for concrete realization and manifestation of the organizational vision ('Let's change') and strategical (WIN) themes.*
incongruency	*When decisions are not in line with a vision, it is felt. Action contradicting policies weakens the trust in and connection to our narrative.*
dissonance	*Too often decisions in the organization are made with little regard to the educational rhythm, the need to support education continuously, or guidelines within the organization.*
And experiencing…	
campus facilities	*Facilities at THUAS are valued low in the NSE scores, there is a need for better facilities.*
external relations	*External partners (research and educational) express their appreciation for a place and programming like this. They are brought into the Innovation Playground and connected directly to students, staff, researchers, and new ideas.*

Table 2 Narrative of needs in categories

The outcomes suggest community building aspects are especially valued by Innovation Playground users. We also see that the value of the space and its programming goes beyond the educational opportunities it offers to the students. Teachers notice fertile grounds and find peers to experiment with, reflect on and evaluate educational forms, which are often cross- or interdisciplinary.

To regard only the users of the innovation playground is an isolated perspective; the testimonials are embedded in a context and also serve as a reflection on the current state of the university's facilities and its vision. The two final categories in the narrative address this.

DISCUSSION & CONCLUSION

The CDIO framework standard 6 offers insight into how to design facilities to fit with the phases c*onceive, design, implement, operate,* and situate them in the building and in relation to each other. Standard 5 offers insight on how to embed these working spaces into curricula of engineering education through design-implement experiences. The different usage modes and challenges of the engineering workspaces are discussed. A see-saw effect appears when wanting to adhere to standard 5's call to be curriculum driven. Focusing on one curriculum made it challenging to stay open to all programs. The vision of the Innovation Playground set out to create their own thematic

programming. Since there were so many curricula to adhere to, the space was not inherently driven by them. Through the themes, a connection was often found for various programs which allowed them to facilitate their educational programs within these contexts. The themes allowed for and invited cross- and interdisciplinary work, something that is much desired, yet difficult to facilitate, in the educational practice of this institute.

The outcomes of the testimonials and analysis of the activities result in seeing that the community building activities are highly valued by the students and staff. This is in line with what Young et al. concluded; that the workspaces play a central role for building communities amongst students (2005): (…) *Students use the spaces to study disciplinary courses and for social functions. The workspaces can _also_ provide facilities for student clubs devoted to tinkering, model-building, and other extracurricular projects. This accounts for both the students and staff members using an MLE.* Even though the curriculum activities might have persuaded the students into this space, it is the community building activities that invited them to explore beyond their discipline and regular activities. The extra-curricular activities that were organized felt like a home space to the students.

There are two facets relevant to the research findings that are underexposed in the CDIO framework and guidelines. The first is to what extent a place like the Innovation Playground offers room for reflection and educational innovation among teaching staff. Staff indicated this space was an enrichment to their educational development process, with the added bonus that students interacted with other disciplines.
The second facet involves the audience beyond the engineering domain. Previous conference case descriptions of engineering working spaces offer insight in how these spaces contribute to the learning outcomes specifically for engineering education. Unfortunately, they lack insight on how to design MLE's relevant for creating a context beyond engineering education. A larger context offers opportunities and encourages behavior that aligns with the extended CDIO syllabus on Leadership & Entrepreneurship.

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BIOGRAPHICAL INFORMATION

We, three THUAS residents, researched the needs that environments like the Innovation Playground fulfil. Through this research we are experiencing and understanding the full and actual value of the Innovation Playground. It was executed by us voluntarily, we were not paid or asked to do this, just intrinsically curious to the magic of this place.

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Redesigning Thermodynamics Labs with a Design-Implementation Experience

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ABSTRACT

We redeveloped one of the second-year thermodynamics labs into a Stirling engine design lab. This paper discusses the project components and deliverables of this design-based lab. The five-part project, completed over the course of the semester, challenged students to design and build a functional Stirling engine, guided by specific technical and reflection questions. In addition, the project was designed with the intention to create a stress-free opportunity for students to fail, to ensure that student time-on-task was minimal and meaningful, and to provide meaningful teaching and learning opportunities for graduate teaching assistants.

This paper presents student feedback to the design-based lab, and lessons learned from the instructors and facilitators. Overall, this work provides insight into an active learning, design-based approach to a second-year thermodynamics laboratory (Design-implement experience, Standard 5).

KEYWORDS

Design-based learning, thermodynamics lab, active learning, Stirling Engine, Standards: 5.

INTRODUCTION

Second-year thermodynamics courses provide foundational skills for chemical engineering students that they will build on during the rest of their education. Laboratories makes up a large component of these courses, and are intended to help students visualize and gain a deeper understanding of the material taught in lectures.

We noticed that the lab components of these courses, many of which had not changed for many years, were set-up so that students could passively follow a lab manual to achieve pre-determined results, and then write a lengthy lab report that was disconnected from the rest of the course material. Students found the labs to be "make-work" projects that were time consuming and did not contribute to their understanding or application of the technical material.

At our University, a CDIO approach was used to redevelop one of the second-year thermodynamics labs into a Stirling engine design-implement experience (Crawley, 2014). The five-part project, completed over the course of the semester, challenged students to design and build a functional Stirling engine, guided by specific technical and reflection questions. Deliverables included thermodynamics calculations and reflections on their experience.

This paper will be structured as follows. First, a brief discussion of how the Stirling engine project aligns with the requirements of a CDIO design-implementation experience. Following this, will be a full description of the five-part project, as well as reflections from the course instructor and TA. The paper concludes with lessons learned and future work.

DESIGN-IMPLEMENT EXPERIENCES

The CDIO initiative is designed to support increased technical understanding of material, and also put students in real world engineering situations to foster professional skills. Students work through four stages: conceive, design, implement, and operate. For a full description, see Rethinking Engineering Education (Crawley et al., 2014). This paper will focus on the design-implement experience, which is standard 5 of 12 of the CDIO program, and is considered a critical opportunity to teach both engineering skills and technical fundamentals.

These experiences mimic the real world and set a foundation for disciplinary skills which help students in their early careers as engineers. They are designed to reinforce understanding of product, process, and system development, set a foundation for deeper conceptual understanding, and increase connections between technical material and professional interests. The design stage focuses on creating the plans, working drawings, or algorithms that describe the project. The implement stage involves transforming the design into the product solution. The experiences strengthen fundamentals through repetition, are active and experiential, and tend to be motivating and fun (Crawley et. al., 2014).

The CDIO conference proceedings showcase many examples of successful design-implement projects. Kontio et. al., 2017 found improved student satisfaction and self-esteem, deepened understanding of material, and professional growth including communication. Vo et. al., 2017 found the experiences to improve self-learning, problem solving, communication, teamwork and knowledge acquisition, and in Piironon et. al., 2017, students felt more prepared for careers in the workplace or in research. Design-Implement experiences are one of the CDIO standards, and they are distinct in their requirements (Crawley et al., 2014):

- Resemble engineering practice in the field of the discipline
- Are realistic enough to challenge students when relating theory to practice
- Develop working modes relevant for students' professional development
- Are aligned with a set of explicitly formulated learning outcomes primarily related to – Integrating, applying, and reinforcing disciplinary knowledge – Developing engineering skills, such as product, process and system design and implementation skills – Developing personal and interpersonal professional skills, such as teamwork and written, oral and graphical communication
- Emphasize and assess these learning outcomes rather than the project goals per se
- Include aspects of design, implementation, and verification
- Are open-ended and allow alternative paths to alternative solutions
- Are fully integrated into the curriculum

Other Considerations to Foster Student Learning

In addition to the design-implement criteria, other factors were taken into consideration in the design of the experience. Specifically, we will discuss three main principles that we aimed to achieve in the project execution: stress-free opportunity to fail, student time-on task and teaching assistant training and mentorship.

Stress-Free Opportunity to Fail

In increasingly complex technical environments, learning to manage, embrace, and learn from failure is increasingly important (Marinovici 2005). Traditionally, in design-implement experiences, the difficulty is chosen so that success is possible if the work is done well, but finding this level of difficulty has been a challenge for previous researchers (Vo, 2017).

This project chose a Stirling engine because it relates to the primary technical components of the course, and is an interesting project. However, the task of building a Stirling Engine is quite challenging for second-year students, and we did not want students to perceive a non-working engine as a failed learning experience (Marinovici 2005).

For this reason, we designed our assessments to help students understand the difference between product performance and learning performance. We did not give credit for fully working engines, and instead gave credit for each step of the design process. While ultimately engineering students must learn to build working designs, we opted to give students a more interesting design task, and remove the stress of complete functionality. Students were expected to complete a Stirling Engine, that is, they were expected to procure or build and assemble all components of the engine. In their meetings with other students and the instruction team, students were expected to describe the functionality of each component, discuss what was not working in the engine, and suggest modifications that could fix the problems. To give credit to teams with working engines, we had a competition with prizes.

This non-traditional assessment helped students understand the primary learning outcomes for this project were to solidify knowledge and increase confidence through the application of theory in a practical project. It also provided an opportunity for students to learn that it is possible to experience positive learning benefits even if a product is not functional (Vo, 2017).

Student Time-on-Task

One of the challenges of design-implement experiences as mentioned in Crawley et al., 2014, is that students have competing demands on their time, and time on task for any project must be carefully monitored. Lichtenstein et al., 2010 further state that the demands of an engineering curriculum often force students to choose between acquiring practical skills and other enriching experiences.

There was concern if too much time was focused on building a functional engine, students may feel overwhelmed by the design aspect of the project and would lose sight of the connection to the technical material. To prevent this, students were given worksheets each lab session that helped focus their attention for that working period, as well as explicitly make connections back to the material from lectures. These worksheets were completed collaboratively with their team, which further encouraged students to reason, explore, and reflect on the project, an important aspect of design-implement experiences (Crawley et al., 2014).

Teaching Assistants Training and Mentorship

To further assist in student construction of knowledge, teaching assistants (TAs) were given training to help them support and mentor students in the project. A training workshop was developed for the TAs to help with the Stirling Engine concepts. During the semester, several of the TAs assembled a Stirling Engine of their own to compare to the students designs. The instruction team met informally to discuss specific technical content and mentorship strategies.

DESCRIPTION OF STIRLING ENGINE PROJECT

The first simple engine which used heat from fire to produce work is credited to Thomas Savery in 1698. Despite utilizing energy in the form of heat, that heat was not converted to useable work for tens of thousands of years. In this project, students were given a few lab sessions to accomplish this goal by creating a Stirling engine that will do work to raise a quarter. Their challenge came from the constraint in time, budget (and therefore the use of rudimentary materials) and minimal amount of heat. The act of designing and testing the device gave them the opportunity to analyze the conversion process using concepts learned in thermodynamics and provided valuable hands-on experience.

Students were assigned to teams of 4-5 students for the design project. Each lab section had 100 – 125 students registered. The teaching team consisted of the course instructor, an undergraduate student teaching assistant, and 5 – 7 graduate student TAs.

Description of the Five-Part Project

Lab 1:
The end goal of this lab session was for the student teams to come up with the preliminary design of their Stirling engine. For the last 20-25 minutes of the lab, the teams were directed to present their design in a "Network" of 2-4 other student teams.

During the lab, the students watched a classroom demo of a store-bought Stirling engine rigged up to raise a quarter. During the demo they recorded the necessary data to calculate work done on the quarter, heat released by the heat source and thermal efficiency of the Stirling Engine. The worksheet completed in the first lab session consisted of questions about the theory of the Stirling engine, calculations of the classroom demo, and finally descriptions of their preliminary design. After deciding on their design, students completed a worksheet regarding the safety hazards and mitigation strategies for their design. They had to think about the safety hazards present during the construction of the engine (depending on what tools they were going to use) as well as the hazards in the heat source chosen (if there were any).

Completion marks from this lab session came from the Stirling Engine worksheet and the safety worksheet.

Lab 2:
The end goal of this lab session was to have the first design built. For the last 20-25 minutes of the lab, the teams met with their network to discuss their progress.

This lab session was primarily unstructured building time for the students. We provided some basic materials needed such a balloons, cardboard, wires, tools, etc. and the students were also encouraged to bring their own. The only worksheet for this lab session was about safety hazards. Lastly, before leaving, groups completed a peer evaluation for their group members.

Completion marks from this lab session came from the safety worksheet, testing their design, and the peer evaluation.

Lab 3:
This optional lab session was provided as unstructured building time for the students. This session had no deliverables, so the students just focused on completing their engine.

Lab 4:
The end goal of this lab session was for students to perform a preliminary test of their machine in their networks.

In the lab session, teams had to complete a worksheet, which consisted of specific and reflective questions about their design process, as well as descriptions of the final Stirling engine design and sample calculations for amount of heat transfer from their heat source. Finally, they needed to update their safety hazards and mitigation strategies if their design had changed from last time.

Completion marks from this lab session came from the design analysis worksheet, the safety worksheet, and testing their design.

Lab 5:
This was the final lab session of the semester. This is when the final testing of the Stirling engine took place!

The groups tested their engine right away in the beginning of the lab. Right after testing, they got started on the thermodynamic analysis worksheet which had to be completed before the end of the lab session. This worksheet consisted of thermodynamic calculations for their engine, the PV diagram of a Stirling cycle, and a reflective analysis. They also had to update their safety hazards and mitigation strategies if their design had changed from last time. Also, the groups needed to show their bill of materials sheet along with the receipts to ensure they did not pass the budget. Lastly, the groups were required to complete another peer evaluation, but they had one week from the final session to complete that.

Completion marks from this lab session came from testing the final design, the thermodynamic analysis worksheet, the safety worksheet, showing the bill of materials, and the peer evaluation.

Exams:
An exam question on the Stirling Engine was included in both the final exam and the midterm exam to evaluate student learning. The midterm exam took place after the first Stirling engine design lab and before the second. Class average on the midterm exam question was 60%, which indicated that many students were not understanding the application of the course concepts to the working Stirling Engine. Class average on the final exam question relating to the Stirling Engine was 75%, indicating that the students became more comfortable with the concepts as the term progressed.

Using the Stirling Engine Project as Design-Implement Experience

Overall, the Stirling Engine Project was a great case study application of a design-implement experience. Below, in Table 1, a mapping is showing of the activities in the Stirling Engine Project to the essential attributes for design-implement experiences as outlined by Crawley et al., 2014.

Table 1. Mapping of Stirling Engine Project Activities to CDIO Guidelines on Design-Implement Experiences (Crawley et al., 2014)

Essential Attributes of Design-Implement Experiences	Application in Stirling Engine Project
Resemble engineering practice in the field of the discipline	• work collaboratively in group, and work with deadlines • design solutions for open-ended engineering problems • use a variety of tools • safety training
Are realistic enough to challenge students when relating theory to practice	• students required to use appropriate knowledge and skills to formulate, analyze, and solve engineering problem (ie. build Stirling engine)
Develop working modes relevant for students' professional development	• develop interpersonal skills as well as team working skills such as leadership and working with others • student had to work efficiently and manage their time in order to complete the worksheets within the lab session.
Are aligned with a set of explicitly formulated learning outcomes primarily related to: – *Integrating, applying, and reinforcing disciplinary knowledge* – *Developing engineering skills, such as product, process and system design and implementation skills* – *Developing personal and interpersonal professional skills, such as teamwork and written, oral and graphical communication*	• Most students had never heard of a Stirling Engine, so it was a learning opportunity where they got to research and learn more about it as they faced the challenge of building one. • Students reinforced their knowledge in every step from the planning to the execution, and finally the analysis. • Working collaboratively with colleagues and friends also improves interpersonal skills such as speaking and listening as well as supporting professional growth.
Emphasize and assess these learning outcomes rather than the project goals per se	• success of Stirling engine was not graded • the worksheets testing knowledge of theory were marked • students to focused less on making the engine work, and more on understanding the concepts behind it
Include aspects of design, implementation, and verification	• Creating a device that converts heat to work, such as a Stirling Engine, requires a plan, design, and execution. • Although not marked, the engines were also tested at multiple steps see if it could raise a quarter.
Are open-ended and allow alternative paths to alternative solutions	• Project was designed open-ended so the groups got a chance to research, discuss, and plan together • We also encouraged them to use their own materials, 3D print parts, etc. to create an engine any way they wanted
Are fully integrated into the curriculum	• This design project allowed students to get a apply the classroom theory to their hands-on experience of building an engine.

FEEDBACK AND REFLECTIONS

Student Feedback

When a significant change is made to a course, there are often many bumps and kinks to work out and student feedback can see a huge decline in the first year. The instructor teaching the ENGG 311 course had previously received scores on her end-of-year evaluation around 6.4/7.0. The first year of the Stirling Engine Project, her scores maintained a 6.0/7.0, which is still above the faculty average. This shows student perception of the new lab was very positive. Students were prompted to complete an online survey about their experience. Major results are highlighted in Table 2 below.

Table 2. Summary of Student Feedback

Question	Summary of Responses
Did the design lab help you understand the following course concepts?	90-95% of students responded "agree" or "strongly agree" on all questions: • Evaluating the efficiency of a power cycle • Performing energy balances on closed systems • Evaluating the maximum theoretical efficiency of a power cycle
What did you learn from the lab section?	48% said helped with course content 20% mentioned teamwork skills 15% learned challenges of design and complex problems
What could improve the lab component?	25% different building materials available 17% more guidance/ better TA support 20% no changes were necessary 5% more time 4% marks for a successful working engine
How many hours outside of scheduled labs did you spend working on Stirling Engine?	28% zero hours 51% 1-5 hours 13% 6-10 hours 0.7% 10-19 hours 3% 20+

One of the teaching assistants provided the following feedback comment, which is a good summary of the student feedback:

When I went around and asked the students if they preferred this lab structure over our traditional labs, they unanimously agreed. They said this gave them hands-on experience which they found useful as an engineer in the making. They also said they feel like they learnt more doing this because they got to build a device on their own, do trial and error to fix their mistakes, and while doing so, they got to understand in depth what is happening. Some of the replies I got when I asked around were:

"I would have this lab over any of the previous labs I have done in engineering, this was a lot of fun and I actually feel like I learned something."

"I think the best way to learn something is to do it, and this is exactly what this lab was. You really had to understand everything that was going on in order to make any changes".

"Thank god you changed it for our year."

From the instructor perspective, she observed students generally were having fun in the lab, there was always a high-level student engagement and energy in the room, and there was a higher rate of attendance. While working with the students, she was also able to observe those "aha" moments with respect to their understanding of energy balances on multiple systems that interact with each other. A colleague and previous instructor of the course, wandered through a few of the lab sessions and said, *"the students are very engaged in the projects, and are clearly enjoying the opportunities these sessions provide in creativity, design, teamwork, and the hands-on active learning."*

Instructor and Teaching Assistant Reflections

At the completion of the course, reflections were gathered from the teaching assistants who facilitated the lab and the instructors. They were given the following questions for their reflection, but these were meant as prompters and they were not limited to these questions or required to answer each:

- How did it go?
- How did it feel?
- What worked well?
- What would you change?

Generally, the comments from the teaching assistants and instructors on *what worked well* fell into four categories: Learning Thermodynamics, Hands-On Experience, Level of Engagement, and Teamwork. In Table 3, we included sample reflections and quotes to highlight each of these four categories. Overall, the students seemed to have a good time and were able to apply the technical concepts they were learning in class. Generally, most teams seemed to work well together and benefit from the teamwork. Perhaps this was an outcome of having only completion marks associated with the worksheets, so there was less pressure on team members contribute towards getting marks and they were just able to focus on learning.

In terms of areas for improvement, the feedback focused on two main areas: more emphasis on technical concepts, and that not all team members were engaged. See a summary of comments in Table 4. Most of this feedback stems from the fact the lab was designed with team assignments for completion marks only. Although most students were engaged and motivated by the hands-on project in itself, this type of design allowed for some students to not participate and be "loafers" or "free-riders". The feedback below also indicates that there would be opportunities for improvement in ensuring the students are able to apply the concepts they are learning in lectures to the labs with more thermodynamics problems required in the lab.

Table 3. Summary of TA and Instructor Feedback on What Went Well

What Went Well	Feedback from Teaching Assistants and Instructors
Learning Thermodynamics	I found it very exciting and highly related to the thermodynamics. This taught them patience and a life lesson that 'failure is okay' [while learning technical concepts], and that is something everyone needs to accept and learn from. First session about compression and expansion of gasses was really good. especially the calculations and questions part. I think after doing all calculations they could figure out the main concept of that part. The idea of practical implementation of what the students learn in class is great as it emphasizes the importance of the concepts taught class. Some students had "aha" moments with respect to energy balances on multiple systems that interact with each other.
Hands-On Experience	I think the best part about this design lab is the fact that students got hands-on experience with various building tools and collaborated with one other to try to build a functioning device; and that is what engineering is truly about. They learn how they should start a project (even by searching in YouTube) and make progress. Also, they learned other engineering knowledge like Mechanical and Civil engineering which was unique. It also paves the way for the students to picture how real life projects are being built starting from theory and going through the design phase and ending with actual construction.
Level of Engagement	High level of students interacting with each other. Watching the students so confused and annoyed in the first lab, to happily making a 2nd or 3rd prototype of the engine by the end really showed that they cared about this lab. High level of student engagement. High energy in the room.
Teamwork	Students have the experience to create an engine in a cooperative group, work together, find problems, collaboration and solving them. Very few groups had group dynamics problems (2-3 out of 55) The Stirling engine part were really interesting. It helped them to work in a group and improve their teamwork skill.

Table 4. Summary of Feedback on Areas for Improvement

Areas for Improvement	Feedback from Teaching Assistants and Instructors
More Emphasis on Technical Concepts	Several students asked me that they could be given some instructions how to make the engine? In my opinion, it would be good to remind them reducing the fractions and making it airtight, etc. If the students could find the chance to do the experiment themselves or provide a video to show a complete experiment procedure and make them to watch before, would help them to understand it more. Many students still struggling with energy balance concepts. I think if we could give them one question (related to thermodynamic and stirling engine) to solve at the end of each session would help them to find the relation between theory and practice.
Not All Team Members Engaged	There were some students who did not involve so much and did not collaborate with other members of the group but it was in minority. I had to ask my groups to go and take a look at the setup and some of them refused to do so. They just finished their worksheet calculation with the provided data. In my opinion, since it is just completion marks, I would have each student fill a worksheet (even before the lab) as oppose to a group worksheet because some groups just divided the work and not all the members were involved in filling the sheet.

DISCUSSION AND CONCLUSIONS

The second-year engineering thermodynamics labs were re-designed from a scripted laboratory exercise to a design-based experience.

The lab session deliverables were intentionally designed to give students a hands-on design experience, to specifically tie the design experience to the course material, to allow the students an opportunity to fail in a low-stress environment, to ensure that student time-on-task was minimal and meaningful, and to provide interesting teaching and learning experiences for the graduate teaching assistants.

Overall, the lab re-design was successful. Each lab session was designed with specific deliverables, including performing thermodynamic calculations learned in lecture and describing the engine in terms of the definitions learned in lecture. Students self-reported that this technique helped them understand course content. In addition, TAs and the instructor saw some "Aha!" moments when working with students in the lab. A question on the Stirling Engine was included in both the midterm and the final. Class average on the midterm question was 60%, and class average on the final exam question was 75%, indicating that student understanding increased through the semester.

The task of building a working Stirling Engine was suitably challenging for second year students. All of the students were able to build a Stirling Engine in the semester, however only 3 of the 55 teams were able to build a *working* Stirling Engine. In order to create an environment where students were safe to fail, (and to minimize the de-motivation that can happen from such a challenging task) completion grades were assigned for the completion of the engine, not its final performance. In addition, the instructor gave a "pep talk" on failure in the middle of the term. Student feedback did not seem to indicate that de-motivation from not being able to make the engines work significantly impacted their experience.

Student time on task was an important consideration in the design of the labs. Student feedback indicate the time spent on this project was reasonable. It was possible for teams to complete the project entirely in the 5 scheduled 3-hour labs. This is great for teams who cannot find time to meet outside of class, or students who would prefer to focus their time on other courses. On the other hand, the few students who spent large amounts of time outside of class (6 students reported spending 20+ hours) were students who were passionate and excited about the project. These few students who were excited about the project took to opportunity to 3D print components, visit welding shops, or develop matlab simulations of their machines.

A training workshop was designed for the graduate student TAs at the beginning of the semester. Student feedback indicates that the TA support was helpful, but it was not as significant a help as it could be. Recommendations for future offerings include:
- Ensure that several of the TAs assigned to this course have been involved it the Stirling Engine design course at least once
- Continue TA training workshop. Increase the focus on mentorship strategies.
- Require that the TAs build a Stirling Engine themselves with the students.

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USING PRINCIPLES OF SCRUM PROJECT MANAGEMENT IN AN INTEGRATED DESIGN PROJECT

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ABSTRACT

Agile project management principles have been applied in a variety of settings to improve team communication, professional development and collaboration. Specifically, "Scrum" is a process used in agile project management in order to have short, iterative sequences to provide frequent feedback on the final product. In an integrated learning stream at the University of Calgary with an integrated design project, principles from Scrum were used to help support the student design project and their learning process. Specifically, using key ideas of Scrum, students were able to better visualize the steps required to complete the final design project. This paper provides an overview of the scaffolding of Scrum activities to introduce the concepts of agile project management and then apply these to their own design project.

KEYWORDS

Scrum, Agile Project Management, Design Project, Lego Learning, Standards: 7, 8.

INTRODUCTION

Scrum is an agile project management process. Simply put, Scrum provides a framework for having short, iterative timeboxes (usually two weeks) to provide frequent feedback on the product being developed. Scrum was initially introduced for software development (Rubin, 2012) however, principles from Scrum and Agile Project Management have begun to be applied in a wide variety of other disciplines such as product development (Ovesen, 2012), design thinking (Häger et al., 2015), and support organization processes (Sheth, 2009).

This paper discusses the application of Scrum principles to an integrated learning experience at the University of Calgary. As outlined in CDIO Standard 7, integrated learning provides students with technical content knowledge while also fostering interpersonal skills and system

building skills. The Scrum processes used through the design project were able to support the bridging of this connection between technical theory, application of knowledge and developing interpersonal skills.

First, an overview of scrum and agile project management processes and terminology is provided. This includes a summary of examples of others applying Scrum in post-secondary education settings. Second, a description is given for the context of the specific integrated course design. Lastly, the design and implementation of the first two Scrum activities are described in detail.

OVERVIEW: SCRUM AND AGILE PROJECT MANAGEMENT

In 1993, ideas from a concept being used in product development in Japan called "Scrum" were applied to software development processes (Rubin 2012). Scrum was brought in a solution to the challenge of keeping up with the fast pace of technology development. It was no longer acceptable to be using code that was multiple years old, and software companies needed to keep up. Scrum was helpful in achieving this due to the iterative nature of the structured "sprints" in the Scrum process.

Simply put, "Scrum is an agile approach for developing innovating products and services" (Rubin, 2012). The end product is achieved through completing multiple timeboxed iterations, commonly two-weeks, but can range from one week to one month in length. During this timebox, the team completes pre-determined product components, including the designing, building and testing. At the end of the timebox, the product components should be ready to go into production and completed features are reviewed with stakeholders to get their feedback. These agile processes allow continuous validating and comments between the product and the customer expectations (Häger et. al., 2015). By presenting a "final" product every two weeks, the iterative feedback process is much more effective at moving the product towards the goal.

A handout on the critical terminology of Scrum was prepared for the students to introduce Scrum. For readers unfamiliar with Scrum terminology, we have included this handout in the appendix. Specifically, for the context of this paper and the implementation of Scrum in our classroom, it is important to understand *backlog*, *sprint*, and *retrospective*. The *backlog* often resembles a task list. However it should also be focused on the features requested by the customer. A *sprint* is a fixed-length iteration during which the sprint backlog items are turned into "potentially shippable product". The intent behind a sprint is that at the end of the sprint, the team has accomplished something that resembles the final product. These short iterations towards a final product allow for critical and clear feedback on the progress. A *retrospective* is a meeting following the completion of a sprint to identify improvements to be incorporated in the next sprint. The intent is not to focus on the tasks or too many details, but rather move forward with a goal of continuous improvement, particularly in terms of team processes.

It is important to note that the application of Scrum in industry environments varies widely, and generally all companies will vary the principles of Scrum to fit their needs. One study of ten companies implementing Scrum found that all companies used variations of Scrum (Diebold et. al., 2015). The least variation was seen in Sprint length, events, team size, and requirements engineering (product backlog). There was large variation seen in team roles, effort/complexity estimations and quality assurance. This is important to keep in mind, as there are many different iterations of how Scrum can be implemented in industry and in the classroom. Both from this study and from the authors' experience, organizations do not conform directly to the Scrum principles and Scrum is most effective when modified to suit the specific context.

Scrum as a Learning Tool

Scrum has been used across multiple learning contexts in postsecondary education. Sarang-Sieminski and Christianson (2016) discuss the implementation of Scrum to Capstone Design projects as a project management tool. They found that by the end of the semester student teams had consistently stuck with three of the Scrum artifacts they were using: sprint review, the role of Product Owner, and role of Scrum Master. Students reported that these three artifacts, as well as the Sprint Board, were helpful in the progress of their project.

In contexts outside of engineering, Scrum has been used as a tool to foster collaboration amongst students. For example, Scrum principles were adapted to an upper-level Publishing elective in order to help students better see themselves as collaborators and encourage professional communication (Pope-Ruark et al., 2011). One student in this course reflected, "[Scrum] is just a fantastic way to discuss the problems everyone has with projects and is a sort of safe place to admit that you are confused or have problems with an aspect of the course or project." Other courses in communications (Opt & Sims, 2015) and professional writing (Pope-Ruark, 2012) had similar findings, where students found that with Scrum there was increased team member communication and reduced team conflict.

When Scrum is introduced in classroom settings, often a game design is used to provide foundational background on Scrum principles and methods. For example, there is a quick activity called the "Ball Game" intended to help participants experience the effects of self-organizing teams. This was applied for students in a systems analysis and design course, which was found to be a useful starting point for aa discussion on Scrum principles (May, York, & Lending, 2016).

CONTEXT: INTEGRATED LEARNING STREAM COURSES

There is substantial research and initiatives globally to increase the quantity and quality of design in engineering undergraduate education. However, even when creating innovative design opportunities for students, often instructors are constrained by the silos of individual

courses. At the Schulich School of Engineering in the University of Calgary, a pilot project was implemented where all five courses for second-year electrical engineering students were designed and delivered in an *integrated learning stream* (ILS).

In this integrated learning stream, the material for all five courses is covered in a collaborative environment with content that connects the courses together (see Figure 1). There is a series of active learning experiences where students learn the material of all of the courses in more of a free-form way, putting the material in the context of real-world situations. Two key components of this course are described here to provide the context for the Scrum and Agile Project Management activities that were designed to support the primary course activities.

Figure 1. Integrated learning stream course structure.

Integrated Design Project: Audio Player

For the students participating in the integrated learning stream, there is one overarching project driving the learning throughout the semester. Specifically, the project is the design, construction, and testing of a simple portable audio player, which could have an application to e.g. allowing autistic children to express themselves easier. Component pieces of this include (a) memory design for storage; (b) Analog-to-digital and/or digital-to-analog conversion; (c) filtering; (d) amplification; (e) LED indicators; and (f) power management.

Learning Communities

A learning community can simply be defined as "groups of people engaged in intellectual interaction for the purpose of learning" (Cross, 1998). Within an academic context specifically, this means deliberately structuring the curriculum so students maintain an engaged academic relationship with their peers and/or faculty member over a period of time (Minkler, 2002). The ongoing social interactions fostered in learning communities help students develop their own voice, and gives them a worldview perspective on what they are learning. Additionally, engagement in learning communities with peers at the University-level was found to be positively linked with academic performance, engagement, attendance, and overall satisfaction (Zhao & Kuh, 2004).

For these reasons, at the beginning of the term, students in the ILS were placed into learning community groups of 5-6 of their peers. The purpose of these communities is to provide students with a peer support network. All their labs and group projects come from these learning community groups, in variations of groups of 3 or 6. Throughout this paper when discussing the Scrum and Agile Project management, the teams mentioned are the learning community groups.

DESIGN AND IMPLEMENTATION

The Integrated Learning Stream course was scheduled with three main parts:
- Week 1: Introduction, Team Building
- Weeks 2-9: Blocked courses, Integrated knowledge building, Project brainstorming
- Weeks 10-12: Project time

The scrum activities throughout each of these blocks were slightly different. In the first week, we introduced Scrum through two activities. During weeks 2-9, the sprints were timeboxed in three-week increments. During the final two weeks, the sprints were time-boxed in one-week increments. Each will be described below.

Scrum Kick-Off Activity (Week 1)

Scrum principles were applied to kick-off the audio player design project for the integrated learning stream. Specifically, students were given a brief project description and told that in 60 minutes they would be giving a presentation of their final product. In other words, the first Scrum Sprint had a timebox of 60-minutes. The goal of this activity was that the students would be required to think through the design elements of their audio player. Immediately the students were very excited about the project and dove right into brainstorming. The energy in the room throughout the 60 minutes was very high, and students considered many different design features of their audio player. This "mini Scrum" was a great way to kick-off the design project.

Lego Learning Activity (Week 1)

As discussed above, activities are often used to teach the principles of Scrum. In the Integrated Learning Stream course, we decided to use Lego as a tool to build foundational Scrum knowledge, particularly around the terminology. This activity was based on the description given on the https://www.lego4scrum.com/ website.

Students were tasked with building a city in three 7-minute sprints, and they were provided with a backlog list of items (ex. one-story buildings, two-story buildings, school, theatre, etc.). At the end of the first Scrum, the instructor provided feedback on things she liked and things she didn't like (ex. "I want there to be a neighbourhood by the park" or "I want all the 1-story and 2-story buildings to be uniform colours."). The teams then start to understand the value of

the Scrum. Early on they show a completed city, and they are able to receive immediate feedback and make adjustments as they go.

In total, students did three 7-minute sprints. Between each sprint were a review and a retrospective. For each retrospective, students were given an activity to do in order to build team communication:
- Each team member writes one "Opportunity" and one "Challenge" on a post-it note before everyone shares their comments with the team.
- Each team member says what they appreciate about working with their peer sitting to their left and their right.
- Each team member writes down on a post-it note how they are feeling (ex. happy, stressed, frustrated, excited, tired).

Overall, the feedback from students was positive about the Scrum activity. They were able to learn the key terminology through active learning. The one area for improvement would be to have a clearer connection to the course design project either during the activity or immediately following so they better understand the direct connections.

Project Brainstorming and Development (Weeks 2-9)

Two sprints were completed during the middle of the ILS courses. During this time, students were developing their technical content that they would need to complete the audio player through active learning and hands-on labs. For example, they learned filters and PIC through different lab assignments. While learning these concepts, the instructors were continuously helping the students make the connections to the integrated project.

Figure 2 and 3 below show the requirements of the first two sprints. Specifically, students were given clear guidance on the first sprint, with both the expected product to be delivered and the backlog items. For the second sprint, students were given the expected product but were expected to determine their own backlog items. After each sprint, students were brought through a retrospective reflection. Appendix B shows details on the retrospective, including the hand-in assignment that was required and checked as a pass/fail.
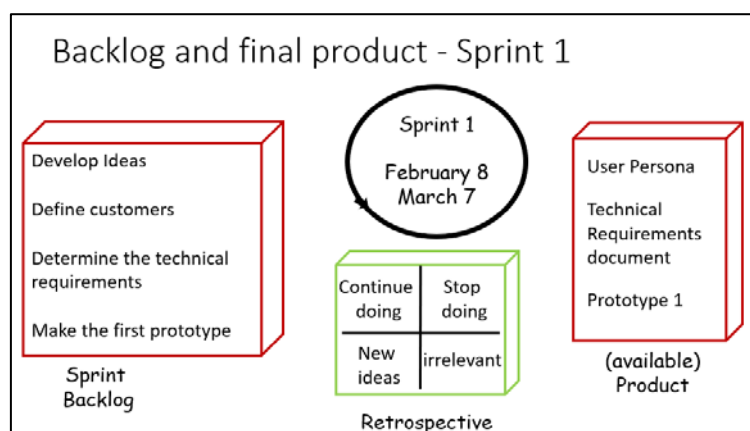
Figure 2. Sprint 1, where the instructor clearly outlined the backlog and the required product to be completed at the end of the Sprint.
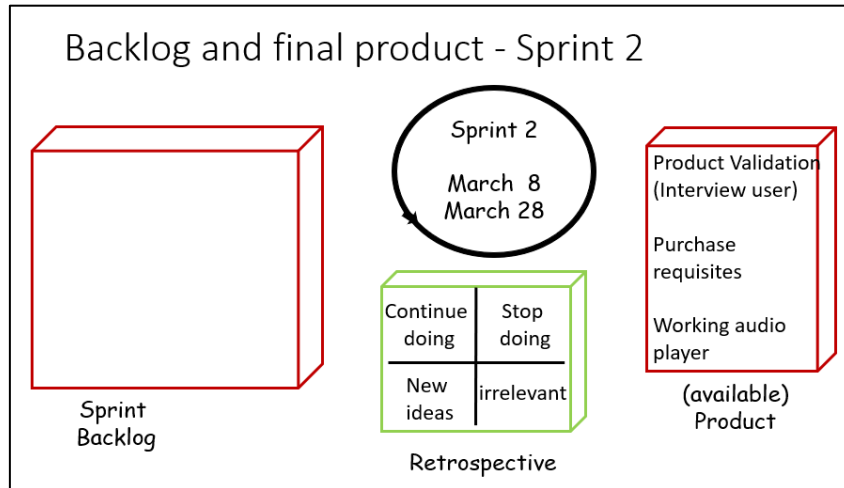

Backlog and final product - Sprint 2

Sprint 2

March 8
March 28

Sprint
Backlog

| Continue doing | Stop doing |
| New ideas | irrelevant |

Retrospective

Product Validation (Interview user)

Purchase requisites

Working audio player

(available) Product

Figure 3. Sprint 2, where the instructor clearly outlined the required product, but expected the students to complete their own individual backlog.

Project Building (Weeks 10-12)

In the final three weeks, the students were asked to complete weekly sprints. They were not given any guidance on their available product, but they were asked each week to pitch their product. The ABC structure was following: the end of the first sprint was considered the "Alpha" phase, the second sprint was the "Beta" phase and the final sprint was the "Completion". Further details on the audio player project and the ILS program can be found in other publications (XX), however here we are just focusing on using the Scrum methodology to support the integrated learning experience.

STUDENT FEEDBACK

In the last week of the course, the students were required to submit e-portfolio entries reflecting on something they learned through Agile Project Management. A few student entries are highlighted below in Figures 4 to 8. Overall, from the themes below it is evident that the students found the Scrum processes effective for ensuring they stayed on track with their project through iterative continuous improvement. Additionally, agile and scrum were helpful in clearly making the integration links between the technical content and the project management skills required.

What I learned from Agile Project Development: The Iterative Process

In Agile Project Development the most important thing I learnt would have been the iterative process. As a perfectionist, the way I would have approached project development before would have been drastically different. I would have tried to make the product perfect on its first attempt and gotten really frustrated along the way. The Iterative process taught me to give a specific timestamp to do a certain amount of work which is a lot more manageable and greatly reduces stress. The iterative process was vital in the ideation of our product, as we changed our product over and over and finally got to a design that we loved.

Figure 4. Student entry reflecting on the agile project management process.

Synchronous

Prior to being in the ILS program, I was unaware about the Agile Project Management technique. After using it for an entire semester, I can confidently say that it has enhanced the efficiency of our group project. I have a better understanding of product backlogs and sprints; where a list of project specifications (backlog) and goals must be made within a time frame (one sprint iteration). Using agile throughout the semester also helped me understand why daily stand-ups are essential to a team and how it can ensure all members are on the same page throughout the entirety of the project. This ensures a synchronized team while working towards a final goal.

Figure 5. Student entry reflecting on the agile project management process.

The Process: Agile Project Management

"Flexibility", image by MemoiresPhotographiques, on Flickr.com

Agile project management has taught me the importance of using our time efficiently, above all else. Doing daily stand-ups, along with product backlogs has been a crucial aid in keeping our team on track. As well, agile project management has directed importance to keeping focus on how much work has to be achieved in the long run. Through the many iterations involved, progress is made quickly and flexibly in order to meet project deadlines in a more frequent fashion.

Rather than just building a product from start to finish, the technique of carrying out work in the form of sprints has shone a light on the significance of having flexibility in our designs. By constantly improving upon our product, more technical issues can be addressed at once. As well, our ideas can be constantly re-assessed, in order to better our product and deliver what the client wants.

Figure 6. Student entry reflecting on the agile project management process.
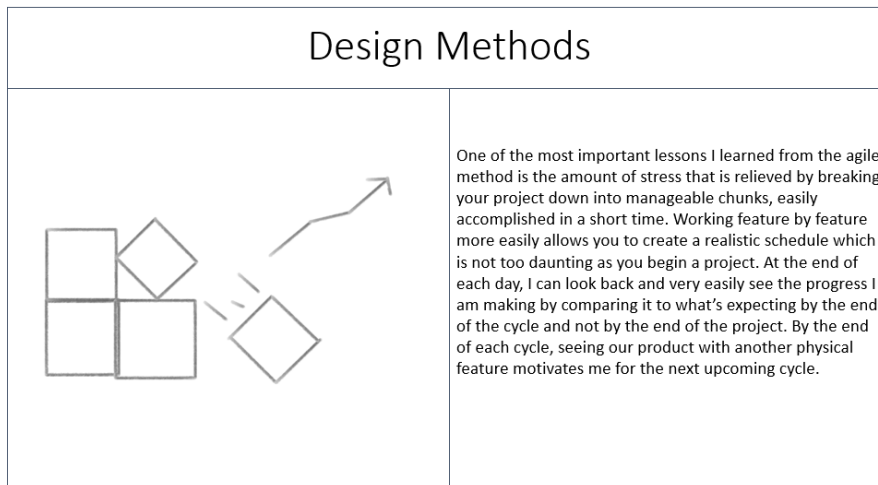
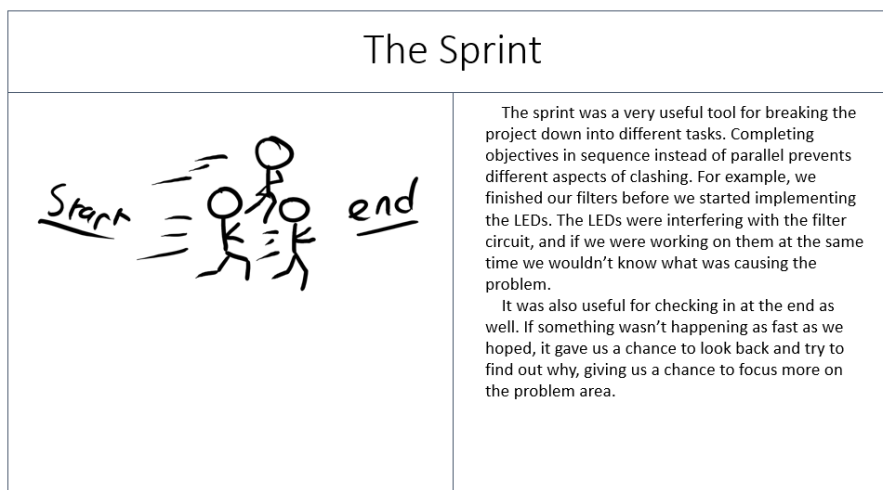Figure 7. Student entry reflecting on the agile project management process.

Figure 8. Student entry reflecting on the agile project management process.

CONCLUSIONS

Overall, it is evident that agile project management and scrum processes were useful in facilitating a successful integrated learning project. The CDIO Standard 7 describes activities that integrate learning experiences to acquire disciplinary knowledge as well as personal, interpersonal skills, and process building skills (Crawley et al., 2014). Scrum was able to facilitate this connection of the disciplinary knowledge with the skill-building activities. The results presented in this paper have been mostly anecdotal from the instructor and graduate teaching assistant involved. In the future, further data collection and student feedback could help to improve the understanding of which specific elements of Scrum were most beneficial to the students integrated understanding of second-year electrical engineering.

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APPENDIX A – Scrum Terminology Handout

Waterfall Development:

Traditional "waterfall" development depends on a perfect understanding of the product requirements at the outset and minimal errors executing each phase.
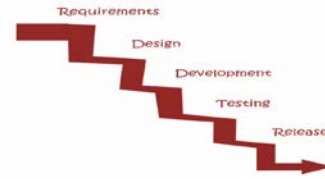
Agile Project Management:

Agile Development refers to the project management approach of developing increments of products in frequent iterations based on evolving requirements.

Scrum Master:

The role within a Scrum Team accountable for guiding, coaching, teaching and assisting a Scrum Team and its environments in a proper understanding and use of Scrum. The Scrum Master does not have any authority over team members, however, they do have authority over the process.

Product Owner:

The product owner writes the acceptance criteria, and prioritizes and maintains the product backlog. Their role is to keep the Scrum Team accountable for maximizing the product value, primarily by incrementally managing and expressing business and functional expectations.


Product Backlog:

The product backlog is not a 'to-do' list; rather, it is a list of all the features the customer has requested be included in the project. The Scrum team uses the product backlog to prioritize features and decide which ones to implement in upcoming sprints.

User Stories:

A user story is a brief, non-technical description of a system requirement written from the end-user's point of view. User stories can be written according to the following structure: as a <type of user>, I want to <perform some task> so I can <achieve some goal.>
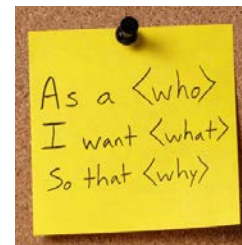

Definition of Done:

A shared understanding of expectations that a portion of the product (or an "increment") must live up to in order to be releasable into production.

Story Points / Complexity:

Story points are a non-unit measure used to determine the complexity of a user story. Story points are relative, not absolute, and do not relate to actual hours. Often, the Fibonacci sequence is used.
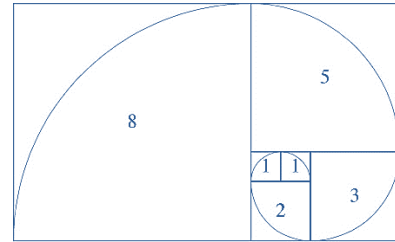
Sprint:

A sprint is a fixed-length iteration during which one user story or product backlog item (PBI) is transformed into a potentially shippable deliverable.
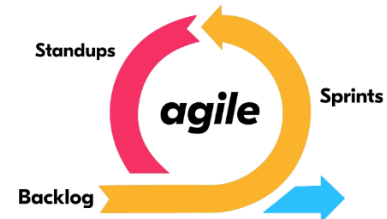
Burn-Down Chart (or Burn-Up Chart):

A chart which shows the amount of work which is planned for a Sprint. Time is shown on the horizontal axis and work remaining on the vertical axis. As time progresses and items are drawn from the backlog and completed, a plot line showing work remaining may be expected to fall.

Retrospective:

A Scrum Retrospective is a meeting held following the completion of a sprint to discuss whether the sprint was successful and to identify improvements to be incorporated into the next sprint. The intent of the retrospective is not to conduct an extensive post-mortem but rather, to focus on specific steps the team can take moving forward toward a goal of continuous improvement.

Impediment vs. Blockers:

An **impediment** is anything that slows down or diminishes the pace of the Team. When the Team is confronted with impediments (or obstacles), the Team could move forward but in advancing they may not be effective. Progress is more difficult than it should be.

In contrast, a **blocker** is anything that stops the delivery of the product. Without the elimination of the blocker, the Team cannot advance at all.

APPENDIX B – Retrospective Assignment

When a Retrospective is...	
Done Well	**Done Poorly**
• Continuous improvement • Move team in right direction	• Blame game, who's fault is it? • Opportunity for loudest voices to complain

Two Retrospective Options:	
Two Questions	**SWOT**

• What went well?
  • Post-it (5 min)
  • Share (10 min)
 	
• What needs improvement?
  • Post-it (5 min)
  • Share (10 min)
	
	• Post-it (10 min)
	• Place on grid
	• Discuss each quadrant (5 min each)

Hand-In Retrospective Summary (Individual) – 5 pts

Peer Feedback:
1. Summarize your peer feedback. What was the most interesting / useful piece of feedback received?

Team Retrospective:
2. Summarize your discussion. Was there anything surprising?
3. What is the biggest area of improvement for your team?
4. What is the biggest area of improvement for yourself?

Should be ½ page to 1 page in length. Point form is acceptable.

BIOGRAPHICAL INFORMATION

Robyn Paul is a first-year PhD student at the Schulich School of Engineering, University of Calgary where she also works as the team lead on all matters related to the engineering accreditation processes. Robyn recently completed her master's degree in engineering education where she studied engineering leadership development's impact on career success.

Dr. Laleh Behjat is a professor at the University of Calgary. Her research focuses on developing mathematical techniques and software tools for automating the design of digital circuits. She has won several awards for her work including the 1st and 2nd places in International Symposium on Physical Design Placement contests. Dr. Behjat's other research activities include developing techniques for engineering education.

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Young Researcher Programme: An Inquiry-based Learning to Cultivate Innovation and Research Mindset

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ABSTRACT

'Students as researchers' is an active pedagogy emphasizing the process of student research and inquiry. When students practice inquiry, it helps them develop all the critical skills needed for the 21st century which include problem identification, problem-solving, critical thinking, team working, data analysis, scientific reasoning, decision making, etc. Similarly, a programme known as the Young Researcher Programme (YRP) has been implemented in the School of Engineering at Nanyang Polytechnic, Singapore since 2017 to nurture students' innovative spirit and develop capabilities in conducting research.

In the YRP, students are to form their own teams that consist of members who are from different years of study and engineering disciplines. The purpose is to train students to find ways to collaborate, learn and share knowledge and skillsets with a diverse group of members in the team. The team is then required to conduct independent research, integrate ideas from different resources, support their ideas with evidence, conceptualise and apply relevant principles in designing the experiments or products, implement them under staff supervision, and evaluate the validity and reliability of their conclusions. As the YRP is conducted beyond the formal curriculum hours, students are not bounded by the requirement of the curriculum and are free to work on research projects that are of interest to them. Students in the YRP are also given ample opportunities to attend training and seminars, as well as participate in industry visits.

This paper describes how the YRP exposes students to a culture of inquiry-based learning starting from as early as their first year of study at the Polytechnic. This paper also discusses the effectiveness of the YRP in inculcating a research mindset among the students and the usefulness in tracking their individual progress in YRP until their final year of study in the polytechnic. Finally, this paper highlights the challenges faced and provides recommendations for future enhancement of the YRP.

MOTIVATION

The School of Engineering, Nanyang Polytechnic (NYP) offers courses in specialized training for youths who have completed secondary school (or equivalent) studies. The completion of this course of 3 years will lead to the award of a diploma, for example, a Diploma in Biomedical Engineering or Diploma in Nanotechnology and Materials Science. Thereafter, a graduate from the course typically enters the workforce as a professional or continues to pursue an undergraduate study at the university.

In response to the shifting expectations of a young professional entering the workforce, and as well as pursuing a university education, the Polytechnic redefined the education emphasis, to one that incorporates present and future industry needs. The intention is to imbue graduates with the following attributes: professionally proficient, competent in 21st century skills, innovative & enterprising and socially responsible (figure 1).
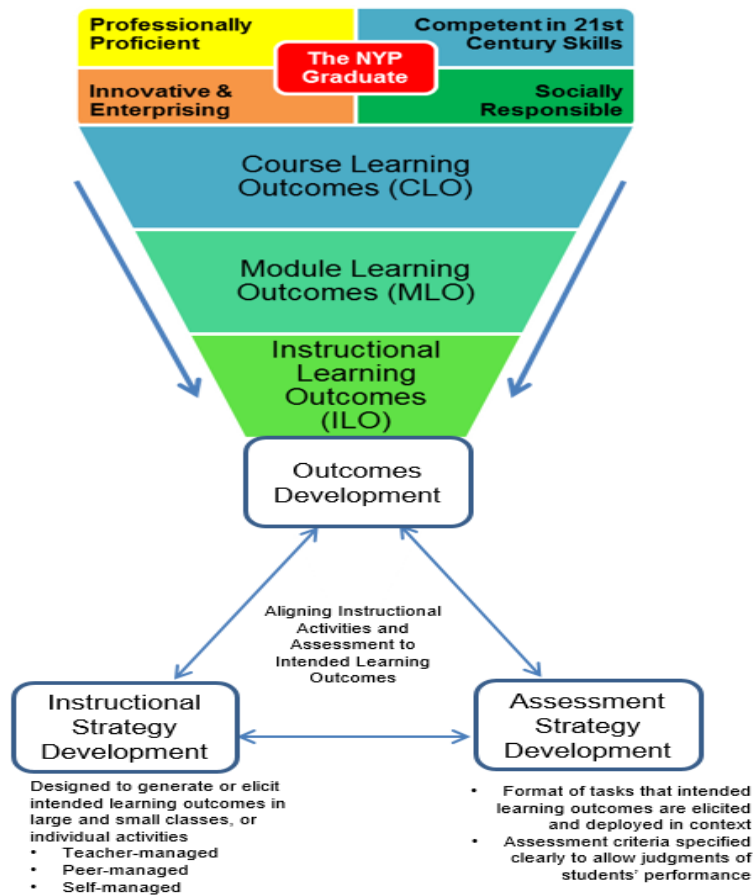
Figure 1: A redefined education emphasis using an outcome-based approach in designing curriculum in Nanyang Polytechnic

Consistent with the Polytechnic's redefined emphasis, the School of Engineering revamped existing curriculum (Choo, et al. 2015) to be consistent with CDIO principles and guidelines (Crawley, et al. 2007). The revamped curriculum is focused on an outcome-based teaching strategy. For example, the module learning outcomes are a subset of the course learning outcome.

There are modules which do not have prerequisites, while others build on the knowledge taught in the prior semester (for example, Mathematics 1B extends the knowledge taught tin

Mathematics 1A). With regards to the current methods of lesson delivery, there is a variety of styles, including the traditional face-to-face approach, and/or flipped-classroom approach. Certain modules have also incorporated mini-projects, where students work individually or in small groups on projects which are devised to allow students to apply the knowledge taught in the module. By and large, the activities mentioned above take place within the module (i.e. students assigned to a mini-project would invariably be from within the same class taking that particular module), or within the same cohort at best (i.e. students assigned to a mini-project might be from different classes, but the classes still take the same module).

Clearly, in this teaching pedagogy, these aspects of active learning can be improved:

- there is no collaboration between students of different courses. Because of the current curriculum structure, it is not possible for students to work on projects where they are grouped with other students from other courses. This curriculum structure inherently reinforces the "silo" mindset amongst students

- there is no possibility of integration across modules, even within the same course. For example, a project with the title of "using films to enhance plant growth" will require knowledge of materials science and statistics

- there is no collaboration between students of different years within the same course. It is not possible to form a project team with say a final year student as the team leader, with the team members from first- and second-years

- project objectives assigned inevitably must conform to the module outcomes. There is no scope for exploring areas outside of module curriculum, but are still related to the module

- more platform to enhance research, innovative and enterprise skillsets before their final year project which is in their formal curriculum

- other constraints like curriculum time, or student mindset ("if it is not assessed, I do not want to pursue this")

To address some of these issues, particularly point 1 above, a new approach was implemented in 2016, called "Integrated Multi-Disciplinary Project" (or IMP in short) (Vinayak Prabhu, 2018), In this new approach, students from different courses are grouped to tackle a project. For example, a team of 4-5 students may comprise of students from Diploma in Biomedical Engineering, Diploma in Nanotechnology and Materials Science, and Diploma in Electrical Engineering (to tackle the various technical aspects of the project). This IMP is graded and has a heavy weightage in the computation of a student's Grade Point Average (GPA). IMP is only implemented in the final year where students only get to work in multi-disciplinary teams when they have no exposure in the first 2 years of their Polytechnic education.

METHODOLOGY AND IMPLEMENTATION

"Young Researcher Programme" (or YRP), was conceived in 2016 to address the gaps identified in the preceding paragraph. This programme is jointly administered by 2 courses, namely, Diploma in Nanotechnology and Materials Science and Diploma in Biomedical Engineering. This programme is conducted outside of curriculum time and is targeted at students who wish to enhance their research, innovative and enterprise skillsets in areas not already covered by the curriculum. There are also a series of activities to complement the programme. Students from any of the courses within the School of Engineering are eligible to participate in this programme. This is of the key features of the programme: allowing a multi-

disciplinary collaboration among the students, unconstrained by curriculum limitations. This pilot scheme is run outside of the curriculum in order to test out the interest of students and also allow the school to evaluate the outcome of this programme. YRP project is different from Final Year Project or Capstone Project which done at the end of the student's final year and it is within their formal curriculum. The project was done by the students usually integrates and synthesizes what they have learned throughout their years of study (P.J. Armstrong, 2005).

Potential student participants are given a list of projects and asked to indicate their preference. Subsequently, a project team is formed based on sign-ups. The projects are scoped to be completed over 1 semester (i.e. 6 months). As a form of commitment to the success of the project, students are advised to spend a minimum of ten (10) hours on the project, and this is outside of curriculum time. The activities that are counted in this time commitment include briefings, meetings, experimental work, etc, and the students typically maintain a timesheet.

In each project team, there is usually a mix of students from different courses, and from different years. Student Mentors will be assigned to the team, based on his or her track record of competency, who will guide the team in the research project. Other administrative matters are managed by Student Programme Leaders. All students who are involved in this programme are awarded Co-Curricular Activity points in the area of leadership, participation, enrichment and service depending on their role. Roles and responsibilities of all stakeholders are shown in Table 1.

Stakeholder	Roles and Responsibility
Course Manager	• Champion of the programme
Staff in Charge for YRP	• Staff advisor of the programme. • Recruit and manage Student Programme Leader • Collate research project submission from staff • Organize programme activities
Staff	• Propose and submit research project • Guide student participants in the research project.
Student Programme Leader	• Facilitate and coordinate programme activities. • Assist staff in managing student roster or activity (If any). • Recruit Student Participants. • Publicity of programme activities. • Communication with Student Participants.
Student Participant	• Work on research project (min of 10 hours) • Participate in programme activities such as company visit, seminar etc.
Student Mentor	• Guide and train student participant in the research project. • Monitor student's work • Update staff progress or status of the project.

Table 1: Roles of the various stakeholders in the YRP

In the Young Researcher Programme, research projects are proposed by staff. While the staff is responsible to scope the project and define the project objectives, staff involvement in the project execution is minimal. This is to facilitate active learning in this programme. Keeping in mind that since this project is outside of the curriculum, and therefore not graded, there is thus more leeway for students to take ownership of the research process, explore and innovate. In short, there is no penalty for not succeeding.

From the onset, students are guided by staff to plan, design, implement and test their ideas to achieve the project objectives. Thus, the students carry out the following activities, as illustrated in figure 2.

Plan:
Based on the project objectives, facilities and staff resources, divide the overall project into subtasks, plan the activities and project schedule accordingly. Given the individual interest and competency, define the roles of each member and the deliverables

Design:
For subtasks, where experiments need to be carried out, the students are guided into designing the experiments, maintaining consistency with the project thesis. This could be modifying existing laboratory manuals, or if there is no precedence, then carry out literature research and then developing the experimental design. The experiment design has to be approved by staff before actual experiments are carried out. Experiments are carried out at this stage, initially under the guidance of staff. More often than not, the experimental design may have to be refined. This is again carried out by the students in consultation with staff.

Implement:
Transformation of design into the delivered solution or product, including manufacturing, software coding, product testing, and validation.

Test/Operate:
Use the implemented solution or product to solve the problem or deliver the intended value.

This process of active learning benefited both student participants and student mentor. Apart from technical skill development for student participants, soft skills such as mentoring and leadership skills are also developed in student mentor Student participants will be able to progress and work as a student mentor or student programme leader in next semester.
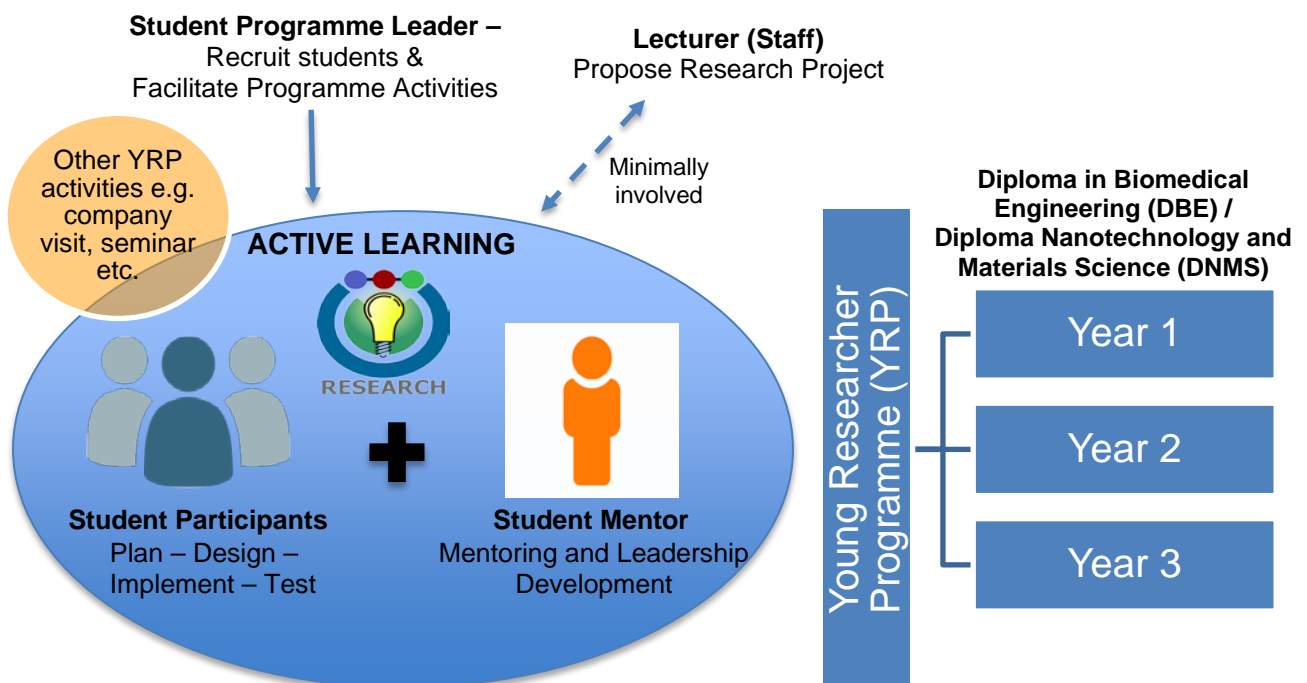

Figure 2: This figure shows YRP is outside of the formal curriculum. Students from DBE and DNMS from a different year of study will be working together in the research project. Active learning is designed in this programme which strives to involve students (both student participants and student mentor) in the learning process. Student Programme Leader helps to

recruit students and facilitate programme activities whereas the involvement of staff in the research project is minimal.

Observations

YRP commenced on 2017 Semester 1. In one of the research projects, students were to measure the electrical conductivity of polymer filaments used in 3D printing. This team of students were from a mix of courses, and some did not possess any knowledge in materials science. The students prepared samples by doping graphene into two types of polymer which were Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). They found graphene doped ABS filament possesses extremely high resistance which decreases over time as current flows through it. They also found that the thicker the sample, the higher the initial resistance.

The project team leader was a first-year student from Diploma in Nanotechnology and Materials Science (DNMS), who has the necessary competency in materials synthesis and characterization. Fellow team members from the Diploma in Biomedical Engineering (DBE) contributed by performing the Computer Aided Design (CAD) and 3D printing. Thus, the students were exposed to knowledge and hands-on experience which are outside of their formal curriculum in biomedical engineering.

Figure 3: Graphene doped ABS samples prepared by YRP students with no materials science background.

YRP is also served as a platform to support industrial collaboration and those projects often address real-life problems. The research work in the project is usually just a bite size of the entire industrial project. They are usually simpler and less time-consuming. An example will be to study light output for each duct of 3M Channel Light System. The objective of this project is to study the light output of each light duct of 3M Channel Light System with a given amount of input and compared with a conventional lighting system. Three year 2 students from DNMS conducted the measurement using a spectrometer and monitor the data collected during their break. The result has shown that 3M Channel Lighting System has a reflective light duct which will reflect the light emitted from the LED at each end of the duct across, with higher luminous efficacy as compared with the conventional lighting system. Students learned how the 3M Channel Lighting System emits more lights across a larger area compared to a conventional lighting system.

Another research project is to study how N/P/K (Nitrogen/Phosphorus/Potassium) value of different fertilizers can affect the growth of the plants. There are companies who passed their fertilizers to the school and they are interested to know how their fertilizers work using the vertical farming system in the school. Three year 2 students from DBE and two year 2 students from DNMS with no background of farming, learned and worked together in the greenhouse to conduct this study. Two types of fertilizers with different amount of N/P/K values (17/11/10 vs 8/8/8) were tested out. The results show that lettuce grew using a fertilizer with higher N/P/K value has higher leaves height, width and weight as compared to the fertilizer with lower N/P/K value. Students learned the higher nitrogen composition in fertilizer with higher N/P/K value does promote leaves growth as lettuce is a leafy plant.

In order to showcase students' research in this programme, technical poster presentation was organized (see figure 4). It served as a platform for the students from different projects to exchange their ideas and also recognize their efforts in the programme. Lecturers and final year project students were invited as a judge to vote for the best project. This had also provided an opportunity for the final year project students to apply their technical knowledge learned throughout their three years of study in NYP to evaluate the depth and value behind each project.
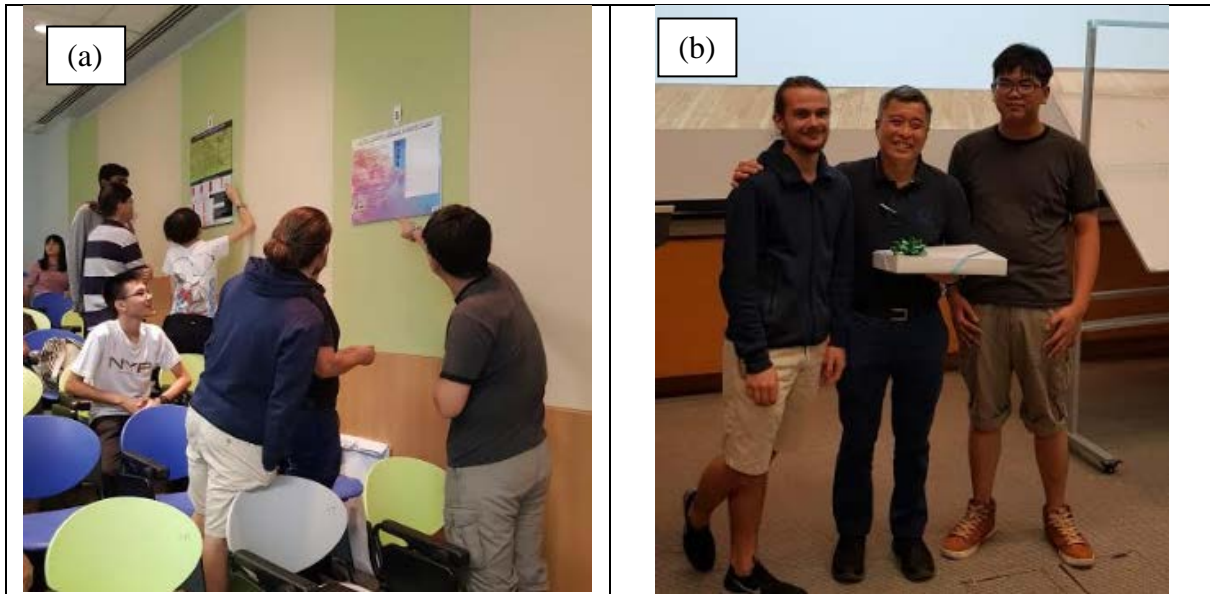
Figure 4 (a) shows students were presenting their technical poster to lecturers and peers. (b) Prize presentation to Best Project award winners.

Apart from just research projects, activities such as company visit, excursion and project exhibition were also organized to enhance students' learning experience in this programme (see figure 5). Some activities are specially organized for YRP students or they have the priority to join those activities. These programme activities are also an active learning for the students. For example, third-year students from Diploma in Nanotechnology and Materials Science had organized a Smart Materials Exhibition to showcase their projects on using smart materials to develop an interactive game. Students from the YRP programme were invited to the exhibition and learned about the smart materials by playing the game with their seniors. The game was interactive and hence the students had fun yet learned about smart materials. This also served as a platform for students in different levels (first, second and third year) or background to exchange knowledge and ideas.
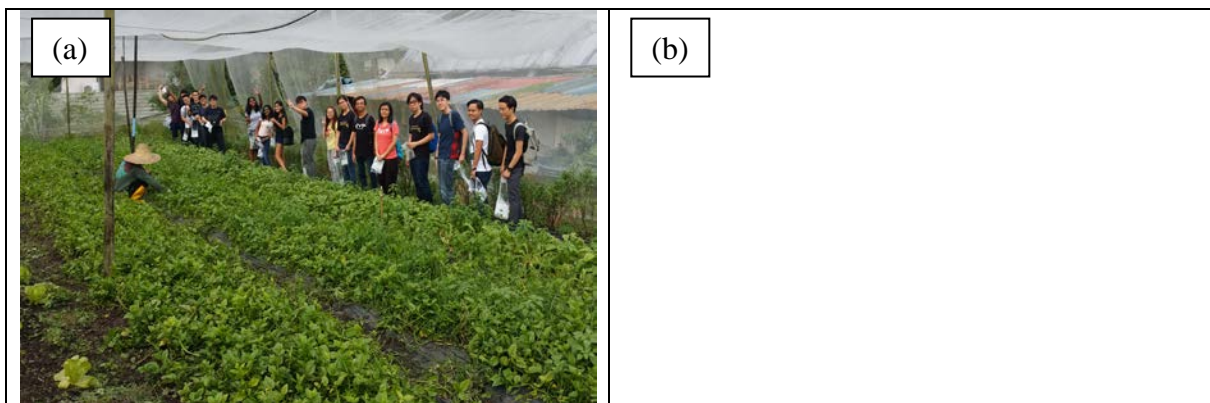
Figure 5 (a): Students visited local farm. (b) Company visit to 3M Customer Technical Center. (c) & (d) YRP students participated in Smart Materials Exhibition which organized by third year students from Diploma in Nanotechnology and Materials Science.

RESULTS AND FINDINGS

The Young Researcher Programme has been running for three semesters (2017 Semester 1, 2017 Semester 2 and 2018 Semester 1), a total 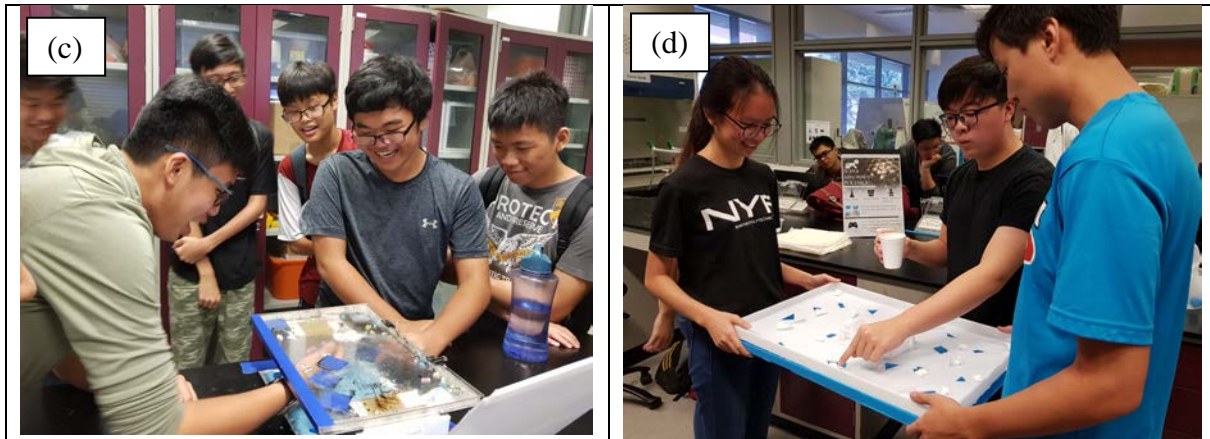of 68 students participated. An online survey was conducted in 2018 Semester 1 to gather feedback from students how well the programme is received by the participants. A few questions were asked in the survey. Total of 10 students joined the programme in 2018 Semester 1 and all of them participated in this survey.

Students were asked how much increase in knowledge and hands-on experience they gained after joining the activities related to YRP compared to before. The rating given to the students is "Excellent", "Very Good", "Good" and "Poor". In this survey, 40% of students rated their knowledge and hands-on experience gained "Excellent" and 60% of students rated "Very Good" (see graph 1).

How much increased in knowledge and hands on experience have the students gained compared to before joining activities related to YRP

■ Excellent　⬚ Very Good　≡ Good　■ Poor
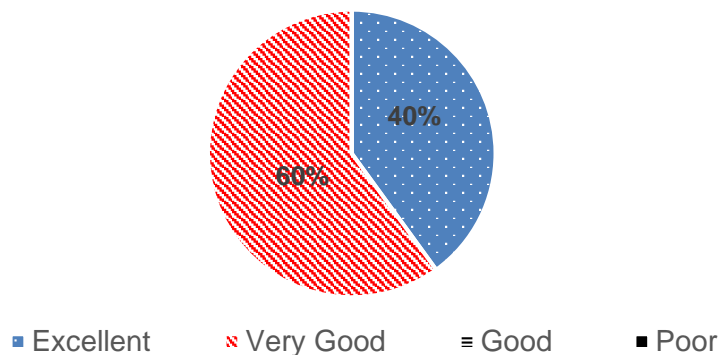
Graph 1: Students' perception of the level of knowledge gained though YRP

The students were asked to rate the usefulness of experience gained throughout the YRP programme with ratings categorized into "Excellent", "Very Good", "Good" and "Poor". 40% of students rated the usefulness of experience gained throughout this YRP "Excellent", 50% of students rated "Very Good" and 10% of students rated "Good" (see graph 2).

Usefulness of the experience gained throughout YRP

Graph 2: Students' perception of the usefulness of YRP

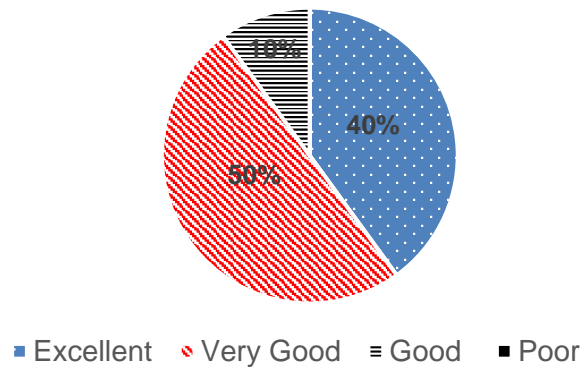These have shown that the research activities in YRP have brought a positive impact to students' learning. The active learning which brought a lot of hands-on experience gained via this YRP played a part in developing a more professionally proficient graduate. Students found it useful as the skillset learnt can be applied in their study or final year project. This could help to nurture student's critical and inventive thinking which are essential skills in 21st century. In addition, all students who participated in the survey would encourage their friends to participate in YRP. There were also students who participated repeatedly in this programme. The school hopes by encourage more students to participate in this programme so that more students can develop capabilities in conducting research and also nurture students' innovative mindset.

There were some other comments left by students such as they appreciated the mentoring from both student tutor and lecturer. As the students researched on the topic that they were not familiar with or not learnt from their diploma, guidance from the tutor were very useful to them. Besides, students also commented they hoped to form their own team next time as it is easier to find a common time slot to discuss and work on the project with their teammates. However, staff also shared with them the benefit of doing a project with students from another discipline.

From the survey and by talking to students or staff involved in this programme, we discovered an area for improvement. In the survey, students were asked whether the project in YRP motivated them to learn more about the topic that they were researching. Eight (8) students indicated "Yes" but two (2) students indicated there was no difference. This could possibly be due to the project assigned to the students were not their first choice or it could be from the same course of study. Additionally, 20% of the students felt that the program leaders who are students facilitating or coordinating could have done more to facilitate the progress of the project. By talking to the staff and students, we found that some staff contact the YRP participants directly, but some staff depended on the student programme leader to contact the YRP participants. This might create miscommunication between these three parties. Moving forward, we will encourage the staff to contact the YRP participants directly to minimize unnecessary miscommunication.

CHALLENGES

As mentioned in the results and findings, miscommunication may be part of the challenges in this programme. This programme involved staff, student programme leader and student participants. The role of student programme leader is created to facilitate or coordinate the whole programme which including the recruitment of students, publicizing programme activities and communicating with student participants. As the student programme leader is not part of

the project team member, they do not lead the project, and this could lead to some deliverables of the project not being met. The leadership for the project or more initiatives should come from the student participants. This can be minimized by communicating the expectation to all student programme leaders and also student participants. Additionally, the student programme leader can appoint a team leader for each team.

One of the challenges faced is to get sufficient mini-research projects in this programme. To mitigate this, suggestion such to encourage all staff take turns to submit mini-research projects every semester. Otherwise, students can also brainstorm and propose their research project under the staff's guidance in order to ensure the feasibility of the project. Lastly based on staff and student programme leader's feedback, it was observed that students were more active in the YRP research project during the beginning of the semester when they were not heavily loaded by their course work or projects in their formal curriculum. Therefore, the golden period to get the students to work on their YRP project is at the beginning of the semester. Therefore, setting a timeline to complete the research project before the mid of the semester will be helpful for both students and staff.

Another challenge is how to better measure students' performance in terms of improving their hands-on experience after participated in YRP compared to those who did not participated. This can be evaluated for students who participated twice in YRP and student's skillset can be evaluated or assessed based on the increase in difficulties in second YRP project. In addition, it may be assessed via some modules which require more hands-on and practical skills. However, skill-set learned from different YRP project will be different, therefore selecting a module to evaluate students' improvement on hands-on skill need to be assessed carefully to study the relevancy.

CONCLUSION

Active learning which involves students' participation rather than passively listening in the learning process has been proven effective in students' learning. Young Researcher Programme (YRP) has provided a platform allowing a multi-disciplinary collaboration among the students, unconstrained by curriculum limitations to learn by working together. Staff involvement in the project execution is minimal. This is to facilitate active learning in this programme. All projects in YRP is outside of the formal curriculum and are not graded which meant to give students more space and ownership in the research process to explore and to innovate.

The overall experience of the students who participated in this programme is positive. Students found they gained more knowledge and hands-on experience after joining this programme. They also found the knowledge gained and hands-on experience are useful which can be applied in their study or final year project. All students agreed to encourage their peers to participate in this programme as they were benefited from this programme. This programme helps more students to develop capabilities in conducting research and also nurture students' innovative mindset.

However, this programme can be improved by overcoming some of the challenges mentioned above. Challenges such as communication between the students and staff can be improved by setting the right expectation to all students and encourage staff to directly communicate to the students. In order to have a more meaningful research project, setting timelines to complete the projects before the students are heavily loaded by their study and projects from their formal curriculum will be helpful. To bring the active learning of this programme to a higher level, students can also brainstorm and propose their own research projects.

The programme has been running for three semesters and the school is seeing the positive impact brought by this programme. Students were directly involved in the research project and actively learning outside of their formal curriculum which is not graded and results in a less stressful environment. Students were also given a chance to work with other students with different backgrounds which has also encouraged more inter- and multi-disciplinary learning. The school hopes to encourage more staff and students to participate in this programme in order to enhance the diversity of the projects as well as the programme activities.

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GAMIFICATION PLATFORM FOR MANUFACTURING SHOPFLOOR TRAINING - A CASE STUDY

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ABSTRACT

This paper shares our work in developing and implementing a gamification training platform for students who undergo manufacturing shopfloor training at the School of Engineering, Nanyang Polytechnic, Singapore. In this gamification training platform, we developed a virtual manufacturing shopfloor that is identical to the actual shopfloor located in the school. Students have the freedom to learn the manufacturing shopfloor operations and safety acts through the various game scenarios and training tasks which include workshop safety, CNC machine introduction, CNC machining dynamics, MES, etc. In addition, the assessment feature with immediate feedback were embedded within the gamification platform, which aims to help students to assess their level of understanding and help teachers to monitor the learning progress of their students. To investigate the impact of this gamification training platform on students' learning outcome and motivation in manufacturing shopfloor technologies and safety acts, a pilot study was conducted in AY2018 semester 2 for a total 134 students from 4 classes of digital & precision engineering diploma. It is found that gamification can be integrated effectively into manufacturing education to motivate students and enhance their learning effectiveness. Based on the collected data from the technical quizzes and satisfactory survey, the results showed that the integration of gamification into the classroom learning not only added a stimulating and captivating game-like layer to the learning experience of the students but also provided a safe environment for students to learn without fear of making errors. Challenges faced in implementing this gamification training platform will also be discussed in this paper.

KEYWORDS

Gamification education, manufacturing shopfloor, virtual reality, student engagement, Standards: 1, 5, 8, 10.

1. INTRODUCTION

Learning is an active and participatory process and requires motivation to begin and continue the journey. Standard lessons for manufacturing shopfloor training are sometimes considered boring and ineffective by some students. Motivation can, therefore, be a problem, especially when students do not have enough technical background to catch the objective of given

learning activities. Moreover, standard training approaches via literal manuals and verbal instructions are inefficient for students to familiarize with the manufacturing systems and operational procedures of manufacturing shopfloor. Considering the common constraints at the shopfloor such as limited facilities, compact schedule, insufficient instruction hours, cost of equipment, students often do not have sufficient hands-on practices, and thus face difficulty in operating the manufacturing systems such as CNC machines and Manufacturing Execution System (MES).

Gamification is becoming more prevalent in education because of its perceived ability to motivate students and make their learning activities more active and participatory (Christensen & Raynor, 2003). In the literature review for gamification in education (Caponetto et al., 2014), the authors confirmed the increasing interest in gamification in education by using Google Scholars. In "Does Gamification Work? – A Literature Review of Empirical Studies on Gamification" (Hamari et al., 2014), the researchers took a structured approach to determining the effectiveness of gamification. In practice, Bradley Wiggins discussed how games and simulations were applied in the classroom of higher education (Bradley Wiggins, 2016). Their research showed that gamification in education produces positive effects and benefits for a majority of current studies.

In recent years, gamification education has been applied in many disciplines such as math, health, aerospace, business, computer science, life and chemistry, digital media, etc. (Oxford Analytica, 2016) and (Yu-kai Chou, 2017). However, little emphasis has been given to the gamification education for manufacturing shopfloor training. Gamifying shopfloor machines and operations can give students support beyond the shopfloor, help to familiarize with shopfloor systems, increase motivation, and reduce their fear while approaching to actual machines. Gamification can be a better education environment for shopfloor training, not only taking advantage of the gaming technology in production, but also transferring the gaming knowledge and expertise on game design to motivate and train students. This paper presents our work on developing and implementing the gamification platform for manufacturing shopfloor training at the School of Engineering of Nanyang Polytechnic. It first covers the development of the gamification platform development and its elements. Subsequently, it presents the creation of gaming tasks to reinforce our teaching curriculum. After that, it describes the implementation results of the gamification platform in enhancing students' learning experience. Finally, the evaluation and discussion of the gamification training platform are given to provide educators with our insights into how to integrate gamification principles into existing curriculums and enhance its effectiveness.

2. DEVELOPMENT OF GAMIFICATION PLATFORM

The aim of the gamification platform is to reinforce our course concepts and enhance students' learning experience beyond the classroom. This gamification platform and its tasks are designed to fit into the current curriculum of digital precision engineering diploma at our school. It is built to train the various manufacturing technologies applied in the manufacturing shopfloor. It also plays an important role in preparing students before they approach the manufacturing shopfloor operating actual manufacturing systems (such as CNC machines, CMM and MES) for their learning activities and final year projects. Educational gamification seeks to add game-like concepts to a learning process and impart educational benefit. The gamification platform presented in this paper thus focuses on achieving four gaming aspects, i.e. gamification reality environment, goal-focused tasks, assessment, and reward mechanisms.

2.1 Gamification Reality Environment

The gamification environment should demonstrate the real-world contexts in a virtual gaming world to foster motivation and enhance learning experiences regarding given teaching contents. One common issue of gamification education is "The gaming environment is not really identical to the real environment". Trainees will still confront uncertain obstacles and frustrations in front of actual objects and situations because they need to cope with the variations among virtual gaming contexts and real ones. Responding to this challenge, we strive to design the gamification environment and contexts identical to the ones of the actual manufacturing shopfloor of our department.

Figure 1 shows the manufacturing shopfloor of School of Engineering, which supports students' training and their final year projects. The shopfloor comprises of various manufacturing systems including CNC machines (including milling, turning, turn-mill center, grinding, etc.), CMM, EDM, MES from different makes and models as listed in Table 1. Compared to the presented virtual gamification environment (seen in Figure 2), it is obvious that all gaming contents and elements are identical to the actual shopfloor in terms of their layout, model, quantity, feature, dimension, appearance, etc. The gaming elements of serval real components are displayed in Table 1. Besides the manufacturing systems, other features and facilities (such as tables & chairs, workstations, workpieces & tools, distinguishers, first aid kit, lighting, etc.) are also created in the gamification environment to realize the full sense of reality. With the practices from such a 'real' virtual gamification environment, students are expected to be able to seamlessly transform their skills gained from the game to the actual shopfloor operations with little transition barrier.
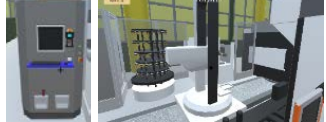
Figure 1. Real manufacturing shopfloor

Figure 2. Virtual gamification environment

Table 1. List of Manufacturing Systems and Gamification Elements

Machine & facility	Model & type	Quantity	Gaming element
CNC machines	DMU 40 Evo (5 axis milling)	4	
	Mikron 400 U (5 axis milling)	1	
	Mikron 500 LP (3 axis milling)	1	
	Mikron HSM 400 (HSM milling)	2	
	DMU 50 Evo (5 axis milling)	1	
	Kern 500 Micro (micro milling)	1	
	Okuma LB3000 (turning)	4	
	Amada MS G3 (profile grinding)	1	
	Studer S31 (grinding)	1	

	Mazak I-200 (turn-mill centre)	2	
CMM	Zeiss DuraMax	1	
	Wenzel Xorbit	1	
EDM machines	AgieCharmilles FO 350	1	
MES	3R ITC System (including CNC machines, CMM, robot arm, control centre, tool magazine, EDM, etc.)	1 set	
Other facilities and systems	Toolbox, work piece, material, Table, chair, distinguisher, first aid, etc.	-	

2.2 Gamification Training Task

Effectively integrating gamification into education demands a thoughtful study of the training contents, learning objectives, and the students involved. After considering the holistic structure of our teaching curriculum and the desired gamification elements and mechanisms for effective training and efficient learning, we strive to achieve the below goals while designing the gamification tasks for manufacturing shopfloor training:

- Scenario-based tasks to make training realistic
- Gaming driven approach by interactive challenges and quests
- Game-based design to enhance entertainment and engagement experience
- Timed decision-making activities to inspire potential learning passion
- Learn by "doing" with step-by-step process

In this gamification education platform, a total of 16 gaming tasks were developed covering the below three topics to support the teaching curriculum for manufacturing shopfloor training:

a) Train the safety awareness and reactive actions of the manufacturing shopfloor
b) Introduce the various manufacturing systems of the manufacturing shopfloor
c) Train and teach the machining techniques, mechanisms, applications, operations, dynamic, and machining methods of different manufacturing systems of the manufacturing shopfloor

2.2.1 Shopfloor Safety Training

Safety awareness is important and a compulsory procedure in manufacturing shopfloor by Workplace Safety & Health Act (WSH). Under this act, all parties must manage risks at work and adhere to safe work procedures. In this gamification platform, three scenario-based gaming tasks were created to reinforce the safety awareness at shopfloor, to cultivate good safety habits, and to promote a strong safety culture for all students in our workplace. Table 2 describes the details of the three safety training tasks including their game scenes, game scenarios, and corresponding training objectives. In the first task (Task 1-1), students need to wear safety suits properly at the entrance of the shopfloor before any other training actives.

Once a fire event is triggered (Task 1-2), students must quickly locate the distinguisher and pull out the fire, which may occur at different locations of the shopfloor. Running out of time for this task will evoke system warning. While Task 1-3 is triggered, students need to pick up the oil blotting paper and clean the oil stain appearing at random sites. Through these activities, we want to cultivate students with good safety habits and reinforce their safety awareness. In addition, students can also familiarize with shopfloor layout and the locations of safety facilities.

Table 2. Shopfloor Safety Training Tasks

Game task	Game scene	Game scenario	Training objective
Task 1-1 Wear Safety Suit		• Pick up and wear safety suit • The first game task	• Aware of safety cautiousness of shopfloor • Wear safety suit properly before any activities • Clean oil stain using oil blotting paper • Aware of fire alert • Familiar with the locations of safety facilities
Task 1-2 Put Out Fire		• Fire event is triggered occasionally with random sites • Pick up distinguisher to pull out fire quickly	
Task 1-3 Clean Oil Stains		• Oil stain event is triggered occasionally with random sites • Pick up oil blotting paper to clean oil stain	

2.2.2 Manufacturing System Introduction

Manufacturing system introduction tasks are designed to introduce the various manufacturing systems of the shopfloor. Through the total seven gaming tasks from Task 2-1 to Task 2-7 (as listed in Table 3), students are expected to familiarize with various CNC machines, CMM, EDM, MES, and learn diverse manufacturing technologies of different manufacturing clusters of the shopfloor. To complete these gaming tasks, students need to explore different manufacturing systems, understand their operations and features, and closely view the machine structures and simulations at the virtual gaming environment.

Table 3. Manufacturing System Introduction Tasks

Game task	Game scene	Game scenario	Training objective
Task 2-1 Learn **DMU Milling**		Based on the given jobs, student should: • Identify the right manufacturing system • Collect appropriate system information • Invoke proper actions and operations • Investigate machine controllers and functions	• Familiarize the layout and system clusters of the shopfloor • Familiarize with various CNC machines (i.e. 3 axis milling, 5 axis milling, turning, HSM milling, turn-mill and grinding machine) • Understand the differences of different machines (including axis, design, key components, configuration, mechanical structure, tooling system, functions, operations and applications)
Task 2-2 Learn **OKUMA Turning**			
Task 2-3 Learn **MIKRON HSM Milling**			
Task 2-4 Learn **MAZAK Turn-Mill**			
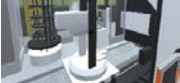
Task 2-5 Learn **AMADA Grinding**			• Familiarize with EDM machine (including key components, configuration, mechanical structure, tooling system, functions, operations and applications)
Task 2-6 Learn **EDM** System			
Task 2-7 Learn **MES** System			• Familiarize with MES and its system elements (including control centre, robot arm, tool magazine, CNC machines, CMM, etc.)

2.2.3 Manufacturing System Mechanism and Application

Six gaming tasks (from 3-1 to Task 3-6 listed in Table 4) are designed for students to learn the manufacturing mechanism, dynamics, functions, methods, and controllers of various manufacturing systems. To complete these tasks, students should find the right machines and operations for specific given jobs, including 3 axis milling, turning, turn–mill, multi-axis machining, drilling, grinding, integrated MES, etc. Through the job executions and simulations without the worry of mistakes and safety issues, students can establish a deep understanding of machining mechanism, dynamics, job operations, functions and machine controllers.

Table 4. Manufacturing System Mechanism and Application Tasks

Game task	Game scene	Game scenario	Training objective
Task 3-1 **3-Axis Milling** Job		Based on the given jobs, student should: • Identify the right manufacturing systems • Execute the right functions and operations with appropriate procedure • Invoke proper simulations and protocols • Fix encountered errors and anomalies accordingly • Answer the in-time questions • View simulations and machine controllers	• Understand the manufacturing mechanism and functions of manufacturing systems. • Understand CNC machining operations, such as 3 axis milling, turning, turn–mill, multi-axis machining, etc. • View machining operations and simulations closely and safely to Understand machine configurations and dynamics. • Able to choose the right machine to operate the specific task • Learn machine controllers and user interfaces • Learn the components of MES and how diverse manufacturing systems are integrated within a single system
Task 3-2 **Turning** Job			
Task 3-3 **Drilling** Job			
Task 3-4 **5-Axis Milling** Job			
Task 3-5 **Turn-Mill** Job			
Task 3-6 **MES** Job			

2.3 Assessment and Reward Mechanism

Assessment features are built within the gamification platform to assess students' learning and training results. Students can view their training progress and results as shown in Figure 3. A leaderboard is typically used in competitive activities and in encouraging repetitive actions. In

this gamification platform, a leaderboard is developed to display students' gaming achievement with their game ranking (in Figure 4). As a coarse-grained technique tool, it provides just-in-time feedback and overall competencies as well as plays as a motivator to encourage little further effort to achieve better results.

Figure 3. Gamification assessment

Figure 4. Leaderboard for gaming results

3. IMPLEMENTATION AND RESULTS

The shopfloor gamification training platform was implemented at the manufacturing shopfloor of Nanyang Polytechnic in AY2018 semester 2. It was launched as an e-Learning platform for those students just before having their learning activities and final year projects at the manufacturing shopfloor. A total of 134 students from 4 classes of digital precision engineering diploma are involved in the gamification evaluation. To investigate the effectiveness of the gamification platform, a set of technical quizzes and game feedback survey are produced. The technical quizzes include 16 questions covering the training objectives based on the digital manufacturing shopfloor training curriculum. The game feedback survey contains 10 questions focusing on the psychological need and game satisfaction of all participants. Before the gameplay, teachers had taught the knowledge of the manufacturing systems of the shopfloor in classroom verbally and their self-learning with literal training documents. Class 1 and Class 2 completed the technical quizzes before playing their gaming tasks, while Class 3 and Class 4 completed the technical quizzes after they played the gaming tasks. Table 5 shows the comparison of the results of technical quizzes by the 4 groups respectively. The average scores of Class 1 and Class 2 are 53 and 56 respectively. The scores Class 3 and 4 are 67 and 68 respectively. It showed an overall 15% learning improvement from gameplay. Regarding of the fail rate (means <50% correct rate), 16% (i.e. 6 students) of Class 1 and 37% (i.e. 10 students) of Class 2 failed in their quizzes. In contrast, only 6% (i.e. 2 students) of Class 3 and 3% (i.e. 1 student) of Class 4 failed in their quizzes. It revealed a significant improvement by use of gamification education in leveling up the fundamental knowledge of manufacturing systems. Our finding implied that gamification education is much efficient in helping those weak learners, for whom classroom teaching is less effective, reaching a satisfactory knowledge level in the shopfloor technology training.

Among the total collected 122 game feedback and satisfactory surveys, the 93% (i.e. 113 students) agreed that the gaming play had much helped them in familiar with the manufacturing systems of the shopfloor. They are more confident in operating CNC machines with much less fear of making errors. The 91% of participants responded that the game play had deepened their comprehensive knowledge in understanding diverse manufacturing systems of the

shopfloor. The 76% (i.e. 99 students) indicated that they would like to have such gamification in other modules in our school.

Table 5. Comparison of the Results of Technical Quizzes

	Class 1	Class 2	Class 3	Class 4
Student number	38	27	35	34
Gaming tasks?	before	before	after	after
Average score (%100)	56	53	67	68
Fail rate (<50% correct rate)	16% (6 students)	37% (10 students)	6% (2 students)	3% (1 student)

The overall evaluation revealed that the gamification platform had a positive impact on engaging students in their learning. It was also observed that students prone to involve in more discussions, engagement and teamwork while playing a game, even for those 'quiet' students in the classroom. Teachers also feel empowered to start integrating gamification elements and mechanisms into their curriculum. It is concluded that gamification can be integrated effectively into manufacturing education to motivate students and enhance learning effectiveness, as well as provide a safe environment for students to learn without fear of making errors.

4. DISCUSSION AND RECOMMENDATION

Based on the findings through the implementation and evaluation of the gamification education platform in our department, we would like to share our insights in several arguments as below:

a) Gamification environment should be identical to the real shopfloor
Manufacturing shopfloor training is in-nature practical training and its objective is to train students in operating different CNC machines. Apparently, gamification training can be much efficient if the virtual machines in game environment are identical to the real machines of the shopfloor. Students can therefore easily match what they have learnt through gameplay with the real systems with fewer variations. Our survey supported this finding. Moreover, we recommended to setup gamification stations at the shopfloor, students can thus immediately compare the actual components with their virtual avatars. We have done so, and the feedback is very positive.

b) Gamification is an effective e-Learning platform
Manufacturing shopfloor training often requires supportive activities, facility sharing, material & tool consumption, operational guidance, as well as progress tracking and interactions. With the gamification platform, students can practice training tasks without physical and time constraints, and learn from mistakes that cannot be afforded at actual shopfloor. Our students and instructors had confirmed the gamification platform as an efficient e-Learning platform.

c) Gamification cannot replace classroom teaching and hands-on training
Our experience indicated that gamification platform works effectively in preparing students with the general knowledge of manufacturing systems such as machine features, applications, operations, etc. Gamification can also lead to building up internal motivation to engage with real activities at shopfloor. However, it is hard to expect gamification platform covering entire comprehensive curriculum contents and to train students in mastering deep and comprehensive manufacturing knowledge. In a word, gamification can be applied to make

learning more engaging, but it should not be viewed as isolation to classroom teaching and hands-on training.

d) Reward mechanism should be achievable
We agree that rewards should be achievable with a sufficient level of effort. It is important to create conditions and opportunities to achieve the ultimate goal. Each level of task is expected to be more complex and require more efforts corresponding to newly acquired knowledge and skills. By repetitive trials, students can improve their skills as well as achieve a better ranking. We also agree that gamification should be used to increase motivation, but may not an effective mechanism to grade students (Ian Glover, 2013). It is not always the case that a student at the top of the leaderboard is the best achiever in formal assessment.

e) Motivation could be related to intrinsic and extrinsic characteristics
We noted that some arguments exist in terms of the motivation by gamification in regard to the individual's intrinsic and extrinsic characteristics. Groh found that gamification seeks to increase motivation by providing extrinsic recognition and reward for completing activities, however, there is the possibility that such rewards can serve to de-motivate learners with an already high intrinsic motivation (Fabian Groh, 2012). Similarly, Olsson (Marie Olsson, 2015) argued that some of the variance in the effectiveness of gaming mechanisms depend on the learner's intrinsic motivation. These arguments need further studies in order to optimize gaming tasks and mechanism with respect to the individual's characteristics.

During the implementation phase, we noticed two limitations of the current gaming platform. One is that students expect more gaming tasks covering their teaching curriculum. The other is the lack of gaming scenarios and consequences caused by mistakes or wrong operations. These limitations will be considered in future work. In addition, the in-game perception of students' intrinsic and extrinsic motivation has not been taken into consideration in our current work. One possible approach is to embed intelligent data analytics methods into the gamification platform to perform learning behavior & pattern perception.

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Engineering Education Research

IS THE CDIO JOURNEY WORTH IT? – AN ANALYSIS OF EUROPEAN INTERMEDIATE CDIO MEMBERS

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ABSTRACT

The CDIO initiative started in 2000 with four institutions. Since then the number of institutions has increased and today there is more than 160 using CDIO in their programs. This increase shows that the CDIO initiative provides something that the engineering programmes, schools, faculties, and institutions are seeking. When institutions apply for membership in the CDIO initiative, they submit an application where they answer several questions reflecting their situation, aims and goals. In the application phase, they look into the future and try to elaborate on the effects they think CDIO might provide and on the effects that they hope CDIO will bring. Furthermore, the universities do a CDIO self-evaluation as part of the application procedure. The authors of this paper have application data of more than 60 institutions starting from 2010 until today. The data is available as both authors act as regional leaders of CDIO in Europe. As the application phase is more or less a description of dreams towards a CDIO future, the authors wanted to study how well the dreams have come true and what have happened after the introduction of the CDIO approach. For this research, we selected six case universities and asked them to reflect on their journey from the application phase to today. The cases represent different countries within the CDIO European region, and they have been members of CDIO over three years. The research focused on three areas: fulfilment of expected outcomes of joining the CDIO initiative, barriers and enablers for changes and usability of CDIO self-evaluation. The results show that universities have fulfilled their expectations very well, and the CDIO approach has benefited them in various ways, and the CDIO journey is worth doing.

KEYWORDS

Join CDIO, Application process, Experiences, Standards 1-12

INTRODUCTION

The CDIO initiative started in 2000 with four universities, in 2011 there was already 62 universities, and today there are more than 160 universities. The rising number of universities in CDIO shows that the initiative provides something that the engineering

programmes/schools/faculties/universities are seeking. Earlier research has shown that there are a variety of reasons and expectations of why universities apply to join CDIO (Table 1).

One of the key reasons to join CDIO is observability which can be understood as learning from the others, sharing own experiences, visibility and availability of information about CDIO, and becoming a member of a network of universities sharing the same idea of education development. Another major reason to join CDIO is the CDIO initiative's compatibility with the university's own vision on education development and with the development actions already taking place. The third major category of reasons to join CDIO is the relative advantage universities are looking to achieve through CDIO initiative. Universities see the CDIO initiative as suitable and superior for engineering education. They are looking for a remarkable impact on their programs and overall development. Furthermore, the universities see that the CDIO initiative is not a complex system rather it can be easily understood and tools such as the CDIO standards and the CDIO syllabus are simple to use. (Kontio, 2017)

Table 1. The key characteristics of the CDIO attracting new universities (Kontio, 2017).

Characteristic	Key characteristics of the CDIO approach
Relative advantage	Suitable and superior for engineering education Remarkable impact on the development
Compatibility	Similarity to university vision Connectivity with earlier development activities
Simplicity	Easily understood Focus on engineering education Tools for development (Standard & Syllabus)
Trialability	Inspires staff Standards and syllabus available for testing Framework for development activities Not limited to engineering education
Observability	Network to learn from the others Network to share their own experiences Visibility and availability of information Network of similarly-minded universities

The characteristic categories are based on the diffusion of innovation theory (Rogers, 1995) and the identified key characteristics of each category are based on an earlier study (Kontio, 2017) where 55 CDIO applications were analysed. One of the key reasons to join CDIO is observability which can be understood as learning from the others, sharing own experiences, visibility and availability of information about CDIO, and becoming a member of a network of universities sharing the same idea of education development. Another major reason to join CDIO is the CDIO initiative's compatibility with the university's own vision on education development and with the development actions already taking place. The third major category of reasons to join CDIO is the relative advantage universities are looking to achieve through CDIO initiative. Universities see the CDIO initiative as suitable and superior for engineering education. They are looking for a remarkable impact on their programs and overall development. Furthermore, the universities see that the CDIO initiative is not a complex system rather, it can be easily understood, and tools such as the CDIO standards and the CDIO syllabus are simple to use. (Kontio, 2017)

When universities apply for membership in the CDIO initiative, they submit an application where they answer several questions reflecting their situation, aims and goals. In the application phase, the potential applicant answer a set of questions in the so-called CDIO questionnaire. There are questions as

- Why does your university want to join the CDIO Initiative?
- How do you expect CDIO to impact these programs?

In the application phase, the universities look into the future and try to elaborate on the effects they think CDIO might provide and on the effects that they hope CDIO will bring. Also, the universities do a CDIO self-evaluation as part of the application procedure.

The authors of this paper have application data of more than 60 universities starting from 2010 until today. The data is available as both authors act as regional leaders of CDIO in Europe. As the application phase is more or less a description of dreams towards a CDIO future, the authors wanted to study how well the dreams have come true and what have happened after the introduction of the CDIO approach. For this paper, the authors selected six case universities and asked them to reflect on their journey from the application phase to today. The cases represent different countries, and they have been members of CDIO over three years. The research focused on three areas: fulfilment of expected outcomes of joining the CDIO initiative, barriers and enablers for changes and usability of CDIO self-evaluation. The results of this research provide more information on the impacts that CDIO has on engineering education and the engineering programs. This information is valuable and interesting for universities, programs and the CDIO community as well. The following sections describe the research approach, the results and finally discuss and provide conclusions.

RELATED WORK

Several authors have evaluated why institutions want to join CDIO and their benefits in doing so.

One of the first is Gray (2009) who, in 2008, focused on how CDIO institutions have used the CDIO standards as a part of their quality enhancement and the progression the 23 institutions (out of 27 CDIO members in total then) had made. As Malmqvist et al. (2015) concluded "Gray's data suggested that many schools had joined CDIO with an already existing interest and experiences in design-implement, but also that the standards related to faculty competence (9, 10) are the most difficult to improve on (p. 3)".

Bennedsen and Christensen (2012) interviewed key persons at four Danish engineering institutions. The focus of the interviews was to find each institution's rationale for joining CDIO. They found six factors that all institutions found enabled the CDIO implementation: "Management support", "Evolution, not revolution", "Common language", "Program view", "Competence matrix" and "Support".

Malmqvist et al. (2015) surveyed 47 institutions in 2014 with the focus of 1) Find out what engineering programs that had implemented CDIO and 2) Evaluate the effects on outcomes, the perceived benefits, the limitations, any barriers to implementation, and ascertain future development needs. They found three main rationales for choosing to adapt CDIO; "ambitions to make engineering education more authentic", "the need for a systematic methodology for educational design" and "the desire to include more design and innovation in curricula".

Meikleham et al. (2018) used bibliometric data analysis to see how the foci of papers mentioning CDIO and engineering education have evolved over the years. They found 1453 papers in their searches (Scopus and Web of Science, note that this excludes the CDIO proceedings). They analysed the how often the different CDIO standard phrases were mentioned and found that "design-implement", "design implement operate", "learning outcomes" and "project-based learning" was by far the most mentioned words. This could be seen as an indication of the focus of CDIO membership. However, the focus of the articles could be on other elements of engineering education than institutional CDIO characteristics for joining and staying within CDIO.

RESEARCH APPROACH

The research approach used in this paper was a multiple case study research. Case research aims for an in-depth understanding of the context of a phenomenon (Cavaye, 1996). This research methodology was selected because the goal of the research is not to achieve statistical generalisation rather analytic generalisation (Yin, 1994). In a case study, each case must be carefully selected so that it either predicts similar results (literal replication) or forecasts contrasting results but for predictable reasons (theoretical replication) (Cavaye, 1996; Yin, 1994). In this research, a literal replication strategy was used as authors' hypothesis was that implementation of CDIO could succeed in any country and any engineering university.

Methodologically this is a descriptive case study research. A descriptive case study presents a complete description of a phenomenon within its context (Yin, 2002). In general, a case study aims for an in-depth understanding of the context of the phenomenon (Cavaye, 1996). Furthermore, a case study is well-suited to capture the knowledge of practitioners and to document the experiences of practice. The unit of analysis is the university and its experience and situation of CDIO implementation.

For this research, six cases were selected. The cases are listed in table 2. The cases were selected as equally representative, with no predetermined ideas. All cases fulfil the following criteria: 1. They were willing to participate, 2. They have been members of CDIO initiative at least three years, 3. They represent different countries, 4. They have been active in the CDIO community. Invitations to nine CDIO institutions was sent, the six choose to answer.

Table 2. The case universities

University	Country	Applied
Bauman Moscow State Technical University	Russia	2014
Blekinge Institute of Technology	Sweden	2013
CESI Graduate School of Engineering	France	2016
Gdansk University of Technology	Poland	2011
The Hague University of Applied Sciences	Netherlands	2014
Technical University of Madrid	Spain	2014

A questionnaire was used for data collection. A welcoming message and a link to the questionnaire was emailed to the university's CDIO collaborator. The questionnaire had three areas:

- Area 1: Fulfilment of the expected outcome
- Area 2: CDIO self-evaluation
- Area 3: Barriers and enablers for change.

For each case, the area 1 of the questionnaire was tailored based on their initial application some years ago. Based on the goals we could identify in their application, we asked the CDIO representative of the institution to evaluate the fulfilment of that particular goal on a five-point Likert scale. Area 2 focused on CDIO self-evaluation and we wanted to know how they have used this tool to support their CDIO implementation and what their experiences are. Area 3 should provide more understanding of why something has happened and why not: are there factors that have hindered/enabled the CDIO journey.

LIMITATIONS OF THE STUDY

Collecting data from six countries is challenging. As a viable option, we did choose to use a questionnaire with both quantitative scales and free text fields. This naturally enhances the chances of getting data but also limits the amount of data that one gets. An alternative to getting richer data could be interviewing the respondents.

In the first area (Fulfilment of the expected outcome), apart from indicating the fulfilment of their goal and how important the participant saw the five categories both when applying and now, they had the possibility of commenting on that in a free text format. There were a total of 141 elements (an element is either one goal or one of the categories now or back then). One hundred and two of these had no comments. For the rest, most of the comments were just detailing the answer to the scale (like the actual period the answer covers).

For the free text field (area two and three), the respondents did give longer answers, but the answers consist almost all of just one line. There were a total of 21 answers with 836 words of text in total (approximately 40 words on average).

RESULTS

Area 1: Fulfilment of the expected outcome

All case institutions had set (more or less) clear goals for what they wanted to happen after they had become members of the CDIO. A typical example could be a goal like "Courses with more hands-¬on learning and active student participation" or a more high-level goal like "Engineering education enhancement". In average, the institutions had 11.5 goals, spanning from 6 to 16.

We have mapped the goals to the five categories described in Table 1. The mapping was first done by one author independently, then checked by the other author and disagreements were finally discussed and a consensus established. As an example, "Courses with more hands-¬on learning and active student participation" was mapped to "Simplicity" since it focuses on the CDIO tools, whereas "Re-assess the curricula every 2 or 3 years by surveying the stakeholders" was mapped to "Relative advantage" since it has to do with quality

assurance/enhancement. The categories are based on the reasons why institutions want to join CDIO (the question "Why does your university want to join the CDIO initiative" from the application form), and this analysis is based on the entire application, so some of the more "strategic" reasons might not be identified as a concrete goal. However, as one of the authors is the inventor of the categories, he has better insight into the categorization and therefore, could give extra descriptions of the categories.

In Figure 1, you can see the distribution of the goals. As can be seen, most of them had to do with "Simplicity" or "Trialability"; most were concrete goals for programmes to implement CDIO in that program.

Figure 1. Distribution of the goals.
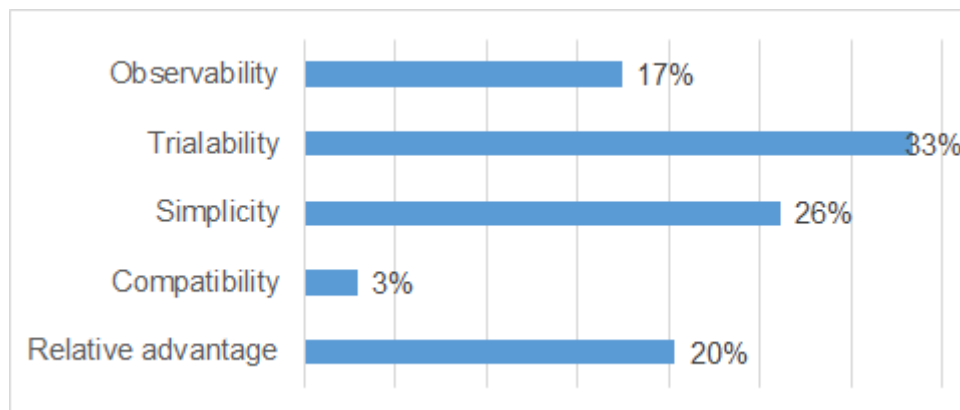
As described, the respondents were asked to assess the fulfilment of each goal. This varies from 0% to 100% with an average fulfilment of 64%. In figure 2, you can see the average of the fulfilment of the five categories of goals. "Compatibility" accounted for just 3% of the goals; they are almost fulfilled, whereas "Simplicity" accounted for 26%, but they are only 54% fulfilled.

Figure 2. Fulfilment of the goals.
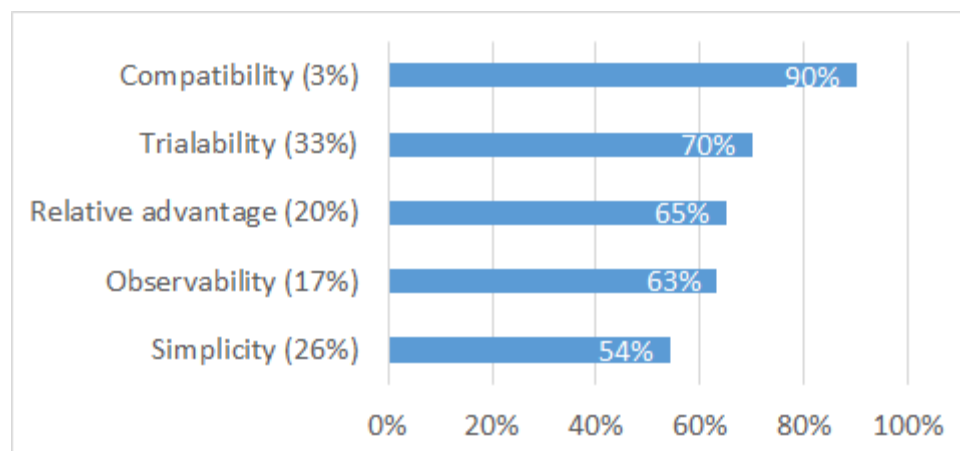
If we look at the average of goal-fulfilment per institution, there are big differences from 39% to 84%. Looking at the number of years the institution has been a CDIO member do not

correlate with their goal-fulfilment rate, neither does the number of goals with the goal-fulfilment rate.

Area 2: Use of CDIO self-evaluation

Every case university has done at least once the CDIO self-evaluation ie. for the application phase. Three of the cases have repeated the self-evaluation after the acceptance to CDIO network and a fourth one has plans for doing it again. The remaining two cases say that they have not repeated it because
- *other reporting responsibilities do not leave time for self-assessment*
- *they are involved in accreditation programmes and have continuous improvement well monitored.*

Still, all cases found the CDIO self-evaluations beneficial. First, it makes people familiar with the standards and improves understanding of CDIO:
- *when we filled it in the first time, not everybody who did so was already familiar with the CDIO jargon.*
- *It helped us to notice that CDIO was much more than conventional active learning based on project-based activities and to see how we could improve.*

Second, the self-evaluation provides information about whether you have made progress in your development and how to continue:
- *You have to evaluate if you have any progress with your work or not (wasted money).*
- *Teams evaluated their programme on the standards. And then the outcome meant something to them, and they derived priorities from it.*
- *To see how we can better follow the CDIO standards, are very important for continuous innovation.*

Third, the CDIO self-evaluation provides a large amount of information about the programs and helps developing new programs:
- *Eight programs out of the 12 have done CDIO self-evaluation now.*
- *Self-evaluations of programs against the CDIO standards enables efficient collection of a large amount of information from many departments in parallel mode.*
- *To create two new integrated curricula with a project-based learning approach.*

Area 3: Barriers and enablers for change

All cases speak warmly about how CDIO has enabled the development of their programs. The cases evaluated for this research the importance of the key characteristics at the application phase and now. The average values of the cases are shown in table 3.

Table 3. Importance of key characteristics at the application phase and now.

Characteristic	Apply	Now
Relative Advantage	3,2	3,5
Compatibility	4,0	4,2
Simplicity	3,3	3,7
Trialability	3,8	3,3
Observability	4,0	4,3

The results show that the importance of different CDIO characteristics has slightly changed from the application phase to today. In all areas except one the importance has increased (Figure 3). The only area where the importance has decreased slightly is Trialability.

Figure 3. The shift of importance.

The areas that are influenced by CDIO can broadly be labelled as pedagogy, network, framework and accreditation. In pedagogy, the CDIO approach has influenced the way engineering education is provided

- *It has importantly supported our systematic promotion of a student-centred engineering education*
- *The active learning workshops and introductory workshops reached about 120 people of our teaching staff, who all went to work with it in their own manner and level of adoption.*

Cases emphasizing the value of the CDIO network say that

- *Shared experiences with colleagues in the CDIO meetings have been inspiring.*
- *Some programmes have started international collaborations with fellow CDIO members.*
- *And about 40 staff members have visited CDIO-meetings to learn and be inspired.*

Maybe the most valuable benefit of CDIO has the role of an engineering education framework. The CDIO initiative is said to

- *provide a well-established context for transformations that we were implementing along the last couple of decades.*
- *Be the framework which acts as a guide rail to hold on to in your process with transforming the programmes.*
- *Provide a common language over the 12 programmes of the faculty to talk about educational improvements.*

Furthermore, the CDIO tools for development have been beneficial:

- *CDIO serves as an open-source resource of new ideas, teaching philosophy, solutions of arrangements of students' workspaces, teaching methods, a template of learning outcomes.*

- *CDIO has been used to design the syllabus and integrated curricula.*
- *to conceive the new CESI engineer vision*

The role of CDIO in accreditation processes is recognised in the cases as well:

- *Interdisciplinary approach and project approach, learning outcomes taking into account competencies - all this is used now in the country's educational standards*
- *It has been positive also for national and international accreditations.*
- *CDIO has been used to prepare the accreditation's renewal.*

Finally, the cases reflected their context where they are operating with their CDIO journey. They were asked to identify possible hindrances and enablers. Many cases mentioned national regulations that set certain boundaries to their CDIO implementations, and they have to make meaningful combinations. For example, one case mentioned that they keep on asking to what extent the CDIO syllabus conforms the national goals. The national regulations also slow down the development with CDIO: *national accreditation requirements of the curriculum are very rigid.* On the other hand, it can be opposite too: *an engineering education reform is performed with the new highest education law.*

Also, the cases reported challenges within the programs such as reluctant colleagues, resources (mostly time), and not knowing the CDIO.

One positive comment based on the structure of the CDIO network was that national gaps and confrontations between research universities and universities of applied sciences are forgotten in the CDIO network. In the CDIO network, all universities are working for the same goal and it is regarded as a powerful enabler and *makes international collaboration easier than those within your country*.

DISCUSSION

Fulfilment of goals in the application
When entering CDIO, the institution had a vision of what they want to achieve by being a CDIO member. Not all of the "dreams" come true, but just one goal has not been reached at least a little bit. Institutions making many goals do not fulfil them more or less than institutions making a few goals, so we cannot advise "a good number" of goals in an application. We can speculate on the reasons for the difference between institutions, but we cannot conclude from our data.

Use of CDIO self-evaluation
The CDIO self-evaluation is a valuable tool for universities. The CDIO self-evaluation not only give information on the progress of the CDIO implementation but also helps to disseminate CDIO awareness to the programs. In faculty level, it works as a management tool as well: giving a common ground for development activities and collecting information of many programs.

Barriers and enablers for change
It is clear that CDIO has enabled positive changes in engineering education. The CDIO initiative is valued as a framework, as a network of engineering educators and as a concrete toolbox. At the same time, countries have their own educational policies and laws that either enable openness in development or build barriers limiting the freedom of going towards CDIO goals.

Implications to CDIO application procedure

The analysis of CDIO applications and goals set in the applications show a lack of real metrics to understand the impact of the CDIO approach. The goals defined in the applications are not easily measurable and it is not easy to estimate the success of CDIO. Therefore, we propose two additions to the CDIO application procedure. First, together with the goals, the application should define concrete actions for reaching the defined goals during the next 2-3 years. Second, a new step is added to the application procedure: the follow-up phase. This step is a reporting and reflecting phase where the applicant analyses their progress and challenges. The reporting could be part of the regional meeting like the new school presentations.

FUTURE WORK

As described in the section on the limitation of the study, the amount of data to be analysed is rather small and thus, the conclusions based on the qualitative data rather vague. We will like to continue this work in a more "normal" qualitative research method, namely by interviewing the relevant stakeholders. Using that approach, we expect to be able to get more in-depth data and have the possibility to start answering the more interesting question "what is the benefits and drawbacks of a CDIO journey"?

CONCLUSIONS

Is the CDIO journey worth it? Based on this study, we can answer: Yes.

We see that at the beginning, universities take the CDIO approach as a continuum with their vision and they see the CDIO approach as an easy starting point. While time goes on the relative advantage CDIO provides becomes more important as well as the network, the community of the CDIO.

We suggest that the CDIO council discusses the proposed application procedure change.

ACKNOWLEDGMENTS

We warmly thank the universities, which shared their experiences for this study.

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ENHANCING STUDENT ENGAGEMENT IN FLIPPED CLASSROOM USING AUTONOMY-SUPPORTIVE TEACHING

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ABSTRACT

An education research project funded by the Singapore Ministry of Education Tertiary Education Fund entitled Enhancing Students' Intrinsic Motivation: An Evidence-based Approach was recently undertaken by the second author, who is also the Principal Investigator; and a group of lecturers including the first author. The broad research questions focused on how students experience their learning when teachers use an Autonomy-supportive Style of teaching and employ Evidence-Based Practices and Principles in their teaching approach. A significant aim is to identify specific evidence-based strategies to enhance students' active participation (agentic engagement) in both pre-class and in-class activities. This paper shares the results of the project by the first author in using autonomy supporting style of teaching to engage students in flipped classroom learning. The study used a mixed methods approach which includes survey questionnaire and focus group discussion of students, and lesson observation of the lecturers, as well as reflection journals by the lecturers. The result of this study showed that both an autonomy-supportive style of teaching and cognitive scientific principles of learning employed by the first author had positively impacted student engagement and self-efficacy. The qualitative data was particularly revealing in terms of how students experience their teachers in terms of the range of instructional and teacher behaviours that are most impactful. Outcomes from the rest of the research team, which cut across a range of disciplines and in different contexts, show similar findings. As such, a compelling case can be made for utilizing the approach employed and the area is rich for further research to delineate more specific aspects of practices that can positively enhance the subjective experience of students' learning in the context of intrinsic motivation.

KEYWORDS

Autonomy supporting, cognitive scientific principles, student engagement, Standards: 10

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to as A "faculty" in the universities.

INTRODUCTION

This paper shares the experience of the first author in executing an education research project in Singapore Polytechnic. The project is entitled Enhancing Students' Intrinsic Motivation: An Evidence-based Approach, and is supported by the Singapore Ministry of Education Tertiary Education Fund. The second author is the Principal Investigator. The first author, who teaches the Diploma in Chemical Engineering (DCHE) from the School of Chemical and Life Sciences, along with 6 other colleagues from various other Schools, took part in the project.

The project involves the lecturers systematically applying Evidence-Based Teaching (EBT) methods and learning principles (e.g. Hattie, 2009; Petty, 2009; Willingham, 2009; Sale, 2015) and autonomy-supportive teaching (e.g. Williams & Deci, 1996; Reeve, 2015) in their respective teaching discipline to the design and facilitation of classroom learning. EBT has evolved from a synthesis of research on what teaching methods work best and the increasing knowledge bases on how humans learn from the fields of cognitive science and neuropsychology. Autonomy-supportive teaching incorporates specific validated practices derived from Self-Determination Theory (e.g. Ryan & Deci, 2017).

There are 7 cohorts of students from different disciplines involved, over a period of one semester of study (15 weeks). The first author applied EBT and autonomy-supportive teaching to a total of 37 students in 2 classes from DCHE, in the Year 2 module entitled *Plant Safety and Loss Prevention*. The module is one of the core modules in DCHE, and is taught using the flipped classroom format. Work done by the 2 authors in flipped classroom are discussed elsewhere (Cheah, Sale & Lee, 2016; Cheah & Sale, 2017).

CHALLENGE OF FLIPPED CLASSROOM: PRE-CLASS LESSONS

It is clear from the literature that flipped classroom, just like other forms of active learning, requires engaged students (Pienta, 2016), especially in going through the pre-class materials on their own before coming to class. However, not all students are motivated to put in the required effort to do so. Motivation and engagement are important drivers of deep learning (Kuh, 2003). But these students lack "homework culture" (Straw et al., 2015) and may come to class unprepared to participate in class activities.

Engagement is an important factor impacting learning: if students perceived that a learning experience was of value to their learning, they were more likely to use it (von Konsky et al., 2009). Murray, et al. (2012) suggested that students selectively access course content based upon the degree to which they perceive it will positively influence performance and outcomes on assignments and assessments. Due to time constraints, students tend to employ strategies that they perceive will provide an optimal outcome (Murray et al., 2013). The challenge for educators, especially those embarking on flipped classroom, is to design interesting pre-class online learning materials that students want to read up. Some authors recommended giving marks to students for completing their requisite pre-class readings, but this is not a position advocated by the first author. Instead, he seeks to motivate students by designing engaging pre-class learning tasks that are closely-coupled to what they will actually be doing in class. It is with this challenge that the first author embark on adopting the autonomy-supportive style of teaching to engage students in learning.

INTRINSIC MOTIVATION AND AUTONOMY-SUPPORTIVE STYLE OF TEACHING

Self-Determination Theory (SDT) of motivation distinguishes between intrinsic and extrinsic motivations (Ryan & Deci, 2000). Intrinsic motivation refers to learning situations when one engages in the learning experience out of genuine interest for that topic or specific activity. Intrinsic motivation is the desired type of motivation for study as it is associated with deep

learning, better performance and positive well-being in comparison to extrinsic motivation (Kusurkar et al., 2011). It is dependent on the fulfilment of three basic psychological needs described by SDT: needs for autonomy, competence and relatedness. Autonomy-supportive teaching proposes to satisfy these needs in order to stimulate intrinsic or self-determined motivation among students as opposed to controlling teaching behaviour. Autonomy-supportive teaching makes students feel autonomous and competent in their learning and also supported by their teachers, fostering relatedness (Reeve, Deci & Ryan, 2004).

Reeve (2016) framed supportive autonomy being (a) the interpersonal effort to provide a *teacher-student relationship* and a *classroom environment* that appreciates and supports students' need for autonomy, and (b) an interpersonal tone of understanding that is highly respectful of the student's perspective and initiatives and implicitly communicates, "I am your ally; I am here to support you and your strivings". Autonomy-supportive teachers showed a distinctive motivating style as measured by their conversational behaviors, interpersonal style, and attempts to support students' intrinsic motivational and internalization processes (Reeve, Bolt & Cai, 1999). In concrete terms, the autonomy-supportive style is operationalized through behaviors such as (a) nurturing inner motivational sources, (b) providing explanatory rationales, (c) relying on non-controlling and informational language, (d) displaying patience, and (e) acknowledging and accepting expressions of negative affect. (Amoura et al., 2015; Reeve, 2009)

Motivation and Engagement

The distinction between these two constructs is that motivation is a private, unobservable psychological, neural, and biological process that serves as an antecedent cause to the publically observable behaviour that is engagement (Reeve, 2012). While motivation and engagement are inherently linked (each influences the other), those who study motivation are interested in engagement mostly as an outcome of motivational processes, whereas those who study engagement are interested mostly in motivation as a source of engagement. So, motivation is the relatively more private, subjectively experienced cause, while engagement is the relatively more public, objectively observed effect.

Four interrelated aspects of students' engagement during a learning activity are: behavioural engagement, emotional engagement, cognitive engagement and agentic engagement (Reeve, 2012). Making a judgment of how actively involved the student was in the learning activity would involve assessments of one's concentration, attention, and effort (behavioural engagement), the presence of task-facilitating emotions such as interest and the absence of task-withdrawing emotions such as distress (emotional engagement), usage of sophisticated rather than superficial learning strategies (cognitive engagement), and the extent to which one tries to enrich the learning experience rather than just passively receive it as a given (agentic engagement, see Reeve & Tseng, 2011; Reeve, 2013).

DESCRIPTION OF WORK DONE

The study involves a series of 7 cases; each case constituting the experiences of a lecturer and his/her students over a 15-week module. It also embodies an action research focus, e.g., understanding practice, how it is experienced by learners, and with a view to enhancing the learning experience for students (e.g. attainment opportunities; intrinsic motivation) and faculty competence in being able to do this better. The use of Petty's framing of 'Supportive Experiments' (Petty, 2015) provided the guiding heuristics for this action research focus. Essentially, this involves the teacher using a strategy (i.e. EBT, autonomy-supportive teaching) for a given period of time in order to adapt it where necessary to the student group(s) and develop the necessary skill to use it effectively and fluently.

Broad Research Questions

The broad research questions focused on how students experience their learning when teachers use an Autonomy Supporting Style of teaching (Reeve, 2015) and employ Evidence-Based Practices and Principles in their teaching approach (e.g. Sale, 2015; Petty, 2009, Hattie 2009). They are:
- How do students experience their learning when teachers use an Autonomy Supporting Style and employ Evidence-Based Practices and Principles in their teaching approach?
- What are the key aspects of a teacher's instructional approach that most impact student's intrinsic motivation (e.g., engagement; self-efficacy); in what ways and how?

Research Methodology

The study used a mixed methods approach (Grbich, 2013), summarized below:
- Quantitative data was collected through a pre- and post-intervention questionnaire incorporating items relating to supportive autonomy style of teaching, Cognitive Scientific Principles, Engagement Dimensions (i.e. behavourial, emotional, cognitive and agentic) and Self-Efficacy.
- Qualitative data focused on a more in-depth understanding of the students learning experience and was largely derived from collaboration with students from the class, who acted as co-participants (volunteers who were interested in the research projects and were prepared to have dialogue sessions regularly with the research team). Focus Group interviews with a larger student cohort and lesson observations by the Chief Investigator were also employed.
- Qualitative data from the first author's use of Evidence-Base Reflective Practice, a tool designed by the second author (Sale, 2015).

The Questionnaire

There are 3 questionnaires used in the process, which were synthesized from the works in the following areas:
- Student Engagement (Jang, Kim & Reeve, 2016)
- Autonomy Supporting Style (Williams & Deci, 1996)
- Self-Efficacy Scale (Bandura, 2006)
- Core Principles of Learning (Sale, 2015)

Questionnaires were administered before and after the implementation (week 2 and week 8 or 9) by the second author. The aim was to capture student's perceptions in the early part of their experience with the lecturer and then again after a substantive period of exposure. This enabled the identification of changes in perception over time, which could then be triangulated with the qualitative data.

The Student Co-participants

The student "co-participants" – a term used by Lincoln (1990), referring to students who take an active and interested participation in the research process and its aim – were an essential part of the research approach, as a main focus was on understanding how they experience and make meaning of their learning and teachers over time. All co-participants were volunteers and each class had a minimum of two. They were given a full briefing by the second author on the research purpose and their role and responsibilities in participating. It was made very clear that they should only participate if they felt that they could meet the responsibilities in an authentic and conscientious manner. They were specifically required to:
- Chat to classmates and identify their experiences of being in that class - what were positive and less positive experiences for them and what makes this so

- Meet with the researchers at least twice during the semester for group sharing
- Communicate on an ongoing basis with the research assistant who had set up WhatsApp groups with each class group of co-participants

The Focus Groups

The use of focus groups was employed for the following main reasons:
- Enables the collection of data relatively quickly from a larger number (as compared to individual interviews) of research participants
- Provides a more naturalistic context than the individual interview in that it is closer to the everyday conversations that people typically participate in
- Offers the potential of a synergistic effect in that it allows participants to react to and build upon the responses of other group members, producing richer accounts of the experience being investigated

The focus group interviews typically lasted around hour for each class in the project; the attendees included both the co-participants for that class as well as at least 6 other class members. The aim was to add further dialogue on what had been conveyed over time by the co-participants and other perceptions that may further enhance "theoretical saturation" (e.g. Glaser and Strauss, 1976) of the data to date.

Evidence-Based Reflective Practice

Reflective Practice (e.g. Schön, 1983; 1987) is not a new approach to improving teacher-effectiveness. The first author made 3 submissions of his reflections to the second author over the duration of the research. In this work, we strived to avoid the common pitfall articulated by Hattie (2009):

> *The current penchant for "reflective teaching" too often ignores that such reflection needs to be based on evidence and not post-hoc justification.* (p.241)

Hence, in this research the aim was to avoid such failings. Given the approach was to ascertain the impact of teaching approaches on the student learning experience that have been extensively validated, it seemed pertinent to use these same practices as the key constructs on which to conduct ongoing reflective practice. In this way the teacher-researchers could both plan their lessons with a high *predictive* capability of effectiveness, as well as use an evidence-based framework in the *diagnosis* of their lessons, post enactment. As this was an iterative process throughout the 15-week programme duration, we can make the case for it not being just "post-hoc justification".

Lesson Observation

Lesson observations were conducted by the second author and his research assistant for each class on at least one occasion. This was used to provide feedback across the research team and added a further dimension to the overall methodology. Observations confirmed the approaches taken, and students showed good attention and engagement. However, it was not viable, in terms of resourcing, to do multiple observations with different observers; hence, such inferences and interpretations are situated to this context.

KEY FINDINGS

In the context of this paper format, only a summary of the range of findings from the research is presented here. Also, these findings are pertinent to the first author's teaching, not the wider research team. Suffice to note that surveys were administered to all 7 groups of students, and at this time of writing, no separate individual results are available for each of the participating

lecturers. However, the quantitative data (see the section below) from student responses were found to be consistent across all 7 lecturers in their use of autonomy-supportive teaching and evidence-based practices and principles. This provided useful insight relating to the first research question:

- How do students experience their learning when teachers use an Autonomy Supporting Style and employ Evidence-Based Practices and Principles in their teaching approach?

Qualitative data from abovementioned sources were analysed by the second author and his assistant in order to answer the second research question:

- What are the key aspects of a teacher's instructional approach that most impact student's intrinsic motivation (e.g., engagement; self-efficacy); in what ways and how?

Quantitative Data

These were obtained from the pre-and post-questionnaires. The total responses for the 7 student groups were 216 for the pre-questionnaire, and 190 for the post-questionnaire. The quantitative data showed some significant positive differences in the students' experience of their learning from the initial to the post questionnaire administration. We were particularly interested in how the intervention impacted students' engagement, particularly Emotional Engagement and Agentic Engagement, as these contained items related to intrinsic motivation and our interest in encouraging students to be less reticent in class. The results were summarised below. A more extensive structural analysis of the data is presently in progress and will be presented at future conferences.

Cognitive Scientific Principles (Core Principles of Learning, or CP in short)

The overall impacts of the cognitive scientific principles were highly significant, Cohen's $d = 0.27$ & $p < 0.01$. Out of the 10 core principles, 5 were statistically significant using paired t-Test, as shown in Table 1.

Table 1. Quantitative findings for impactful core principles of learning

CP3: My teacher uses methods/activities that help us to understand the important concepts for this class.	Cohen's $d = 0.19$	$p = 0.04$
CP4: My teacher encourages us to think about what we are learning so that we can develop a good understanding of the topic areas.	Cohen's $d = 0.20$	$p = 0.03$
CP5: My teacher uses a variety of teaching methods and media that make the learning/lessons more interesting for us.	Cohen's $d = 0.40$	$p < 0.01$
CP7: My teacher provides us with useful practice activities to develop the skills we are learning.	Cohen's $d = 0.23$	$p = 0.03$
CP8: My teacher provides helpful feedback to help us develop and manage our learning effectively	Cohen's $d = 0.28$	$p < 0.01$

Engagement, Self Efficacy & Autonomy Supported Style

Overall increase in engagement was significant, Cohen's $d = 0.21$ & $p = 0.03$. The increase in emotional engagement was significant, Cohen's $d = 0.19$ & $p = 0.05$. Similarly, the agentic engagement's increase was significant, Cohen's $d = 0.24$ & $p = 0.02$. Likewise, a significant increase was shown for autonomy-supportive teaching Cohen's $d = 0.33$ & $p < 0.01$ and self-efficacy Cohen's $d = 0.20$ & $p = 0.05$.

These results showed that both an autonomy-supportive style of teaching and cognitive scientific principles of learning employed by the first author had positively impacted student

engagement and self-efficacy. These results match the qualitative data in terms of how students experience their teachers in terms of the range of instructional and teacher behaviours that are most impactful.

Qualitative Findings

Qualitative Data was collected from both students and lecturers involved; the former from student co-participants and focused group interviews; the latter from Evidence-Based Reflective Practice (Sale, 2015). There was also classroom observation by the Principal Investigator. The main qualitative data is in the form of transcripts from interviews with the student co-participants (41 in total), which provided the basis for understanding the experience of learning from a student's perspective. While focus groups were conducted for all 7 classes, they revealed little beyond what had been created through the interactions of the student co-participants and the researchers involved. We seemed to have attained, over the duration of the research some measure of 'theoretical saturation' (Glaser & Strauss, 1967).

The following are excerpts taken verbatim from notes of focus group discussions conducted by the second author and his research assistant. There were 4 focus group discussions conducted over the research period. The first author is not present in all these discussions.

"*When asked if the class felt comfortable with the teacher, the students felt that they were. Across the whole class, students felt comfortable asking questions. Humor was also used in his lesson. One student commented that the atmosphere and relationship built was 'good for tertiary education'.*"

"*When asked if other teachers were like Sim (sic) Moh, it was agreed by the group that he was different. Unique meant 'better'. One student explained that Sin Moh encouraged the students to think instead of just 'copying the model answer'. The teacher always encouraged students to think of other alternative answers instead of just the most basic answer. The student felt that this method was very useful as it allowed them to understand better as it is not just memorization.*"

"*When asked if the teacher was sensitive to the students, one student commented that he was. The teacher was aware that the students were very lethargic and thus, he gave them an activity to wake them up. The teacher did not tell them off. When asked if they felt comfortable asking the teacher questions, the students said that the teacher was very open to their questions. When the students asked a question, the teacher would say 'what can I NOT do for you'. The students also felt that the teacher interacted with them, so they felt very comfortable around him. This led them to feel that the lesson was more enjoyable.*"

"*Students felt that although the module itself was boring, the lecturer was doing his best to make it fun. For example, the lecturer uses humor. One student said that the lecturer did bother to foster good relations with the students. For example, if a student came early, the teacher would engage in conversation with him.*"

"*When being asked whether they felt if they were able to ask questions and suggest ways of doing things, students felt that they had choices. E.g. how they learn the material for their own work like watching videos and case studies. Students liked the fact that they had choice on how they learn the content.*"

"*The students felt that the tasks they were given increased difficulty. Learning was challenging but achievable. They did not find the learning to be boring. Also, they felt that they had plenty of opportunities for feedback. E.g. Material was put up on Google docs and plenty of test opportunities on what was right and not right and what to do if they got the wrong answer.*"

"*An important thing which one student mentioned was that the teacher had a good balance of strictness and humor. They felt that the teacher was very serious about their learning but at the same time could have a bit of fun and balance that → students were comfortable and could have a laugh with the teacher.*"

DISCUSSION ON WORK DONE

From these results, it can be seen that a lecturer using autonomy-supportive teaching is able to impact students' engagement in class despite teaching a module that is widely perceived as boring in nature. From the experience of the first author, using informational, non-threatening language certainly helps in quickly building rapport with the class. By acknowledging their negative feelings allows one to come across as sincere, and also permits the author to further engage students in diagnosing issues they faced, as well as possible ways of solving them. In fact, what the author observed is that, often, students themselves are aware of the underlying causes, and plausible solutions, and they readily acknowledged that what they lacked is the discipline to regulate their own learning process.

It is of interest to look at the general student feedback (SFB) on modules, an undertaking required by the institution once every academic year. Students need to answer 6 questions relating to the module. Figure 1 shows the SFB results for the module on 4 consecutive runs since teaching was undertaken by the first author back in April 2015, where flipped classroom is implemented. Run No.4 is the one whereby autonomy-supportive teaching is used by the first author. The SFB survey is based on a Likert Scale from "1" (for "Strongly Disagree") to "5" (for "Strongly Agree"). From Figure 1, it can be seen that students in Run 4 generally found the workload to be comparable with that in Run 3. However, there is a significant increase in their satisfaction with the way the module was taught and the quality of the module. What can be inferred from this is that while students still have strong negative feelings and lamented about flipped classroom, their engagement in this mode of learning nonetheless had increased. From the qualitative feedback, it appears that the students certainly had a sense of autonomy in their learning of the module, developed a feeling of relatedness, and attained a certain level of competency in handling safety issues in a chemical plant.
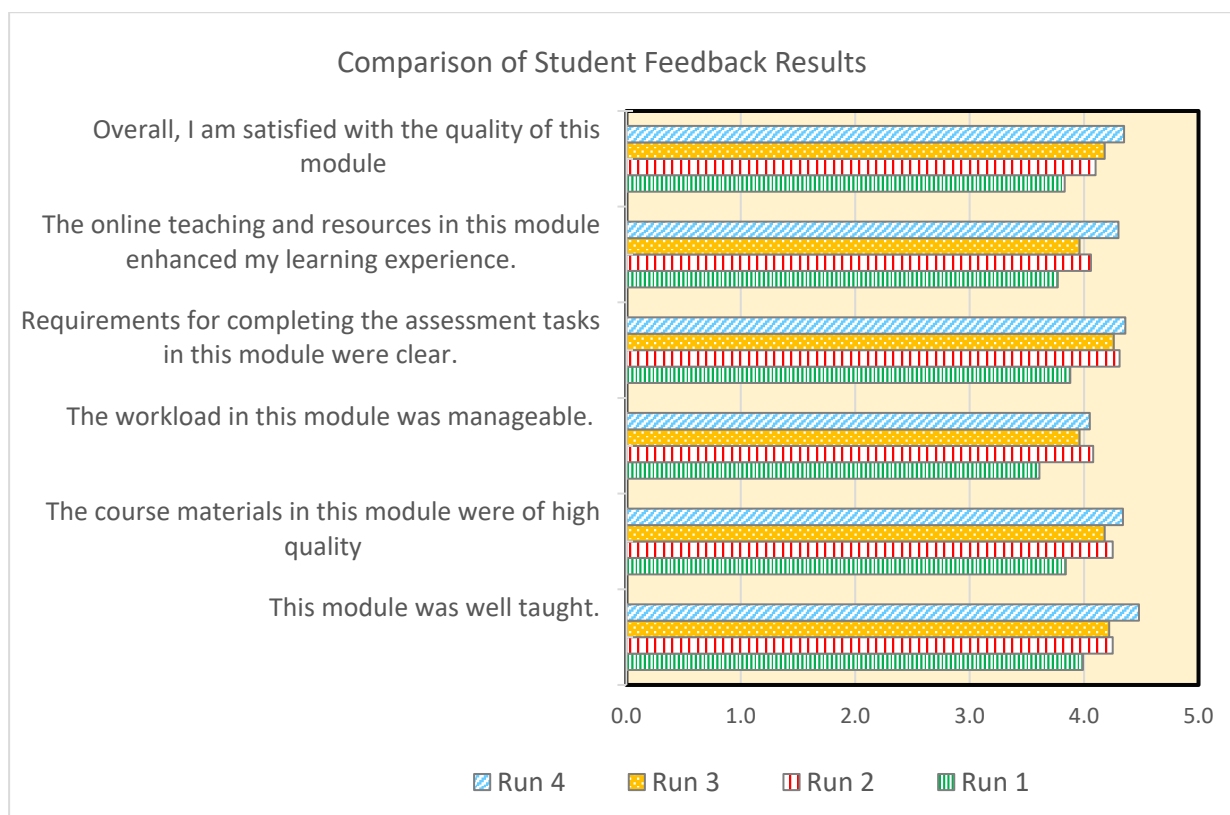
Figure 1. Comparison of student feedback for the module

It may also be useful to compare and contrast the findings from the first author's "experiment" with the other colleagues involved in this study, who may or may not employ a flipped classroom learning format. Also, extracting findings from student surveys that are specific to the first author's teaching of the module may enable more insight into student's engagement and self-efficacy in flipped learning.

Based on the results, it can also be suggested that it is the skilful use of the core principles of learning in the design of the learning materials, coupled with use of autonomy-supportive teaching that can turn subjects thought to be boring into more interesting learning experiences, regardless of the format that a subject is taught (flipped classroom or otherwise).

POSSIBLE FUTURE WORK

Moving ahead, there are several opportunities for further research. One important area is the present SP institution-wide initiative to infuse self-directed learning into all curriculum in an effort to support a nation-wide SkillsFuture Initiative (Cheah et al., 2019). This will necessitate providing more regular feedback to students on their learning progress. Butler & Winne (1995) had earlier highlighted the importance and role of feedback in engagement and achievement. To be effective, feedback must be used by learners. Jonsson (2013) noted that students might not engage with their feedback for 5 reasons: (a) it may not be useful; (b) it may be insufficiently detailed or individualized; (c) it may be too authoritative in tone; (d) students may not know suitable implementation strategies; and (e) students may not understand the terminology used in feedback. Winstone et al. (2016) suggested the study of "proactive recipience" as a form of agentic engagement that involves the learner sharing responsibility for making feedback processes effective. Also looking at engagement from student's perspective, Reeve (2013) proposed an investigation into how agentically engaged students create motivationally supportive learning environments for themselves, and hence supporting self-regulated learning. Such self-regulation may come about when learners identify with the relevance of the learning task, via the process of internalization. Vansteenkiste et al. (2018) argued that the process can come about with autonomy-supportive teaching, especially the provision of a rationale. Such internalization, in addition to intrinsic motivation, constitutes a critical growth process within SDT.

CONCLUSION

This paper presents a research project that employed an Evidence-Based Teaching approach, encompassing the systematic use of an Autonomy-Supportive Style of teaching for a flipped classroom module. The findings have been positive in terms of the ratings for the engagement items from the questionnaires employed. Of most interest is the data from the student co-participants as this catches their experiences over time and in their own words. While we can teach from good pedagogic intentions, it is how students actually make meaning of what we do from their perspective that counts in terms of their orientation to learning. The student response here suggests that the approach has resulted in good rapport and engagement with students, facilitating favourable outcomes both in terms of attainment opportunities and making the learning experience more engaging and fun. The development of agentic engagement is especially important, as it constitutes an essential component for developing the capability for self-determined lifelong learning.

This is especially important, particularly from the point of view of CDIO Standard 10, which emphasizes the continuing professional development of lecturers to teach and assess students in new ways (such as flipped classroom). Being able to identify with the students' needs is an important factor as lecturers moved from the traditional role of teaching of knowledge to facilitate student learning of such knowledge alongside key skills and attitudes. More significantly, students are more motivated in their learning and take positive steps in

constructively, contributing to his/her own learning. This can serve to retain student interest in learning engineering, which is one of the fundamental goals of the CDIO Initiative.

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AN ADAPTIVE ALGORITHM FOR LEARNING COMPUTER PROGRAMMING COURSE

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ABSTRACT

This paper aims to compare active learning and passive learning in a Computer Programming course for the 1st year engineering students. The CDIO standard 7 and 8 was implemented to change teaching methods. The students were divided into two classes. An active learning environment was provided for Class A, while Class B was offered a passive learning classroom environment. The passive learning included a lecture and computer-based materials. Meanwhile, the active learning class focused on designing activities that were suitable for the expected learning outcomes and whether students understood the concept behind programming. Active learning activities were designed to assure students' learning outcomes from remembering and understanding to applying the knowledge in computer programming. To develop a deeper understanding, the students practiced the algorithms using interactive programs. To improve the thinking process, visual block-based programming language in form of a jigsaw puzzle was introduced. Each specific block has a different color, which can be dragged together to build applications that creates different possible outcomes. Later on, the student applies their knowledge of programming languages to electronic devices that use sensors and microcontrollers, which translates analog input into a software system that controls electro-mechanical devices such as motors, servo, lighting or other hardware. This last phase has engaged students in applying, analyzing, and evaluating ideas with text-based programming language based on active experiential learning. Both classes were evaluated based on their pre-test and post-test performances. The independent sample t-test result found that the outcomes of Class A students were statistically significantly higher than the Class B students at the 0.05 level of significance. It encouraged the instructor to further develop the course, regarding the visual block-based programming language, the text-based programming language, problem-solving skills and other necessary skills.

KEYWORDS

Visual block-based programming, computer algorithms, computer engineering, standards: 7, 8.

INTRODUCTION

Extreme modifications in the tertiary education system require the university to improve the quality of education. Several new curriculums are designed to support a more diverse range of students. State-of-the-art infrastructures and technology are able to enhance learning experiences. However, the university pedagogy remains challenged, with most lecturers still use lecture-based practices. The assessment of student competency relies on how students solve exercises and textbook problems (Vega et al., 2013).

This situation also occurs in the Computer Programming course at the faculty of engineering, Rajamangala University of Technology (RMUTT), Thailand. This course is offered to all new 1st year students entering all of the engineering disciplines. The course covers computer concepts, computer components, hardware and software interaction, electronic data processing concepts, program design, development methodology and high-level language programming. The teaching team found that non-programming engineering students did not fully understand the content due to the increasing level of difficulty in recent years. The topics that the students struggled with the most with was program design and development methodology, problem-solving, and algorithm. The student's feedback results reveal that the main issues interfering with their learning were the heavy lectures with minimal activities to provide students experiences that shape their understanding of the content. Berglund and Persson (2018) stated a similar situation where computer programming is perceived as theoretical, abstract, and complicated with less connection to real-world application, especially for non-programming engineering students.

In order to solve the mentioned problems and encourage non-programming engineering students to gain a deeper level of understanding and achievable learning experience, the lecturer applies Integrated Learning Experiences (CDIO standard 7) and Active Learning (CDIO standard 8) techniques. Thus, this paper aims to:

- Design appropriate activities that support students learning experiences and increasing levels of interest in learning computer programming.
- Compare learning outcomes between an active learning and passive learning groups of 1st year non-programming engineering students

EARLIER WORKS

Computer literacy education becomes crucial for younger learners in this decade. Many primary and secondary schools worldwide integrate the knowledge of RFID cards, radar ranging, smart street lights, intelligent traffic lights, remote control, game programming, scratch programming and Arduino in educating young learners to experience basic computer programming (Yongqiang et al., 2018). Computational thinking is an essential problem-solving technique that involves logical, algorithmic processes and reasoning abilities. Computational thinking is regularly brought up in the context of learning computer programming. Wing (2006) has developed key principles of computational thinking, as shown below:
- Decomposition: divide the problems into a small portion
- Pattern Recognition: observe the similarities and differences of sequences, formats or steps
- Abstraction: select format, apply problem solving process, trial-and-error
- Algorithmic Thinking: create a solution with systematic problem-solving skills and reasoning.

There are several examples of literature that focuses on teaching and learning 1st year students and computer programming. Siong and Thow (2017) succeeded in raising students' motivation by using a "learning-by-doing" approach for the 1st year digital electronic course. The inquiry and reflection process allows the student to develop a better understanding of the concept. Deep learning in experimentation, discussion in seminar group, 3D-model software to develop physical products and programming exercises show a promising approach to motivate non-programming engineering students in the introductory 1st year course (Berglund and Persson, 2018). Shorn (2018) stated that the student found computer programming courses boring, time-consuming and difficult. Gamification, an application of gaming elements in a non-game context, was used. Positive results show that the methodology can support students' learning and gains more interest in learning computer programming.

Among many applications on teaching computer programming, Scratch-Arduino is a highly effective tool to teach logical thinking and creativity. The S4A (Scratch 4 Arduino) provides a high-level user interface with simple and interactive functions. Thus, the S4A platform is appealing to novice programmers (Gupta et al., Hladik et al., 2017; Roscoe et al., 2014; Tangney et al., 2010).

RESEARCH METHODOLOGY

The research question is "Is there any differences in computational skills between Class A (active learning with a visual block-based programming language) and Class B (passive learning with text-based programming language)?"

The author applies the Tyler model along with Behaviorism and Constructivism theories in designing the Computer Programming course. Tyler model (Tyler, 1967), is an essential theory of curriculum development in the scientific approach. With four steps:

1. Determine the objectives course or learning outcomes
2. Identify educational experiences related to the purpose
3. Organize the experiences
4. Evaluate the purposes

Nature of Course and Requirements

The Computer Programming course grants 3 credits to 1st year engineering students from different engineering disciplines and is mandatory for all engineering majors. The students are diverse in backgrounds, prior knowledge in programming, skills and interests. A semester contains 16 weeks of lessons, midterm and final examinations. Each week, the lesson comprises of a 2-hour lecture and 3-hour practical exercises. The normal class size is 40 students.

Participants

An active learning classroom environment was provided for Class A (an experimental group), while Class B (a control group) was offered a passive learning classroom environment. The active learning class focused on activities designed to be suitable for the expected learning outcomes and to check whether the student fully understands the concept behind programming. The passive learning environment included a traditional lecture and computer-based materials. The experiment was conducted using purposive sampling of registered

students in the course of semester 1 in the 2018 academic year (June - October 2018). Class A (an experimental group) had 39 students, while Class B (a control group) had 38 students.

Assessing Learning Achievement and Data analysis

An assessment tool was a test including 50 multiple-choice questions (50 points). The students' pre-test and post-test results were used to assess and determine the student learning achievement. The pre-test was conducted in week 2, while the post-test was in week 11 of the semester. The questions covered the program design and development methodology of algorithm concepts with flowcharts, which were validated by all the lecturers in the course. A quantitative analysis was performed using an independent sample t-test with a confidence level of 95%.

Intended Learning Outcomes

Intended learning outcomes (ILOs) are set as shown in Table 1. The students are expected to achieve these following outcomes after finishing this course.

Table 1. Learning outcomes for 1st year computer programming course

ILO1	To understand the concept of problem solving
ILO2	To understand steps in an algorithm development
ILO3	To understand the concept of an Algorithm
ILO4	To understand the concept of a Flowchart development

Designing a Course Syllabus

A 16-week course syllabus was designed, as shown in Table 2. The authors applied a Constructive Alignment theory (Biggs and Tang, 2007) to design classroom activities that focus on developing the student's logical and creative thinking skills, engineering reasoning and problem-solving skills. The designed activities must be aligned with the intended learning outcomes.

Table 2. Course Syllabus

Week	Topics
1 – 2	Introduction to Computer
3 – 6	Introduction to Problem Solving ● Procedure and Steps ● Algorithm ● Flow Chart ● Symbols used in Flow Charts ● Pseudo Code
7 – 8	Introduction to C Language
10 – 11	Control Structure
12 – 13	Function
14 – 15	Array
16	String

Teaching & Learning Activities

Teaching and learning activities focused on developing professional skills with knowledge construction rather than memorization. Table 3 shows 3 active learning activities offered to Class A (an experimental group)

Table 3. Active learning activities

Activity	Bloom Taxonomy	Week	Topics and Activity Details	Practice Hour
1	- Remembering - Understanding	3 – 6	Introduction to Problem Solving ● Use a Flowgorithm program ● Drag and drop flow chart symbols to the problems	8
2	- Understanding - Applying	7 – 8	Introduction to C Language ● Use Scratch program which is a Visual Block-based Programming Language to create a simple game	4
3	- Analysing - Evaluating - Creating	10 – 11	Control Structure ● Use Scratch for Arduino program with Electronic board (Arduino UNO) ● Control an LED circuit and small-sized motor	4

Activity 1: Introduction to Problem Solving

Entering week 3, the topic was Introduction to Problem Solving, which covered the procedures and steps in problem-solving. The students were expected to explain the algorithm with workflow and the thinking process. The Pseudocode was used to show the sequencing in the flowchart. Later on, the student-built up more understanding in the text-based programming language. The Flowgorithm, an application that creates programs using simple flowcharts, allowed the student to write and execute programs. It assisted the student in emphasizing on the algorithm rather than the syntax of a specific programming language. Figure 1 shows a screen capture of Flowgorithm. This activity expected students to review the meaning of symbols used in the flowcharts, and 3 control structures; namely, structure sequence, structure selection and structure repetition.
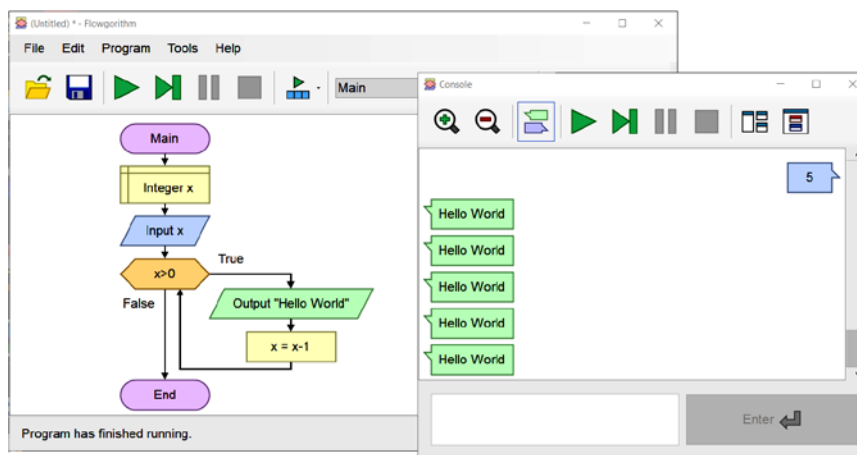
Figure 1. Screen capture of Flowgorithm program

Activity 2: Introduction to C Language

During week 7-8, the topic was structured programming languages, preparing the students to learn the text-based programming language. Once the students developed an understanding of programming logic, it is relatively easy for them to start learning one of the major programming languages. Thus, for the 2nd activity, a Scratch program was introduced to the students. The visual block-based programming language allows the student to program their own interactive stories, games, and animations. As a result, Scratch helps students engage more in class and show good signs of creative thinking, systematic thinking, engineering reasoning, and team collaboration. Figure 2 shows a screen capture of a Scratch program.
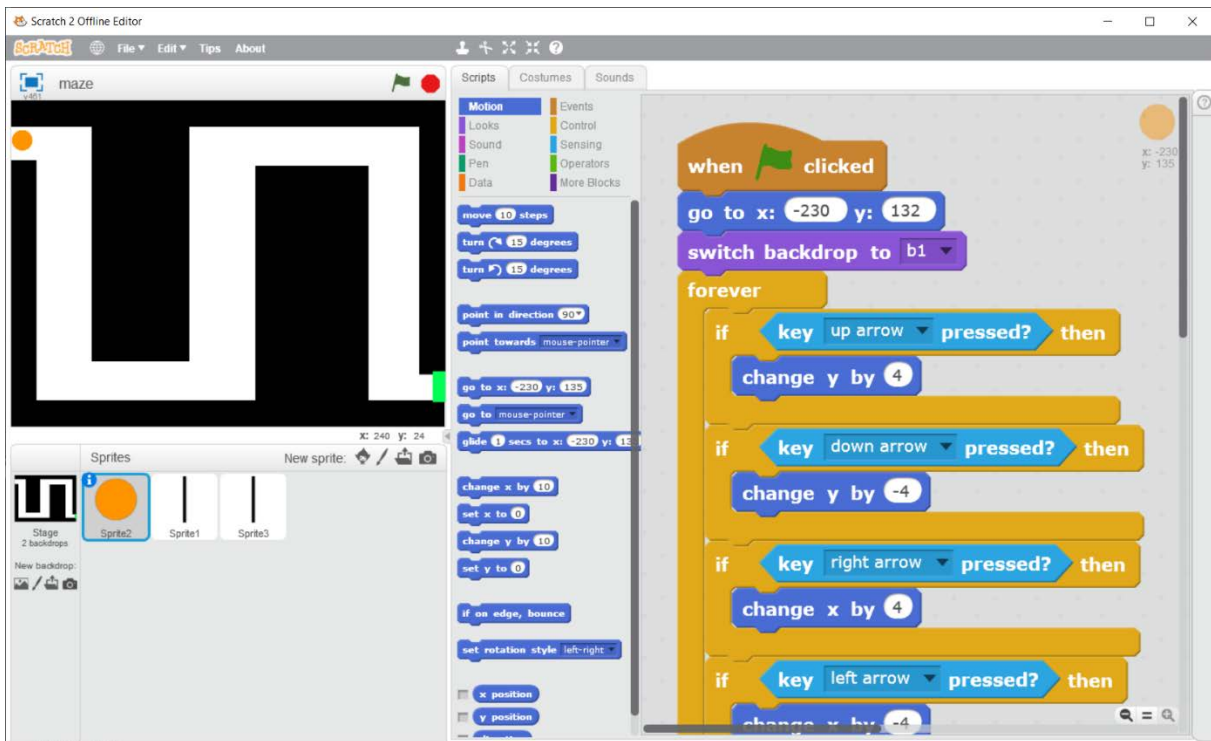
Figure 2. Screen capture of a Scratch program

Activity 3: Control Structure

For week 10-11, the students started using text-based programming languages. A majority of the students had difficulty understanding this content due to the increased level of complications and difficulties. This was the main cause of the students decreasing interest and motivation for coding. In order to overcome those challenges, Scratch program for Arduino board (S4A) was introduced to keep the students interested and motivated.

S4A is a Scratch modification that permits simple programming of the Arduino open-source hardware platform, containing a new set of blocks for managing sensors and actuators. The program itself can be connected to an Arduino microcontroller board which directly uploads control codes through the USB socket. With these features, the students are able to do tasks such as selecting blocks to turn on and off an LED light bulb and to rotate the servomotors. Figure 3 shows a hands-on practice of a student using the S4A in an active learning lesson.

Figure 3. Example of student in-class activity

RESULT

Statistical Test

The Class A (experimental group) and Class B (control group) students took a 50-multiple-choice questions (50 points) pre-test on week 2. The same questions are used for the post-test on week 11. The mean scores of both groups were compared and statistically tested by an independent sample t-test with a confidence level of 95%.

Table 4. T-test for Equality of Means Pre-test for Class A and Class B

	N	Mean	S.D.	Mean Difference	t	df	Sig 1 tailed
Class A	39	8.18	3.88	0.42	0.501	75	0.309
Class B	38	7.76	3.40				

From Table 4, the comparison between 2 groups from the pre-test results in week 2 shows that Class A average score was 8.18, and Class B averaged 7.76. The mean difference was 0.42. The sig (1-tailed) value of 0.309 was > 0.05. Therefore, we accepted the null hypothesis that there were no differences between Class A and Class B at the significant level of 0.05.

Table 5. T-test for Equality of Means Post-test for Class A and Class B

	N	Mean	S.D.	Mean Difference	t	df	Sig 1 tailed
Class A	39	23.36	7.01	4.37	3.004	75	0.002
Class B	38	18.63	6.79				

From Table 5, the comparison between 2 groups from the post-test results in week 11 showed that the mean score for Class A was 23.36 and 18.63 for Class B. The mean difference was 4.37. The sig (1-tailed) value of 0.002 was < 0.05. Therefore, the null hypothesis was rejected.

We can conclude that the mean score of Class A was higher than the mean score of Class B at the significant level of 0.05.

Student Feedback

At the end of the semester, the students gave feedback on their learning experience for the computer programming class. Table 6 shows a contrary of feedbacks between Class A and Class B students. The students in Class A that were offered active learning activities remained their motivation throughout the semester and achieved the learning outcome, in the process building a positive attitude towards the computer program. Meanwhile, Class B students showed distress and difficulty in grasping the concepts of computer programming.

Table 6. Feedbacks from the students after the semester ended

Class A (experimental group) Feedback	Class B (control group) Feedback
The activities help me understand with step-by-step explanation from the teacher.	*I didn't understand what you taught.*
The teacher did not rush when teaching. The good pace helps me who is a slow learner understand the subject.	*The examination was very difficult*
In the beginning, I didn't like this subject at all. Then, I understood and started to feel that it was actually fun.	*The teacher showed examples on the screen. I had no clue what programming is about.*

DISCUSSION AND CONCLUSION

The design and development of active learning activities were based on the linkage of topics, learning style, and learning outcome. The results of the study conclude that not only was the expected learning outcomes achieved, but the student's engagement and motivation were also maintained throughout the entire semester. According to Leong et al. (2016), the motivation that drives the students is directly affected and impacted by different settings: classroom characteristics, pedagogical approaches, physical environments, collaborative teams, and student autonomy. Students in the experiment group had experiences in a self-paced learning based classroom, hands-on pedagogical methods, visual and physical devices (Scratch and S4A) and an autonomous learning environment.

The research findings conclude that active learning activities can support the computational thinking process for the students. The students have achieved the expected outcomes including problem-solving and algorithm refining and reviewing, computational thinking, flowcharts writing, coding and computer programming. The experimental group students were satisfied with the course with positive attitudes and learning motivation towards computer programming. This is similar to Vega et al. (2013) findings, where the students' interests in polished and attracting activities resulted in an increase of the student's motivation. The visual block-based programming in the active learning sessions alongside hands-on practices using Flowgorithm, Scratch and S4A successfully supported the students in learning computer programming, with paralleling to the results from Gupta et al. (2012), Roscoe et al. (2014) and Tangney et al. (2010). Moreover, the level of student's satisfaction and motivation was pleasant, similarly to Siong and Thow (2017) findings that the learning-by-doing method can enhance the students' motivation.

The effort of supporting the 1st year non-programming engineering students learning computer programming was successful. The students had a positive attitude towards the course and proved that it is not extremely challenging and can be enjoyable. The course can be applied and extended to a larger scale, considering there are 10 faculty members who teach the subject. However, the teacher should be able to observe and assess the student's background knowledge, as well as their willingness and eagerness to learn new things. Future work will be the implementations of project-based approaches in the course. A programming contest environment can drive challenges in promoting motivation and self-directed learning within students.

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LEADING AND COMMUNICATING CHANGE
IN AN ENGINEERING FACULTY MERGER

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ABSTRACT

Higher education institutions (HEIs) have been exposed to several change drivers during the past few decades. The global expansion of higher education together with the financial cuts in several countries have caused structural and organisational changes on different levels. In addition, the general requirements on the efficiency of public organisations, so-called New Public Management, are connected to the trends of developing the organisations and management policies in HEIs more towards entrepreneurial or corporate cultures. Successful implementation of these change processes challenge the change management and communication skills of the managers and leaders of the institutions. Communication is a vital element of leading a change successfully towards the defined vision. This concerns also the change and development processes facilitated by the CDIO Initiative. Similarly, Turku University of Applied Sciences (TUAS) has undergone a number of changes in the recent years and the change is still ongoing. One of the central elements of the most current change was to merge two faculties to form a new Faculty of Engineering and Business. This case study analyses how this organisational change process of TUAS was actualised and communicated in the internal documentation and presentations during 2016–2018 in relation to the so-called eight-step change management model presented by Kotter (1995/2007). The analysis found elements of the first six steps in the data, however the last two steps need a longer timespan to realise. As a conclusion, it seems that the Kotter model is a viable tool to assess leading change also in the HEI context.

KEYWORDS

Change management, leading change, organisational change, higher education institution, CDIO Standard: 12.

INTRODUCTION

"The only thing that is constant is change." (Heraclitus, c. 500 BC.)

TUAS is a multidisciplinary higher education institution with three faculties and a community of 10,000 members, of which about 670 are staff members. The context of this study is the series of the most recent organisational changes at TUAS that have started in 2015, with special

focus on the process and timespan during which two faculties were merged into a new Faculty of Engineering and Business. At the same time, a new Dean started in the Faculty of Health and Well-being; thus Arts Academy is the only faculty that has not met any substantial changes in recent years. The changes in terms of the merger are still ongoing.

This case study explores how the ongoing organisational change process of TUAS was actualised in relation to the so-called eight-step model of leading change presented by John P. Kotter (1995/2007). We chose Kotter's model because it is one of the most well-known of its kind, and we were interested in testing its applicability also in the HEI context. The Kotter model outlines the following steps when leading change: 1) Establishing a Sense of Urgency, 2) Creating the Guiding Coalition, 3) Developing a Vision and Strategy, 4) Communicating the Change Vision, 5) Empowering Employees for Broad-Based Action, 6) Generating Short-Term Wins, 7) Consolidating Gains and Producing More Change, and 8) Anchoring New Approaches in the Culture (ibid. 96–103). The data consists of the top management's documentation and presentations from 2016–2017, which have been analysed and categorised according to the eight steps of the Kotter model. As a result, we can trace which steps have been taken and to what extent, and see how this process has been communicated internally. The authors of this article are not part of the top management of TUAS.

The research questions were: How is the change process constructed in the top management documentation in relation to Kotter's eight-step model? Has the change process followed the Kotter model and to what extent?

BACKGROUND

From ivory towers towards entrepreneurial universities

The higher education institutions have globally faced numerous change requirements, expectations and processes during the past few decades. The expansion of higher education in general and the significant cuts in government funding in Finland, in particular, have caused structural changes in several levels of educational organisations and programmes. The development also includes requirements of effective and efficient management of public institutions. This so-called New Public Management paradigm aims at changing the management and administration practices of higher education towards an entrepreneurial culture, which has often replaced the traditional collegial structures at least to some extent (Blaschke, Forst & Hattke, 2014). Bleiklie (2014) categorises the change drivers in European higher education institutions starting from the 1980s as follows: 1) European and national policy programmes, administrative structures and governance practices, 2) administration of the higher education institutions and its relation to academic work, disciplines and communities, and 3) development and differentiation of higher education systems.

Higher education institutions need to regularly provide evidence on the efficient use of government funding and the societal impact of their results. Accordingly, HEIs are often considered as entrepreneurial actors that provide educational and research services to their students, customers and different organisations. Meeting these expectations requires efficient and dynamic administrative structures and processes that are able to function in the network of strategic goals, financial constraints, rapid technological development and complex operational environments (Mainardes, Alves & Raposo, 2011). The ability of the traditional collegial university organisations to respond to these challenges is often questioned. Balbridge (as cited in Mainardes, Alves & Raposo, 2011) describes universities and their faculties as complex institutions in which isolated disciplinary groups use lots of energy to complete routine tasks. The characteristic features of a traditional university organisation have been described for example as follows (Van Vught & Maassen, as cited in Mainardes, Alves & Raposo, 2011):

- The main structures and positions are based on knowledge/competences.
- The departments are isolated due to a discipline-based structure, knowledge management and methodological choices.
- Decision processes are unclear; the different departments focus on driving their own goals regardless to their connection to the HEI's strategy.
- The activities within a competence area can be innovative and adaptive to changes, yet most of the innovations are incremental. There is strong change resistance concerning the structures.
- The operational environment of a HEI has a significant effect also on the HEI's organisation.
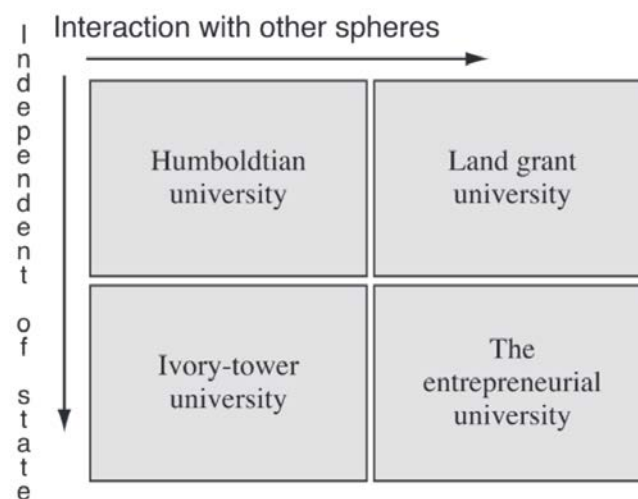
Figure 2: Classification of different types of HEIs ("The Second Academic Revolution") (Etzkowitx, 2003)

Different types of HEIs are illustrated in Figure 2 (Etzkowitx, 2003). The traditional Humboldtian university reflects an organisation that is tightly controlled by the state and that is very loosely coupled to the other sectors of society. Even the Land Grant HEIs are strictly controlled by the state, but they cooperate widely and get funding especially from large corporations. Instead, the ivory tower universities are rather independent actors when it comes to governmental steering and they typically keep a distance to other organisations and enterprises as well. The desired direction of the development of higher education is considered the entrepreneurial university that is able to produce new knowledge and competencies efficiently to be utilised widely in different parts of society. (Mainardes, Alves & Raposo, 2011.)

HEIs need to find models and practices in order to succeed both in national and international competition. Ramirez & Tiplic (2014) summarise this as follows: "Throughout the world higher education is in a state of flux, seeking the holy grail of excellence and invoking world standards and "best practices" as road maps in this quest of excellence". Assumptions behind this development are the HEIs' ability to become the engines of national progress, the impact of better organisation and leadership as enablers of this ability, as well as sharing and benchmarking good practices between the HEIs, also concerning organisation and management (Ramirez & Tiplic, 2014).

Also, the development of Turku University of Applied Sciences can be considered as part of the global change of higher education, and the implementation of the features of New Public

Management in the context of Finnish higher education. For example, the change of the administrative model of Finnish universities of applied sciences to limited companies is a characteristic step towards an entrepreneurial university structure. In the background of this development similar goals that Shepstone & Currie (2013) report can be seen, connected to the change process of Prairie West University (PWU). PWU had previously been a Bachelor-level teaching-oriented institution that had gained a stable position and good reputation in its domain. In the PWU's case, its research activities were systematically developed aiming at creating new opportunities for activities as well as external funding. As one of the development actions, PWU created a so-called tenure track system that stressed not only pedagogical merits but also, especially, success in research work and gaining research funding.

Leading Change

Leading change is one of the most difficult tasks to give a leader – also in the context of HEIs. According to research studies, two out of three change management processes fail (Langstrand & Lundqvist, 2015). The need for change is often related to a situation in which the present situation and actions/operations do not lead to a desired future mission (Lanning, Roiha & Salminen, 1999). The change process should be led according to a process that is goal-directed and systematic progressing towards the ideal state (Pettigrew & Whipp 1991).

The change process can be described by different angles/perspectives. Jones (2007) defines the change as a process, in which the main goal is in increasing the effectiveness. The transmission to a chosen volition can be in the form of slight improvement or a radical change. Nadler and Tusham (1990) indicate that the change can be described as an occurrence, which happens in the certain period of time and changes processes, structures and personnel in a way that they are suitable for the purpose. The change can be proactive or reactive, and it can be described as a kind of reform that possesses features such as sustained and controlled.

The change processes of an organisation can be hard and complex to describe. They have been studied and documented widely. In the 1950s, Kurt Lewin introduced a model of a change process, which is widely known and used. This process has three phases: melting, changing and icing. In the first phase, the focus lies on breaking the tradition and identifying the possible new organisational models. In the second phase, the change will be implemented according to a plan and in the third phase, procedures are locked and new routines and standards are created and followed. (Lewin 1951.)

Kotter developed his own model of organisational change and emulated Lewin's model. Kotter's (1995/2007) model of eight steps describes how the change process should be implemented in a successful way. The Kotter model is internationally known and used as a road map of change. However, the model is based on Kotter's personal experience and, therefore, criticized.

Kotter's model of leading change

John P. Kotter published his article "Leading Change – Why Transformation Efforts Fail" originally in 1995 in Harvard Business Review. In this article, Kotter outlines the eight steps to transform your organisation: 1) Establishing a Sense of Urgency, 2) Creating the Guiding Coalition, 3) Developing a Vision and Strategy, 4) Communicating the Change Vision, 5) Empowering Employees for Broad-Based Action, 6) Generating Short-Term Wins, 7) Consolidating Gains and Producing More Change, and 8) Anchoring New Approaches in the Culture (Kotter, 1995/2007, 99).

In the first step of the model, the current state, crisis or need of the organisation is identified. This is followed by the establishment of a group or team leading the change. This team and its

members should have enough authority and organisational status to be able to execute the change. From the beginning, the team should be encouraged to work and act uniformly. After the second step the vision is formed, and the strategic choices by which the vision can be achieved made. The first three steps are creating the right climate for the change. (Kotter, 1995/2007.)

After creating the vision, the vision and the change strategy should be communicated in all possible ways. The change is also led by example. In step five, the personnel is empowered and authorised to take actions towards the objective. The empowerment includes encouraging to take risks, to innovate new ideas and procedures simultaneously removing obstacles identified on the way towards the vision. Short-term wins should be planned ahead and ensured by acknowledging and rewarding the personnel executing actions promoting the change. The aims of the steps from four to six are engaging and enabling the organisation to change. (Kotter, 1995/2007.)

In the seventh step, where consolidating gains and producing more change should take place, the systems and structures that are recognized as incompatible are further modified, keeping in mind the personnel working towards the vision. In addition, the process should be reinvigorated with e.g. new projects and themes. Implementing new ways of action into the organisation is ensured by presenting the positive impacts of the new behaviour for the organisation and by providing systems for sharing new information. During the last two steps, the focus is on producing more change and anchoring new approaches in the culture. (Kotter, 1995/2007.)

Criticism of the n-step models

Several n-step models based on the Kotter model have been created. The criticism towards these models includes the argument that the models are too simplified and they give too straightforward a picture of the change process (Langstrand & Lundqvist, 2015). In 2012, Appelbaum et al. published an article where the Kotter eight-step model was compared with literature published on change management during the past fifteen years. In the study, the whole model, as well as its steps, were individually evaluated. The results indicated that the Kotter model can with certain additions be utilised as a tool for change implementation. However, in future research, the Kotter model should be considered as a whole, because no research including the entire model has yet been published. (Appelbaum et al., 2012.)

METHOD AND DATA

The data of this study consisted of TUAS board documents and memos, TUAS top management team memos, top management blog posts, staff meeting materials, and intranet news postings that commented on the ongoing organisational change. The analysed data is from the beginning of 2016 until the end of March 2018. The data was collected and analysed in April 2018. Before the autumn of 2016, there were no mentions about the organisational or management system change, so there was no need to collect material before the year 2016. The data is represented in Table 2.

Table 2. Research data: type, timespan and number of documents.

Data type	Timespan	(n)
Top management team memos	2016/11/1 – 2018/3/27	29
Top management seminars	2017/5/9 – 2018/1/10	2
Middle management forum memos	2016/1/14 – 2018/1/11	13
Top management blog	2016/1/15 – 2018/3/28	74
Staff meeting materials	2016/12/2 – 2017/12/12	5
TUAS board memos	2016 – 2017	22
Intranet news postings	2016 – 2017	3
Total		148

All this material is available to the staff in the intranet of the organisation. The staff is also informed when new memos and materials are available and encouraged to read them. Thus, the collected data can also be considered as a part of internal communication, which is extremely important when leading an organisational change.

The data were analysed with respect to the Kotter model: Which steps have actualised from the basis of the internal communication and how? The main research method was theory-based content analysis. The data were categorized according to the eight steps in the Kotter model.

APPLYING KOTTER MODEL TO THE DATA, AND THE RESULTS

The aim of this study was to categorise and analyse the data on the basis of Kotter's eight-step model to trace, which steps have actualised during the organisational change process of TUAS and how these steps are represented in the internal communication.

In practice, it was possible to analyse only the first six steps of the model, because the change process is still ongoing. In the following subchapters, the implications of Kotter's steps in the data are further explained and explored. Table 3 represents the number of data sources and references identified in the data per each step.

Table 3. The number of sources and references per steps in the Kotter model.

Kotter's step	Data sources (n)	References (n)
1. Establishing a sense of urgency	11	14
2. Creating the guiding coalition	6	12
3. Developing a vision and strategy	10	19
4. Communicating the change vision	7	13
5. Empowering employees for broad-based action	10	15
6. Generating short-term wins	7	10
7. Consolidating gains and producing more Change	0	0
8. Anchoring new approaches in the culture	0	0
Total	51	83

Step 1: Establishing a sense of urgency

The first step in the Kotter model is to communicate the urgency of the change: why the change is necessary and what is the problem that needs to be solved. Communication is also needed to motivate the staff to the change. The first references to the reform of the management and organisational system are from autumn 2016. The preliminary debate with the TUAS Board was in December 2016.

In the oldest data from the first six months of the studied timespan, the necessity of the change is justified with the centralisation of the operations to the new campus area, and with the end of the term of the middle management (i.e. heads of education and research):

> The current organisation is functional but is under pressure to change because of the future centralisation of actions to the Kupittaa campus. Until now, faculties have operated on different premises and also their modes of operation have been slightly different. There is more pressure to unify procedures on the common campus. There is also pressure for change because the four-year term of the heads of education and research is ending by the end of 2018. (TUAS Board minutes, January 2017)

In the next phase of the change process during the first quarter of 2017, the top management e.g. collected feedback from the stakeholders, and the summary of the feedback as well as suggestions on how to proceed with the change was presented to the TUAS board. After the board meeting, the same presentation was given to the TUAS top management team, and in the general staff meeting.

In the presentation material from May 2017, the number of justifications for the change has increased and got more focused as well. There were now three justifications for change: focusing the operations according to the strategy, moving to the new campus, and the ending of the term of the middle managers. In addition, the need for change was complemented by representing the principles drafted by the TUAS board, and with the views of the stakeholders about the strengths and weaknesses of the current organisation and management system. In the conclusions, also the facts and steps that need to be taken to make improvements were presented, bringing the change to a more concrete level. After a year since the change process had started, the justifications for the change started shifting towards and focusing more on the strategy, and the change in the number of the faculties:

> TUAS has started an internal organisational change to strengthen its strategic focus as the technical innovation university. (TUAS board minutes, October 2017)

> In the heart of the development of the management system is the change [from four] to three faculties starting from January 1, 2018 […] Operations have been planned based on the strategy that is valid until 2025. Thus, the four strategic focus areas will strongly steer the actions of TUAS also in the future. [...] (TUAS Board minutes, December 2017)

Thus, the ongoing development processes such as the new campus and the reorganisation of the management system were explicitly constructed as a means to support the strategic goals.

In conclusion, the sense of urgency in the data was first established by stressing the concrete and inevitable changes ahead, such as moving to the new campus and the organisational reform needs deriving from it, and also by the ending of the term of the middle managers. However, the importance of the change in relation to the strategy was brought up as well. After

collecting the stakeholder feedback, the urgency was rising from even more concrete and precise needs but later the arguments for the change were more strategy driven.

In Kotter's view, the more convincingly it can be represented that following the current path will only lead to a serious crisis, the stronger the management and staff will commit to change (Kotter, 1995/2007, 97–98). In this material, the change of the management system is not justified with a potential crisis: quite the contrary, the existing system was concluded to be functional as it is (TUAS Board minutes, January 2017). Thus, there is a risk that the staff may not consider the new campus and the need to unify procedures as adequate arguments to reorganise the whole system. Furthermore, justifying changes simply with the strategy can be experienced as too abstract or vague to motivate the staff for change.

Step 2: Creating the guiding coalition

The second step in the Kotter model is the creation of the guiding coalition to promote the change. In addition, to have an impact and make progress, the coalition has to expand outside the top management. If the coalition is not strong or impactful enough, the progress of the change will eventually stop when the resistance increases (Kotter, 1995/2007, 98). The data of this study shows that there has been interest to engage extensively both internal and external stakeholders and that this goal has also been achieved. At first, the stakeholders mentioned in the data were mostly internal:

> Both projects [changes in the management system and middle management] will be carried out as a collaborative process with top management, staff and students. (TUAS Board minutes, January 2017)

> An open discussion will be a part of the planning process – the feedback from the staff and students will be taken into account in the preparations. To support the plan, there will be a survey and the results will be published in the [intranet]. (Top management team memo, January 2017)

The more precise list of the stakeholders was given at a Board meeting in May 2017 after most of the feedback had been collected. In addition, when accepting the proposal for the new organisational model at the very same meeting, the Board emphasised the need to engage the staff, the students and external stakeholders also in the future:

> According to the guidelines given by the TUAS board, the model has been discussed with staff during the staff development days on all five faculties, [student association] representatives, employee cooperation advisory board, middle management meeting forum and top management team. From the basis of the discussions, a preliminary proposition about the management system was formulated. [...] The TUAS board emphasized the need to engage the staff, students and external stakeholders in the further preparations [...]. (TUAS Board minutes, May 2017)

The data suggest that the engagement of the different stakeholders has been extensive and a strong part of the preliminary planning process. The coalition was expanded outside the top and middle management and the stakeholders were consulted in multiple ways: face to face in staff and other meetings, and they were also encouraged to give feedback either personally by email or in the intranet workspace dedicated for the change process.

Step 3. Developing a vision and strategy

The third step in the Kotter model is the development of the vision and the strategy in collaboration with the created coalition. The purpose of the vision is to bind together all the

separate change projects, to motivate, and help to understand the connection between actions and their necessity (Kotter, 1995/2007, 98–99). In this data, the focus is on the vision and strategy of the new organisational and management model and the reorganisation process, not on the vision and the strategy of the whole of the organisation. However, the latter was also used to justify the need for the change.

As was stated in the previous subchapter, both internal and external stakeholders were extensively engaged to plan the change and its implementation e.g. by email, face-to-face discussions, and project workspace. The progress of the process was presented to the staff for the first time in the top management blog at the end of March 2017. At the same time, the staff was informed that the preliminary model will be available for final comments and change suggestions in April:

> I have now visited all the faculties and met [the student association] and we have discussed about the ideas of how to develop the management system. As you may expect, there has been feedback and ideas of all sorts. During the weekend, I will once more study the comments in the [intranet] workspace, to find commonalities and try to form an overall view. [...] The [preliminary model] will be available in intranet in April thus it is possible for all interested to make some suggestions before the model will be presented in the employee cooperation advisory board and further in the university board in May. (Top management blog, March 2017)

The opportunity to make suggestions was also taken:

> The preliminary development plan for the management system evoked good conversation. Thank you for all those who commented either by intranet or e-mail. It was a pleasure to read and contemplate well defined questions that promoted at least my own thinking. (Top management blog, May 2017)

According to both the Board and top management team memos in January 2017, a goal was set that the basic principles of the new management structure should be defined during the spring of 2017. In the Board meeting that took place in April 2017, it was reported that by that time the proposal for the new management system had been discussed in e.g. unit staff meetings, workshops led by the Rector, and in other forums. The schedule was defined and thus the vision about the new model and the strategy was represented both to the Board and staff during the same day in May 2017.

According to the data, both the model (vision) and the means to implement it (strategy) has been constructed in collaboration with different stakeholders. The vision and strategy are further described in the following subchapter.

Step 4. Communication of the change vision

According to Kotter (1995/2007), the communication of the change vision is typically problematic in change management. Typical problems are lack of communication, clarity, or the commitment of some visible and influential figures in the organisation. Change is only possible when people understand its necessity and are willing to commit to it. In successful changes, the vision is communicated vividly, inspiringly and via multiple channels. This also means that in every opportunity and form of interaction there is a connection made to the big picture and the change. (Ibid., 99–100.)

The data discloses that the reorganisation and its details have been communicated especially in the top management blog, top management team memos, staff meetings (both general and faculty-level meetings) and in the workspace set up for the discussion about the change. Thus,

communication has been mostly in the hands of the top management. However, there are no mentions in the data that there was any specific communication plan made for the change project already at the beginning of the project.

Probably the biggest individual investment in the communication of the vision was in May 2017 when the preliminary model was introduced to the staff in the staff meeting. The presentation material was the same that was introduced to the Board before the staff meeting and later in faculty staff meetings. The material included justifications, preconditions, principles constructed by the Board, analysis of the current model (strengths and development needs according to stakeholders) and what needs to be considered in the new model. Finally, as a conclusion the following "general guidelines", that seem to have vision-like qualities, were listed for the new management system:

> Evolution, not revolution; Expanding the opportunities for students; Increasing collaboration and community spirit; Emphasizing the opportunities and responsibilities of the experts; Improving the efficiency and clarity of services. (General staff meeting, May 2017)

The vision in regards of the new faculty was clarified in the top management blog a few weeks later at the beginning of June. In the same posting, the next steps were also described:

> The new faculty [...] will be a significant cluster of technology and business economics. There is next to six thousand students in the new faculty, which will exceed even some universities. The six million euros of external funding indicate the immense potential of the new faculty. [...] The new faculty offers education extensively both when it comes to bachelor and master levels of education. This faculty responds particularly well to the current need for professionals in the [local] trade and industry." [...] Combining two active faculties is a fine opportunity that should not be missed. Both faculties have several innovative and functioning solutions and practises. By finding and recognising these, we could build the [locally] lacking technical (innovation) university. All the measures indicate that we have the right building blocks, right direction, and right people both in the personnel and as students. So let´s start building this strategically emphasized technical innovation university of the future together." (Top management blog, June 2017)

The challenges in the change management communication were realized at the latest in the beginning of 2018: the communication services represented a plan to support the change communication in the top management team meeting in March 2018, obviously by request. According to the memo, the top management team assessed that the staff had a good idea about the necessity of the changes, however it was acknowledged that communicating the vision and what it means in a concrete level can be a challenge to the change communication. Thus, it was agreed that the Communications Services of TUAS will provide supporting material for the managers, communicate the success stories in our community, and also the concrete improvements that will realise in a couple of years.

In the data, there are more mentions about the justifications and concrete actions than about the actual vision of the new management system. It could be that the reorganisation of the management system was seen more as a part of the organisational strategy and vision, and not so much as an individual process that has its own ideal state. On the other hand, the memos that form most of the data are probably not considered as means to communicate the vision, but to inform about decisions and actions. The communication that has happened face-to-face might very well have had a different approach in comparison to the documents when it comes to the inspirationality and vividness of the message.

Kotter also emphasizes the importance of the clarity of the constructed vision. Unfortunately, from the basis of the data, it is impossible to say how clearly the vision about the reorganisation came across to the stakeholders. However, when change projects fail, it is typical that there is a lack of a clear and inspiring goal that justifies all the new directions and change projects.

Step 5. Empowering Employees for Broad-Based Action

Successful change management calls for engaging and encouraging the staff to develop new approaches, new ideas, and to provide leadership within the parameters of the vision. However, there might be some organisational structures or system-based obstacles in the way, such as inflexible job categories, compensation systems that steer the efforts, or key personnel that refuse to change and thus undermine the efforts to change. (Kotter, 1995/2007, 101–102.)

In this data, engaging and innovating have particularly been a part of designing the vision about the change. It is very probable that during the process, a lot of practical ideas and innovations were brought up by the staff. The ways the vision will be transformed into concrete actions and e.g. how the practices will be developed accordingly will mostly take part within faculties and units of education and research, which is implied in the top management blog in June 2017:

> I would ask you some patience, because presumably all the details are not yet defined or have not yet even emerged. We will probably also face some discrepancies with operations models and how they take place, however let us not get irritated or stressed over them but solve the unsolved things when needed one at a time. (Top management blog, June 2017)

The data does not clearly suggest what obstacles there might have been that had to be removed from the way of the reorganisation of the management system. However, a lot of other changes and reorganisations were necessary to support the management system change at the faculty level. Some of them were brought up in the top management blog post from June 2017 along with the next steps.

The preparations for the change continued in autumn 2017 when some practical questions were discussed in the top management team meeting in August, including the new marketing materials and renaming of the new faculties.

Step 6. Generating Short-Term Wins

According to Kotter (1995/2007), short-term wins are needed to keep the momentum going: most people expect to see some results in one to two years to stay motivated. These short-term wins need to be actively planned and created by the management. (Ibid. 102)

In the data, there is communication about the planned phases and schedules of the change process, about milestones, and progress of the management system change. At the end of 2017, some of these milestones were listed in the Board meeting. At the beginning of 2018, both the staff news and the top management blog brought up the merger of the two faculties:

> The faculties of TYT and LIKE have been officially buried now but, naturally, they will keep haunting in many of our information systems, reports and financial accounts. The faculty of Engineering and Business has replaced these two faculties and thanks to the quite massive preparations during last autumn, I am very confident about this launch. (Top management blog, January 2018)

During the studied timespan, the faculty merger was probably the most visible of all the changes and milestones in the organisational level. The changes continued during spring 2018

e.g. by the nominations of the new middle management. In the top management team meeting memos from March 2018, it was also stated that the successful internal communication about reaching the milestones needs to be ensured with the support from communications specialists.

Summary of the results

The aim of this study was to trace the progress of the management system change process from the internal documentation of TUAS, and to compare it to Kotter's eight-step model of leading change. It was possible to find only the first six steps from the data, which is explained by the fact that the change process has been officially going on for just a year and a half. The last two steps will be relevant only after the change has been going on for several years.

The change of the organisation and management system was justified with very concrete and inevitable changes in the near future, i.e. moving the operations to one campus and the reorganisation needs stemming from it, and the ending of the term of the middle managers. However, at the same time, it was stated that also the old system was quite functional, which may question the absolute need for the change. As Kotter has pointed out, the urgency of the change is very important to communicate right to ensure the engagement of the staff to the change.

On the other hand, the change has been supported by actively engaging the staff and other stakeholders to the creation of the vision and strategy for the new system. Then again, it seems that the communication about the created vision has been overtaken by more concrete actions. Thus, the vision and strategy may not have become so clear. However, the lack of vision in the data can be at least to some extent explained by the "official" nature of the material. It is also possible, that the vision has been communicated more face-to-face e.g. in the stakeholder meetings.

When it comes to empowering and removing obstacles from the way of the change, the data does not clearly suggest what obstacles there might have been. However, several other changes and reorganisations were necessary to support the management system change on a faculty level.

During the studied timespan, the merger of the two faculties has been the most visible milestone or "short-term win" of the change process in the organisational level. The change has been driven forward in the new faculty along with engaging and empowering the stakeholders.

CONCLUSIONS

Leading change is one of the most challenging tasks that a manager can execute. A change process is not necessarily linear, but it clearly has a process-like nature, when the change is constantly in progress simultaneously in different areas of management. In this study, the leadership within the organisational change currently being executed at Turku University of Applied Science was explored and reflected the well-known Kotter model of leading change. The research questions were: How is the change process constructed in the top management documentation in relation to Kotter's eight-step model? Has the change process followed Kotter model and to what extent?

The Kotter model (1995/2007) has eight steps where the first three steps (establishing of urgency, creating the guiding coalition, and developing a vision and strategy) are about creating a climate for change. The next steps (communicating the change vision, empowering

employees for broad-based action and generating short-term wins) are related to engaging and enabling the organisation. The last two steps are about producing more change and anchoring new approaches in the culture. The conducted study found that there was a sense of urgency. At first, the justifications for the management system change were drawing from other concrete, inevitable upcoming changes, such as the formation of the new campus, where all the faculties would be present, the need to unify procedures, ending of the middle management term and advancement of TUAS strategy. The justifications got even more concrete after stakeholder interaction, but in the end, they form a stronger link with TUAS strategy.

Also, Kotter's second step, creating the guiding coalition, was executed strongly by involving extensively both internal and external stakeholders in the planning of the change from the beginning. There was also evidence that Kotter's third step, developing vision and strategy, was executed in collaboration with the stakeholders. Based on this study, the fourth step, communicating the change vision, was conducted with various methods and channels. However, from the basis of the data, it is not possible to tell, how clearly this developed vision eventually came across to the stakeholders. In addition, there was no mention of a particular communication plan for the change process until 1.5 years after the beginning of the change. The communication was led and executed by the top management without any middlemen.

Kotter's fifth step, empowering employees for broad-based action, was implemented in the form of reorganisation of the support functions, rearrangement of the schools and realignment of the research groups. Kotter's sixth step, generating short-term wins, was executed by defining and reporting about the change process phases, milestones and advancement. This was followed by constant measuring and following of the deliverables. The most significant short-time win during the studied timespan was the official merge of the two faculties into one. However, the implementation of the organisational and management system change process still continues. The last two steps, producing more change and anchoring new approaches in the culture were not analysed in this study since they need a longer time span (several years) to become relevant.

In conclusion, it was possible to find evidence of the first six steps in the Kotter model in the studied organisational and management system change process at TUAS. Thus, in this sense, the change has been led with success. However, this study does not evaluate how effectively these steps have been taken or to what extent they may have been able to reach the intended results.

The Kotter model seems to be a viable framework to analyse leading change also in the higher education context. Even though the CDIO Initiative does not directly focus on topics in higher education change management, it has facilitated numerous change processes globally. Studying and understanding the different phenomena connected to change in higher education benefits the potential to reach the Initiative's intended goals of continuous improvement of education and the skill set of future professionals.

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FLIPPED LEARNING TO NURTURE SELF-DIRECTED LEARNERS AT SINGAPORE POLYTECHNIC

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ABSTRACT

Self-directed Learning (SDL) is recognised as one of the critical 21st Century skills for life and career (Partnership for 21st Century Skills, 2011). As advances in technology increase the pace of change and the shelf life of knowledge decreases, students have to have more than thinking skills and content knowledge. They have to develop the skills sets and mindsets to be able to learn independently so as to be able to adapt to a constantly changing world. With the various definitions in mind, Singapore Polytechnic (SP) proposed a SDL model that involves 2 key components: Motivational or mindset component and Cognitive or skills set components. In this paper, the authors will describe the SDL model and will explore the extent to which flipped learning provide students with opportunities for self-directed learning. The paper will also detail a study, involving both qualitative and quantitative methods involving 4000 students, conducted to ascertain the impact of flipped learning on students' self-directed learning. The paper will present the analysis of the quantitative data findings of the study and the learning and future work that emerged.

KEYWORDS

Self-Directed Learning, Flipped Learning, Learning To Learn, Standards 7, 8, Evaluation.

INTRODUCTION

In recent years, there has been a growing recognition that the advances of technology is disrupting work and impacting the way we live. Many of today's professions did not exist twenty years ago and likewise, jobs that exist today may not exist in the future. In addition, the life expectancy of Singaporeans has been improving (Dept of Statistics, 2018). Singapore youths will live healthier lives and have longer working years. When this development is coupled with the speed of the digital revolution, it becomes plausible that today's youths will have 2 or more careers in their lifetime. In other words, they must acquire the versatility to ride the waves of transformation that will take place in their lifetime.

Hence, to progress in their careers and live fulfilling lives in this rapidly changing society, our graduates will have to constantly learn, unlearn and relearn throughout their life. They will have to have greater control over their own learning process to be able to steer their own career

development. To prepare our graduates for the challenges they will face in the future, we embarked on a whole institution curriculum revision to give our students more autonomy over their own learning. In the curriculum review, we aimed to nurture in our students the mindsets and skillsets to be self-directed learners. We also introduced flipped learning as the pedagogical approach to provide opportunities for students to learn and apply the self-directed learning process.

In the CDIO syllabus, the importance of self-directed learning is reflected in 2.4.5 (self-awareness, metacognition and knowledge integration), 2.4.6 (Lifelong learning and Educating) and 2.4.7 (Time and Resource Management) in the section on Attitudes, Thought and Learning.

In this paper, the authors will first describe the SDL model and the flipped learning approach adopted. Next, the paper will detail a study, involving both qualitative and quantitative methods, conducted to ascertain the impact of flipped learning on students' self-directed learning. The paper will present the **quantitative analysis** component of the findings of the study and the learning and future work that emerged.

SELF-DIRECTED LEARNING – A PROCESS AND AN OUTCOME

A key goal of higher education is to prepare graduates to be self-directed lifelong learners with the ability to continuously learn, unlearn and relearn to keep pace with the rapidly transforming industry needs. Self-directed Learning (SDL) is recognised as one of the critical 21st Century skills for life and career (Partnership for 21st Century Skills, 2007). Much of the definitions of SDL have focussed on either the process or learner attributes. Knowles (1975), for example, offered the following definition:
".. process in which individuals take initiative, with or without the help of others, in diagnosing their own learning needs, formulating goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies and evaluating learning outcomes."

Gibbon (2002), on the other hand, stressed the importance of developing ownership of learning and the motivation of the learner to pursue a learning goal and persist in the learning process. In his model, the students take on the personal responsibility of identifying learning gaps and setting learning goals; managing their tasks, time and resources and conscious efforts to improve their learning strategies; and extend their learning by making links with other formal and informal learning and interests. Building on Gibbons' work, Tan & Koh (2014) proposed considering self-directed learning as a spectrum that begins from the lowest level of incidental self-directed learning to the highest level of self-directed learning to indicate a progressive development of students' readiness in self-direction.

Similarly, Long (2000), proposed that self-regulation is a critical and necessary element in self-directed learning. Processes of self-regulation such as monitoring, goal setting, planning, choice of learning strategies and self-evaluation are important. Underpinning self-regulation is the students' abilities to engage in metacognitive monitoring where they analyse their personal strengths and weaknesses to identify the factors that influence task performances (Zimmerman & Campillo, 2003). Hence, students' ownership, control and metacognition of their learning are important when developing students' self-direction.

In the CDIO syllabus, the skills of self-directed learning are reflected in 2.4.5 (self-awareness, metacognition and knowledge integration), 2.4.6 (Lifelong learning and Educating) and 2.4.7

(Time and Resource Management) in the section on Attitudes, Thought and Learning (Table 1). Similar to Gibbons (2002), the CDIO syllabus also identifies "one's responsibility for self-improvement to overcome important weakness" as well as the importance of "task prioritisation". In addition, the syllabus also identifies the need for "motivation for continued self-education" and the "skills of self- education".

Table 1: Self-directed learning skills in CDIO syllabus

2. **PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES**
   2.4   Attitudes, Thought and Learning
   2.4.5   *Self-Awareness, Metacognition and Knowledge Integration*
           One's skills, interests, strengths and weaknesses
           The extent of one's abilities, and one's responsibility for self-improvement to overcome important weaknesses
           The importance of both depth and breadth of knowledge
           Identification of how effectively and in what way one is thinking
           Linking knowledge together and identifying the structure of knowledge
   2.4.6   *Lifelong Learning and Educating*
           The motivation of continued self-education
           The skills of self-education
           One's own learning styles
           Relationships with mentors
           Enabling learning in others
   2.4.7   *Time and Resource Management*
           Task prioritisation
           The importance and/or urgency of tasks
           Efficient execution of tasks

With the various definitions in mind, SP proposed a SDL model (Figure 1) that involves 2 key components:
1. Motivational or mindset component which includes the students' motivation and self-belief about themselves as learners; and
2. Cognitive or skills set components which includes the cognitive and metacognitive learning strategies that learners use.

Figure 1: Singapore Polytechnic's Self-directed Learning framework
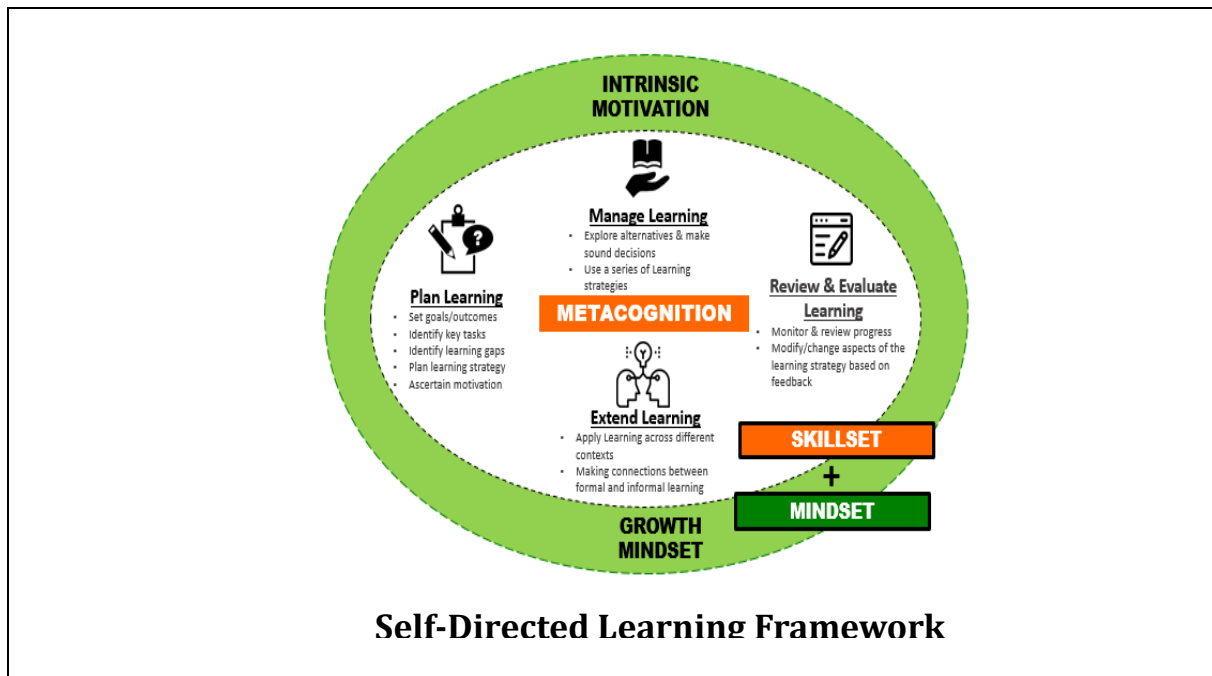
FLIPPED LEARNING

Blended learning is an established part of the educational landscape and is growing in popularity as evidence suggests that not only is it more efficient and flexible but also more effective than either face-to-face or fully online learning (Means, Toyama, Murphy, Bakia, & Jones, 2010). Flipped learning is a particular format of blended learning and has become one of the emerging technology to foster students' active learning in higher education in recent years (Johnson, Adams Becker, Estrada & Freeman, 2014).

Flipped Learning is defined as "a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides the students as they apply concepts and engage creatively with the subject matter" (Flipped Learning Network, 2014).

Tan & Koh (2014) wrote that "for self-directed learning experiences to be effective, teachers need to carefully structure the task environment to provide sufficient scope for students' self-direction" (p. 16-17) and one of the ways highlighted was the case of flipped learning. Abeysekera & Dawson (2014) also proposed that flipped learning might improve student motivation and help manage cognitive load. However, there is little literature on the effectiveness of flipped learning to inculcate self-directed learning in students.

In Singapore Polytechnic, we piloted flipped learning in our classes in 2015 in 3 schools: Business, Math and Science and Communication, Arts and Social Sciences. In April 2019, all programmes will adopt flipped learning in at least 25% of their first year curriculum.

In this paper, we will detail a study, involving both qualitative and quantitative methods, conducted to ascertain the impact of flipped learning on students' self-directed learning. The study was initiated to provide a structured research-driven approach to monitor and review the implementation of 2 key initiatives in Singapore Polytechnic: flipped learning and self-directed learning.

The evaluation activities were designed to address three broad research questions central to understanding the impact of key aspects of the two initiatives:

1. How are the students experiencing the flipped Classroom?
2. Does the flipped classroom format inculcate self-directed learning in students?
3. What is the impact of flipped classroom format on assessment outcomes?

We will focus on **research question 2** and report only the quantitative results of the study for the purpose of this paper.

METHODOLOGY

The study involved polytechnic diploma students from a mixture of academic schools and years of study. Table 2 gives the details of the students who participated in the study. The students had one semester of flipped learning where approximately 50% of the lectures were converted to online videos which the students viewed at home. During the face to face tutorials, the lecturers adopted active discussion teaching methods.

Table 2: Details of students who participated in the study

Module	Number of students	Year of study	Academic school/s
Engineering Math 1	2208	Year 1	Built Environment, Media and IT, Electrical and Electronics, Mechanical and Aeronautical, Singapore Maritime Academy, Chemical and Life Sciences
Communicating for Project Effectiveness	1428	Years 1 to 3	Built Environment, Media and IT, Electrical and Electronics, Mechanical and Aeronautical, Chemical and Life Sciences
Fundamentals of Marketing	903	Year 1	Business
Management & Organisational Behaviour	900	Year 1	Business

A mixed method approach involving qualitative, as well as quantitative data collection, was used. For the quantitative data, pre and post-tests were conducted using a 34 item questionnaire made up of the Learning Strategies and Motivation Scales of the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich et al., 1991). The MSLQ is a validated questionnaire. The description of the scales is elaborated in Tables 3 and 4.

Table 3: Learning Strategies Scale

Sub-section	Scales
Cognitive and metacognitive component	• **Metacognitive Self-Regulation** Metacognition refers to the awareness, knowledge, and control of cognition. 3 processes make up the metacognitive self-regulatory activities: Planning, monitoring, and regulating. • **Elaboration strategies** help students store information into long-term memory by building internal connections between items to be learned e.g. summarizing, generative note-taking. These help the learner integrate and connect new information with prior knowledge.
Resource management component	• **Help Seeking** There is a large body of research that indicates that peer help, peer tutoring, and individual teacher assistance facilitate student achievement.

Table 4: Motivation Scales

Sub-section	Scales
Expectancy component	• **Control of learning beliefs** This refers to students' beliefs that their efforts to learn will result in positive outcomes. If students believe that their efforts to study make a difference in their learning, they should be more likely to study more strategically and effectively. • **Self-efficacy** This is a self-appraisal of one's ability to master a task. Self-efficacy includes judgments about one's ability to accomplish a task as well as one's confidence in one's skills to perform that task.

The two MSLQ scales were selected as they represented the research questions most closely. The Learning Strategies Scale contained questions on learners' resource management and the cognitive and metacognitive self-regulations strategies while the Motivation scale assessed the learners' expectancy component of their self-directedness. Table 5 shows the MSLQ scales used, the number of items in each scale and an example of an item for each scale.

Table 5: MSLQ scales used in the study

Section	Sub-section	Scales	No of items	Example item
Motivation	Expectancy	Control of learning belief	4	If I don't understand the module material, it is because I didn't try hard enough.
		Self-efficacy for learning and performance	8	I'm confident I can understand the most complex material presented by the lecturer in this module.
Learning strategies	Cognitive and meta cognitive strategy	Elaboration	6	I try to apply ideas from module materials (e.g. lecture notes, videos, readings and discussions) in other class activities such as lecture, tutorial and discussion.
		Meta-cognitive self-regulation	12	If module materials are difficult to understand, I change the way I learn the material.

	Resource management strategy	Help seeking	4	I ask the lecturer to clarify concepts I don't understand well.

The questionnaires were administered to students at the beginning of the semester and at the end of the semester using an online survey tool, Verint Systems. All 4000 students enrolled in the module were asked to participate. Participation was voluntary and no extra credit was given for participation. Altogether, 1231 respondents took the pre-test while there were 1242 respondents for the post-test. This is a response rate of approximately 30%.

The 34 items in the questionnaire were randomised. For each, question, the students rated themselves on a seven-point Likert scale where 1 is "not at all true of me" and 7 is "very true of me". The student responses were analysed using independent t-test done at 5% significance level. The analysis was conducted on the student cohort as a whole and no attempt was made to identify individual students.

RESULTS

We will focus on **research question 2** and report only the quantitative results of the study for the purpose of this paper.

Table 6 shows the results of the independent t-test conducted on the survey results. Significant increases (p-value= 0.0001) were observed in all the 5 scales used in the study. The largest gain was in "self-efficacy for learning and performance" followed by 'control of learning belief, 'elaboration' and 'meta-cognitive self-regulation'. The smallest gain was observed for 'help seeking'.

Table 6: Independent T-test analysis of selected MSLQ scales

Scale		Mean	Std Dev	SE Mean	Mean diff
Meta-cognitive self-regulation	Pre-test	4.650	1.420	0.013	0.211*
	Post-test	4.861	1.441	0.013	
Elaboration	Pre-test	4.750	1.361	0.015	0.243*
	Post-test	4.993	1.392	0.016	
Help seeking	Pre-test	5.034	1.438	0.023	0.175*
	Post-test	5.209	1.414	0.023	
Control of learning belief	Pre-test	5.262	1.353	0.019	0.27*
	Post-test	5.532	1.362	0.018	
Self-efficacy for learning and performance	Pre-test	4.808	1.311	0.0132	0.412*
	Post-test	5.220	1.312	0.0131	

*P-value = <0.0001
N= 1231 (pre-test) N=1242 (post-test)

DISCUSSION

Motivation: Expectancy

Of the 5 scales surveyed in this study, the highest mean difference observed was in self-efficacy for learning and performance. Students' self-efficacy beliefs play an important part in their confidence in themselves as effective learners and their abilities to master a task. The significant increase in the self-efficacy scores in the study indicates that the students'

judgement about their ability to accomplish a task as well as their skills to perform the task was enhanced by flipped learning. According to Stegers-Jager *et al.* (2012), strengthening the students' self-efficacy will help to enhance student performance. Similar results were reported by Sun *et al.* (2018) who found that students' self-efficacy in learning math was significantly positively related to academic achievement in both pre- and in-class flipped learning environments.

The second highest score was obtained for 'control of learning beliefs'. This second scale in the motivation section refers to the students' beliefs that their efforts to learn will result in positive outcomes. If students believe that their efforts to study make a difference in their learning, they should be more likely to study more strategically and effectively.

According to Dweck (2006), non-cognitive factors, which includes students' belief about themselves, their goals in school, their feelings of social belonging and their self-regulatory skills, are critical for ongoing academic success. Dweck (2006) divides students into 2 groups. Students may view intelligence as a fixed quantity that they either possess or do not possess (a fixed mindset) or as a malleable quantity that can be increased with effort and learning (a growth mindset). The two motivation scales, self-efficacy and control of learning beliefs, are pertinent to students' mindsets of themselves as learners. The positive increases in both scales indicate that flipped learning helped to enhance the students' growth mindsets and motivation to learn. They developed confidence in themselves as learners and felt that their learning success was dependent on the effort they invested in their learning.

Learning Strategy: Cognitive and Meta-cognitive strategy

Learning strategies can be seen as a description of behaviours and thoughts which the learner engages in to support and facilitate their learning process (Hoskin and Fredriksson, 2008). These thoughts and behaviours may include plans of actions and learning techniques adopted by the learner to achieve a learning goal. Two scales were examined under the Learning strategy section: Elaboration and Meta-cognitive self-regulation.

Elaboration strategies refer to behaviours or thoughts which the learner engages in to help store information into long-term memory. These could include making connections between concepts learned in the pre-class to concepts to be learned in-class. For example, students may apply ideas learnt from video recordings or pre-class readings to other class activities like tutorial questions or class discussions. Adopting learning strategies like rehearsal, summarising, mindmapping, note taking and paraphrasing also help students integrate and connect new information with prior knowledge. In our study, the elaboration scale showed a significant positive mean difference between the pre- and post-tests of 0.243 indicating that students had a greater tendency to adopt learning to learn strategies in flipped learning.

The Metacognitive Self-Regulation scale measures the students' perception of their awareness, knowledge, and control of cognition. Self-regulation and metacognition are sometimes used interchangeably. However, according to Whitebread and Pino Pasternak (2010), there is consensus that "metacognition refers specifically to the monitoring and control of cognition, while self-regulation refers to the monitoring and control of all aspects of human functioning, including emotional, social, and motivational aspects" (p. 693). In our study, metacognition is described as the processes involved when learners plan, monitor, evaluate, and make changes to their own learning behaviours.

Research indicates that metacognition is a powerful predictor of learning. A learner's metacognitive practices can influence learning over and above the influence of intellectual ability and may compensate for any cognitive limitations (Veenman, Wilhelm, & Beishuizen, 2004). Nelson and Narens' (1990) Model of Metacognition describes metacognition at two levels: the object level and the meta level. In the object level, cognitive processes or 'one's thinking' occurs. At this level, cognitive strategies (e.g. paraphrasing) are used to help learners achieve a particular goal (e.g. understanding a concept). At the meta level, 'thinking about thinking' takes place. Here, metacognitive strategies are used to enable learners to reach learning goals. This includes monitoring how well they are learning and adapting their strategies accordingly. In our study, the meta-cognition self-regulation scale showed a significant positive mean difference between the pre- and post-tests of 0.211 indicating that flipped learning encouraged students to adopt meta-cognitive strategies as they learnt.

Learning Strategy: Resource management

In this resource management subsection of the Learning Strategies section, we analysed the students' 'Help seeking' inclinations. This refers to the learners' tendencies to seek assistance from either peers or lecturers when meeting difficulties in understanding the learning material.

Help-seeking behaviours, in a learning context, refers to the strategies learners use to determine when help is needed and how to receive that help (Nelson – Le Gall, 1986). In most instances, the learner will ask for help from a more knowledgeable person when faced with difficulties in understanding the learning material or in reaching their academic goals. Although help seeking is an important learning strategy for academic achievement, not all students use it. There are several reasons for this behaviour. For example, students may desire greater autonomy over their learning (Deci & Ryan, 1987) or may perceive asking for help as a sign of academic incompetence or lack of ability (Karabenick, 1998). Classroom environment and peer and teacher relationships may also affect the students' propensity to seek help.

In our study, the 'Help seeking' scale showed a significant positive mean difference between the pre- and post-tests of 0.175. While significant, this scale had the lowest mean difference indicating that in flipped learning the tendency for students to work independently even when they had difficulties understanding the materials.

CONCLUSION

The study was conducted to ascertain the impact of flipped learning on self-directed learning in students. The study addressed three broad research:

1. How are the students experiencing the flipped Classroom?
2. Does the flipped classroom format inculcate self-directed learning in students?
3. What is the impact of flipped classroom format on assessment outcomes?

Pre and post data were obtained using questions from 2 Sections of the MSLQ: Motivation and Learning Strategies. These 2 components were selected as they represented the skillsets and mindsets that students possess as self-directed learners. Statistical analysis using independent t-test was used to analyse the data.

The findings from the study show that flipped learning may have a positive impact on the students' metacognition and learning strategies. The independent t-test analysis of the means of the pre-test scores and post-test scores of the MSLQ components of 'meta-cognitive self-regulation', 'elaboration', 'help seeking', 'control of learning belief' and 'self-efficacy for learning and performance' showed significant, positive increases.

In the study, triangulation of data was employed to generate multiple framing and the possibility of enhancing validity in relation to some questions. Besides the reported survey, student co-participants were asked to blog their learning experience in a flipped classroom and their achievements in the flipped modules analysed. This paper, however, shares one aspect of the study, the quantitative data obtained for a survey of 4000 students, due to space and time constraints. A more complete picture would be obtained when the quantitative data is triangulated with the qualitative insights obtained from the co-participants' journaling and students' achievements. Areas for future exploration will include a study of the lecturers' perspectives and a longitudinal study of the impact of flipped learning on the students' self-directed learning abilities and mindset.

Self-directed learning skills and mindsets are important 21st century skills that graduates require to progress in a fast changing, technologically disrupted workplace. Flipped learning can play an important role in enhancing students' self-directed learning skills and mindsets, making the approach a valuable pedagogy in higher education.

ACKNOWLEDGMENTS

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BIBLIOGRAPHIC DATA ANALYSIS OF
CDIO CONFERENCE PAPERS FROM 2005-2018

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ABSTRACT

Tools for bibliometric data analysis offer opportunities to analyze the evolution of a field of study over time. VOSViewer is a popular tool for such analyses, allowing the user to create and interpret visualizations of publication data, such as word co-occurrence analysis, co-authorship networks, and geographic patterns of collaboration. Meikleham et al. (2018) previously demonstrated the utility of applying this analysis to engineering education publication data from Scopus and Web of Science. By conducting a temporal analysis, the authors demonstrated how geographic, co-authorship networks and key thematic trends changed over time. A limitation to the results found in Meikleham et al. (2018) was that, at the time of the analysis, publications from the CDIO Knowledge Library (CDIO Initiative, 2018) could not be included due to an incompatible data structure. VOSViewer requires publication metadata to be structured according to a particular standardized format, and this prevented the Knowledge Library data from being used. Over the past year, the data has been restructured for analysis as reported in this paper. The basis of the current work is a revision of the database schema for the CDIO Knowledge Library that has enabled export of CDIO conference papers to the Scopus format and subsequent import into VOSViewer for analysis. The data shows that researchers from 47 countries have contributed to the CDIO Knowledge Library with Sweden taking the lead with the maximum number of publications. Researchers tend to collaborate with the same co-authors over a period of time, thus forming networks or clusters of researchers. Each cluster of researchers tends to publish their work independently of other clusters. A newer network of authors has formed in the past 4 to 5 years who collaborate locally within a geographical region. This indicates a presence of local CDIO communities which have not yet integrated with the global CDIO community. In decreasing order of influence, CDIO Standards 8, 7, 3 and 5 have been the major focus of CDIO publications from 2005 until 2018 as indicated in the data included in this analysis.

KEYWORDS

CDIO, Bibliometric analysis, VOSViewer, CDIO Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

The CDIO (Conceive-Design-Implement-Operate) initiative began in the year 2000 as a collaborative effort between four institutions from two countries. The aim of the CDIO initiative was to bridge the gap between newly-educated engineers and their related industries, to ensure that new engineers possessed the abilities to handle real-world scenarios (CDIO Initiative, 2019). This was accomplished by the collaboration of industry representatives, academic professionals, university review committees, alumni, and students to create the CDIO syllabus and CDIO standards which acted as a framework for transforming engineering education around the world. The CDIO initiative has now grown into a global network of more than 140 institutions from around the world. This growth has led to numerous contributions to the CDIO Knowledge Library that date back to the initiative's inception. The CDIO Knowledge Library is an extensive database of all the documents and resources required to implement a CDIO program such as the CDIO syllabus, CDIO standards, conference proceedings, and much more (CDIO Initiative, 2019). With the addition of the annual conference, first held at Queen's University Canada in 2005, contributions to the CDIO Knowledge Library have steadily increased from 24 entries in 2005 to 114 entries being shared in 2018.

Bibliometric data analysis is a quantitative and statistical analysis of a corpus of literature which can be used to gain an overview and insight into the impact of scientific publications (Ellegard and Wallin, 2015). Such analysis can be used to track citation data as well as to generate maps on the historical and geographical trends in publications such as the CDIO initiative (Meikleham et al., 2018). An open-source software tool called VOSViewer is used to construct, analyze and visualize two-dimensional bibliometric networks obtained from datasets. Attributes such as author names, country names, keywords, etc. are called entities in VOSViewer and are represented as circles or rectangles. The size of an entity is directly proportional to the number of occurrences or the number of documents associated with that entity, depending on the type of analysis being performed. The closeness of entities to one another indicates a strong relationship between the entities. The lines or curves connecting different entities represent a link or connection between entities, thicker lines/curves representing stronger links. Colours are used to denote clusters of items or entities that are related or grouped together.

As the CDIO initiative continues to grow and expand, utilizing available data can help to provide decision makers with a triangulation point for future decision making. Meikleham et al. (2018) visualized and analyzed the historical evolution of engineering education and the influence of CDIO by performing bibliometric analysis of relevant literature available from Scopus and Web of Science databases. The total of 1426 records was obtained by Meikleham et al. (2018) of which 881 were conference papers and 131 were proceedings papers. The investigation by Meikleham et al. (2018) revealed that the geographic network of collaborations as indicated by external publication data had expanded to 38 countries with a set of core collaborators and communities over a period of 17 years. These communities of researchers were found to become independent, or isolated, over time. It was also found that China followed by the United States of America were the most significant contributors on the topics of engineering education and CDIO in the databases that were analyzed by Meikleham et al. (2018). Throughout the years, it was found that a high emphasis was placed on learning tools with keywords such as engineering, design, student, and projects finding repeated and consistent mentions in the literature obtained from Scopus and Web of Science databases. The limitation to the investigation by Meikleham et al. (2018) was that at the time of the analysis, the CDIO Knowledge Library data was in a format that prevented the use of software tool VOSViewer

for bibliometric analysis, and therefore it was not possible to gain an understanding of how the internal corpus of literature has evolved over the same time period.

Over the past year, data in the CDIO Knowledge Library has been restructured into the Scopus metadata scheme, allowing for seamless use of the data and ability to compare with results reported in Meikleham et al. (2018). The CDIO knowledge library currently contains more than 1000 papers. Some data clean-up operations were needed to be performed prior to export. As an example, variations in the name of the same author were identified and merged while migrating the CDIO Knowledge Library into the Scopus format. This reduced name duplication in the Scopus export. With the new metadata structuring of the Knowledge Library, geographical collaborations, author collaborations, and topics of interest could also be analyzed using VOSViewer and the methodology previously described in Meikleham et al. (2018). The visualization process offers an ability to gain an insight into past trends and provides some insight into future opportunities for the CDIO initiative.

The main aim of this paper is to analyze the historical and geographical trends over time of the conference paper publications available in the CDIO Knowledge Library as well as to visualize the influence of the CDIO initiative on engineering education around the world. Thus, it is necessary to understand how authors and educational institutions from different countries collaborate with each other as well as how they contribute to, assimilate, and fulfill the visions of the CDIO initiative. Another objective of this paper is to compare how the data available in the CDIO Knowledge Library differs from data available in external databases such as Scopus and Web of Science and described previously in Meikleham et al. (2018). Further, this work provides a description of the process followed by the authors to restructure an existing dataset for integration to available, open-source software, providing readers with a framework that they could follow for other datasets in the future. This work is valuable for those looking to augment their analysis of datasets with VOSViewer. This framework, therefore, provides future authors with the necessary steps required to integrate their own datasets into the Scopus format for integration into VOSViewer and will allow future authors to compare findings with those published in this paper and previously in Meikleham et al. (2018).

METHODOLOGY

The Knowledge Library was restructured and migrated to export data structured analogously to a Scopus data file. Scopus exports bibliometric data structured in columns with the order and arrangement of these specific columns being imported seamlessly into VOSViewer. For example, there need to be two separate columns in the Scopus file format named 'Author Keywords' and 'Index Keywords' for the co-occurrence function of VOSViewer to work correctly. In the same way, author names, affiliation names, keywords, etc. need to be separated by specific punctuation marks to have a homogenous data set. These specific attributes were identified to ensure that the CDIO Knowledge Library export would function properly.

The following analyses were performed using VOSViewer: co-authorship analysis based on author name; co-authorship analysis based on author country; and co-occurrence analysis of author specified keywords as well as keywords extracted from the conference paper title. Co-authorship analysis for both author name and author country were performed to visualize changes with different time periods and to perform a comparative analysis with the findings of Meikleham et al. (2018). A minimum threshold value of 3 documents per country was used for co-authorship analysis based on author country, the same as Meikleham et al. (2018). The co-authorship analysis was done for authors who have at least one document and who have

collaborated with at least one other author. The punctuations after the author name in the Scopus data file were found to be important as VOSViewer considers punctuations as a new character. Thus, although duplicate author names were merged during the migration of the CDIO Knowledge Library to the Scopus format, VOSViewer was duplicating certain author names and creating false clusters. It is important that each author name ends with a full stop (.) even if it is the last name inside a column. This ensured that the authors were not eliminated from the analysis.

The keyword analysis was done in VOSViewer using the co-occurrence option. Only the author specified keywords could be analyzed from the CDIO Knowledge Library. An additional keyword co-occurrence analysis was done by extracting keywords from the paper title. The VOSViewer option to create a map based on text data was used for these keywords. A minimum of 3 occurrences of a keyword was the boundary condition for the keyword analysis.

The conference papers from the year 2005 to the year 2018 were exported individually to enable a year-wise analysis of the data. This enabled data analysis in the form of groups or clusters of authors, countries, and keywords for each year. The results of these analyses have been discussed without reporting the images. The conference papers were also exported in the following year groups: 2005 to 2007; 2005 to 2010; 2005 to 2012; 2005 to 2014; 2005 to 2016; and 2005 to 2018. This was done to enable the Knowledge Library data to be analyzed and compared with the analysis performed by Meikleham et al. (2018) as well as to understand the historical and geographical trends with time. Due to inconsistencies in the data of certain papers such as absence of author information, conference date and location data, etc., 30 papers were not included in the Scopus export.

RESULTS AND DISCUSSION

The number of archived conference papers per year from 2005 to 2018 is shown in Figure 1. The data shows that there was a rise in the contribution to the CDIO initiative from 2005 until 2011, except for the year 2010. In the period after 2011, there has been a steady number of contributions to the CDIO initiative each year. As Meikleham et al. (2018) point out, the steady state of the number of CDIO conference papers may be due to the absence of major changes to the CDIO approach. However, it is also interesting to note that the year 2018 witnessed the maximum number of conference papers since 2005. It can be further observed that the conferences with the largest number of papers have been held in either Asia or Europe, i.e., the two largest CDIO regions. The conferences with the lowest number of papers during the last ten years have both taken place in the North American region. This is a very important finding for CDIO leadership strategizing about future conference locations. On one hand, holding conferences in emerging areas is important to ensure the initiative continues to expand globally and attract new participants, while on the other hand, a lower volume of publications in that year may have intangible negative downstream effects. Equipped with these findings, CDIO leadership could ponder or implement policies and incentives to encourage participation at conferences in geographic regions with lower attendance rates, which would help mitigate this tradeoff.

VOSViewer Analysis - Co-authorship analysis based on country

The VOSViewer analysis was conducted for each year from 2005 to 2018. The number of participating countries gradually increased from 8 in 2005 to 16 in 2010. In 2011 the number of participating countries increased to 24 and remained nearly the same until 2017. The year

2018 witnessed 31 participating countries, which is the largest number for a single year. Figure 2 to Figure 7 shown below indicate the collaboration links of authors and co-authors across different countries.
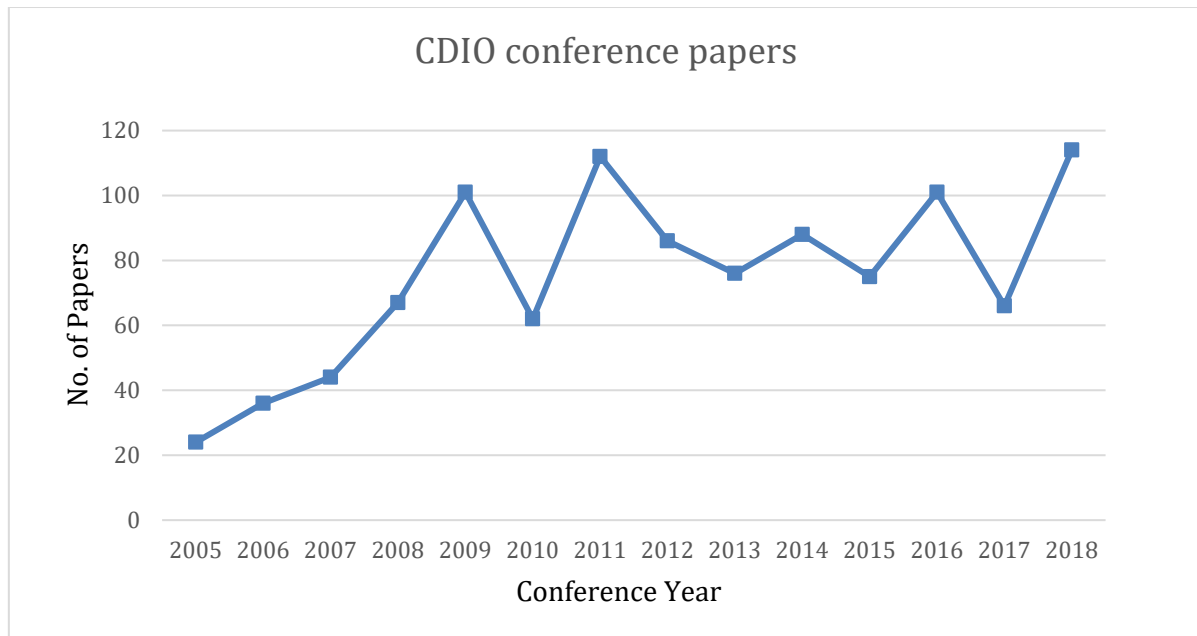
Figure 1. Number of archived conference papers per year in the CDIO Knowledge Library

Figure 2. Countries with co-authorship collaboration from 2005 to 2007, 6 countries out of 16 countries with co-authorship links

The country-wise co-author collaboration from 2005 to 2007 as shown in Figure 2 excludes the contributions of China, Singapore, and South Africa as the authors from these countries did not collaborate with authors from outside their home countries. Similarly, the period from 2005 to 2010 in Figure 3 excludes the contribution of Finland, Portugal, Australia, South Africa and Malaysia; the period from 2005 to 2012 in Figure 4 excludes the contribution of Portugal,

Japan, Malaysia, New Zealand, South Africa, and Russia; the period from 2005 to 2014 in Figure 5 excludes the contribution of Portugal, Russia, Malaysia, Columbia, and New Zealand; the period from 2005 to 2016 in Figure 6 excludes the contribution of Portugal, Columbia, and New Zealand; the period from 2005 to 2018 in Figure 7 excludes the contribution of Portugal, New Zealand, South Africa, Taiwan and Mongolia.

Figure 3. Countries with co-authorship collaboration from 2005 to 2010, 10 countries out of 26 with co-authorship links, 3 clusters formed.

A comparison with Meikleham et al. (2018), who examined CDIO data external to the CDIO Knowledge Library reveals very different co-author collaborations between countries, not only in terms of the links between countries but also in terms of the number of documents from a particular country. The finding that different collaboration patterns are observed in the CDIO internal conference data and the external corpus of literature is an extremely promising result as it provides a level of validation that the CDIO annual conference plays a role in forming collaboration networks that may not have existed otherwise. The difference in collaboration patterns from internal to external may indicate the presence of local CDIO communities who are increasingly publishing papers in external databases independent of the annual CDIO conferences.

The contributions of countries and the co-authorship links from 2005 to 2018 have been summarized in Table 1. As observed from Figure 2 to Figure 7 and Table 1, Sweden is the country with the highest number of contributions to the CDIO Knowledge Library from 2005 to 2018. However, the Scopus database analysis performed by Meikleham et al. (2018) reports Sweden as the third largest contributor behind China and the United States of America (USA).
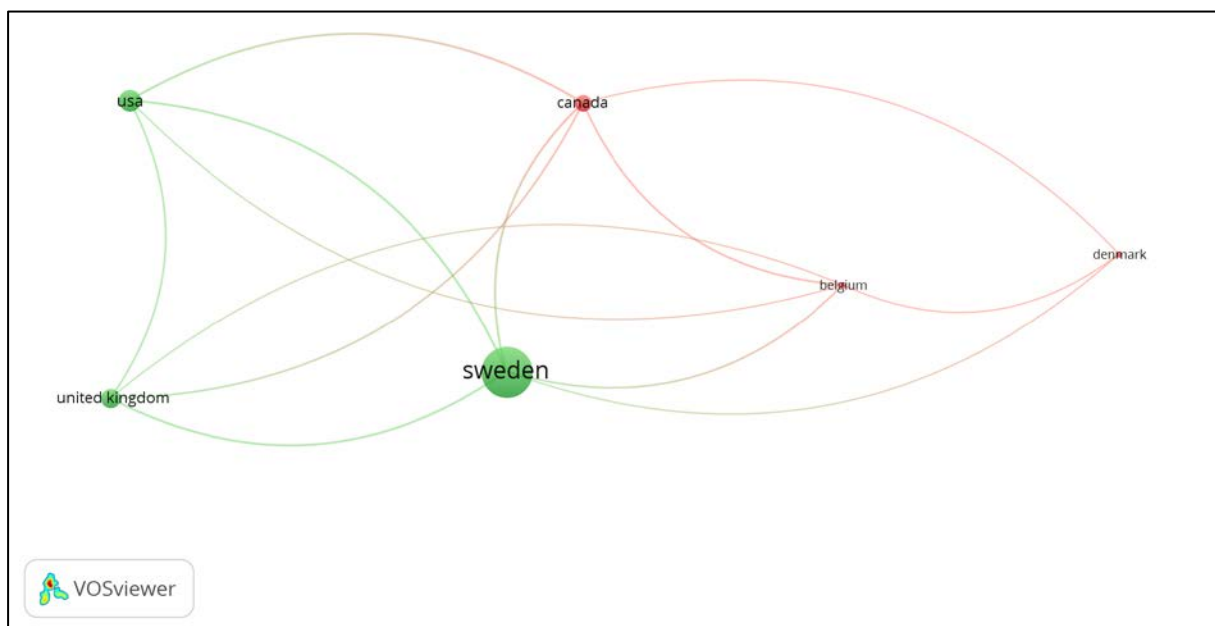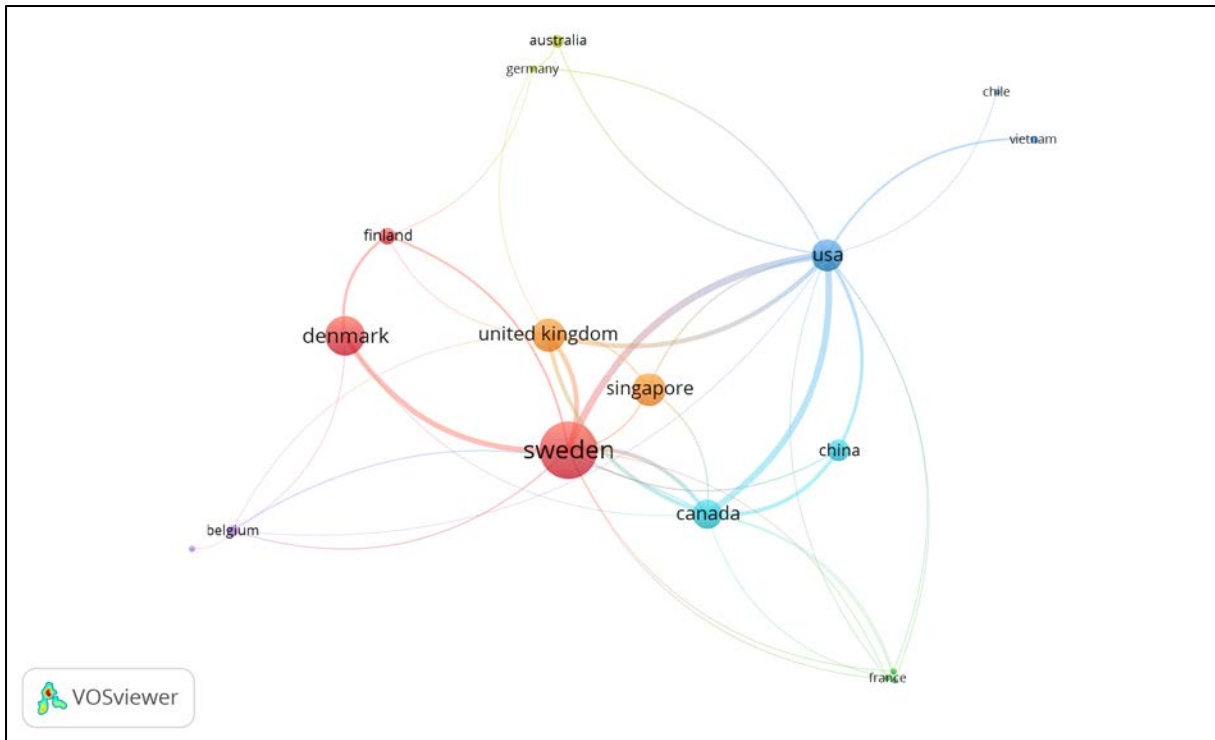
Figure 4. Countries with co-authorship collaboration from 2005 to 2012, 17 countries out of 31 with co-authorship links, 7 clusters formed
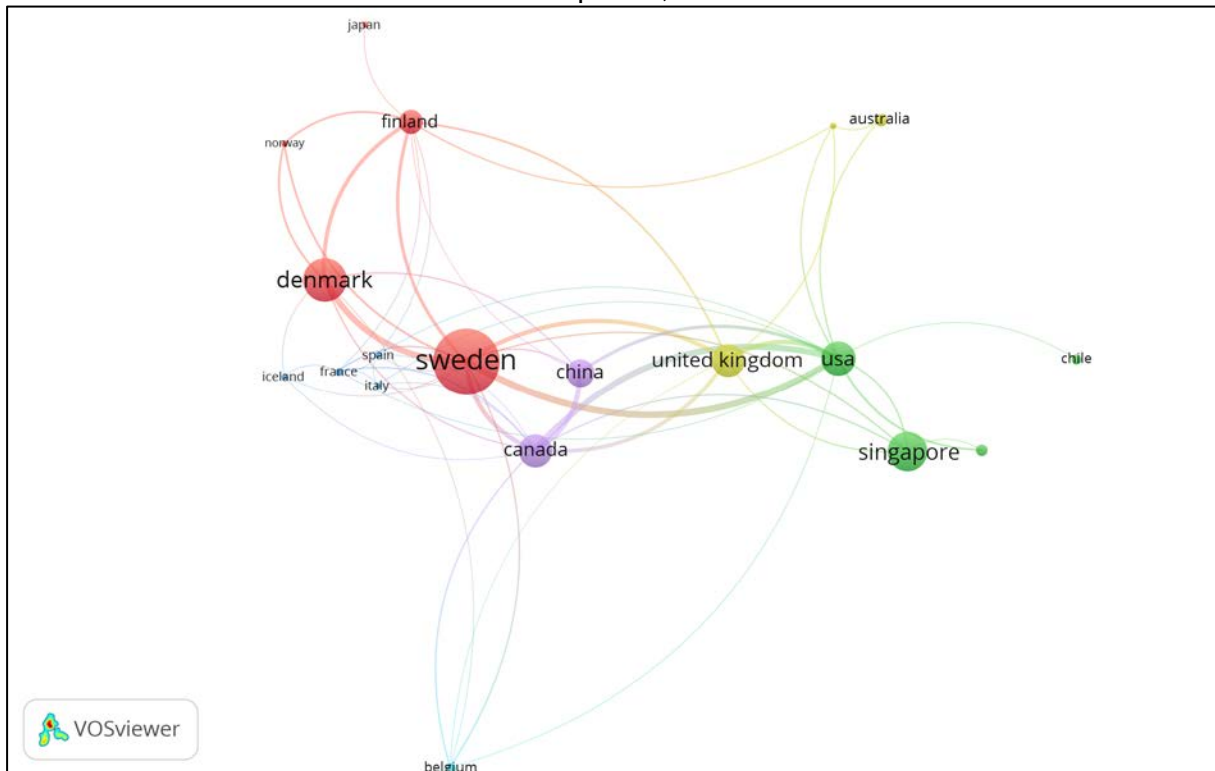
Figure 5. Countries with co-authorship collaboration from 2005 to 2014, 20 countries out of 36 with co-authorship links, 6 clusters formed
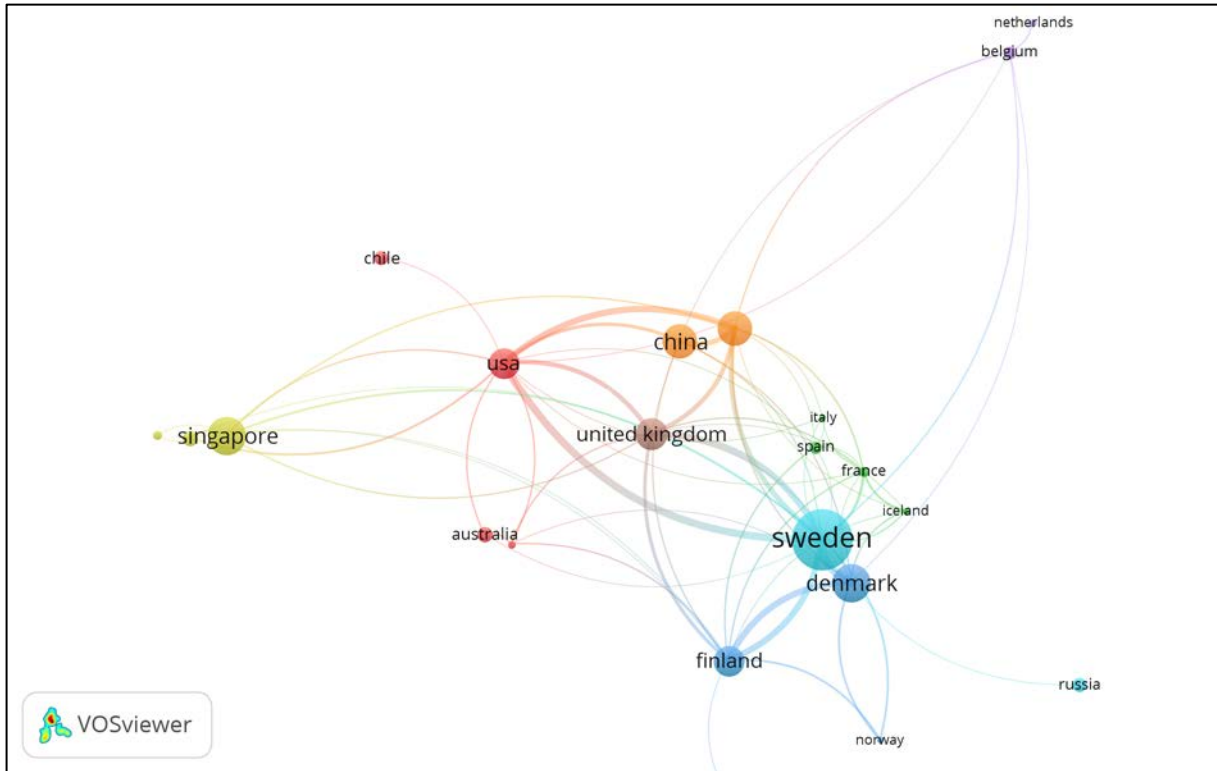
Figure 6. Countries with co-authorship collaboration from 2005 to 2016, 22 countries out of 38 with co-authorship links, 8 clusters formed (Out of frame- Japan)
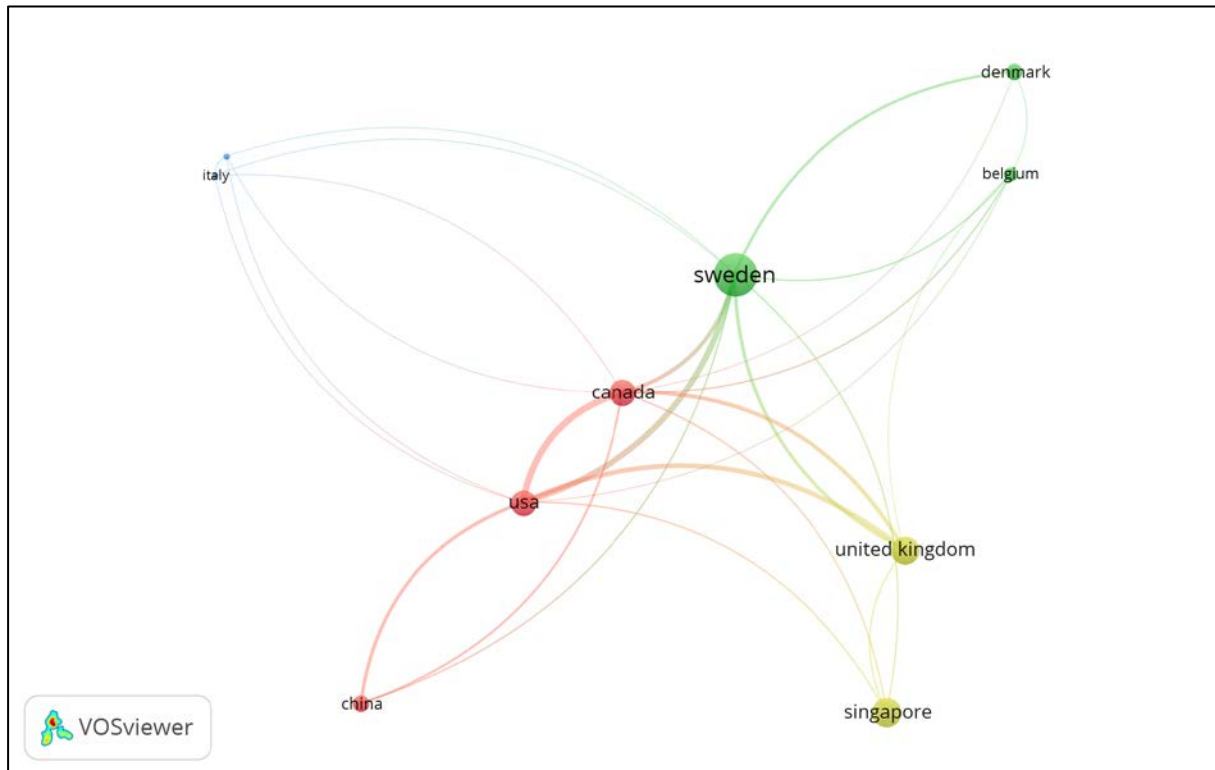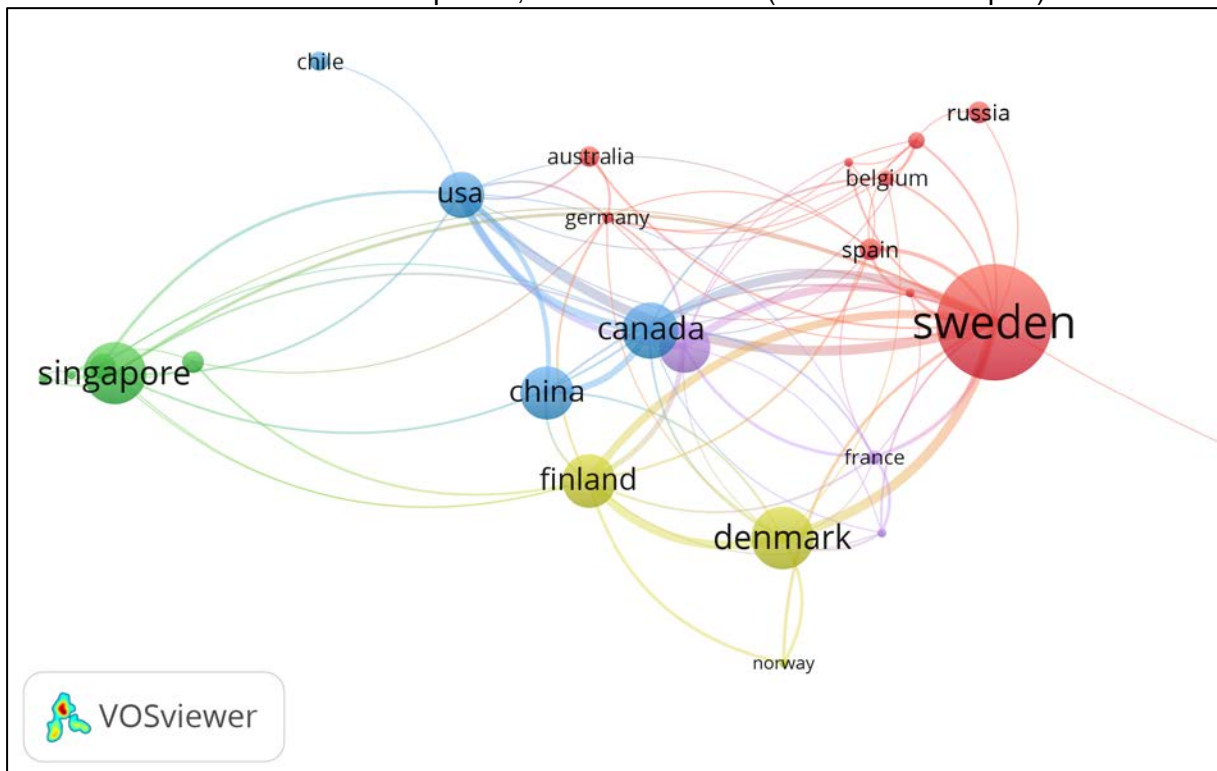

Figure 7. Countries with co-authorship collaboration from 2005 to 2018, 26 countries out of 47 with co-authorship links, 6 clusters formed (Out of frame- Colombia)

Examining only the CDIO Knowledge Library, China and Finland have been contributing significantly to the CDIO Initiative since 2010, China is the largest contributor in 2015, which coincided with that year's conference location (Chengdu, China). It can also be noted that Japan contributed significantly to the CDIO initiative in 2018, which coincided with the 2018 conference being held in Kanazawa, Japan. A repeating trend is observed for individual conferences wherein the maximum number of contributions to the CDIO knowledge library come from the country hosting the CDIO conference.

Table 1. Country Wise Co-authorship from 2005 to 2018 (Minimum 3 documents)

No.	Country	Documents	Collaboration Links
1	Sweden	219	90
2	Denmark	104	37
	Singapore	104	16
3	Canada	91	49
4	Finland	85	43
	China	85	19
5	United Kingdom	80	41
6	United States of America	70	49
7	Vietnam	36	12
8	Japan	29	5
	Russia	29	2
9	Spain	28	15
10	Australia	26	6
11	Chile	24	1
12	Portugal	23	0
13	Netherlands	22	10
14	Belgium	20	9
15	Columbia	18	1
16	France	17	19
17	Germany	13	14
18	Malaysia	12	3
19	Iceland	11	10
20	Brazil	9	2
	New Zealand	9	0
21	Italy	6	9
22	Norway	5	9
	Ireland	5	5
	South Africa	5	0
23	Thailand	4	5
24	Mongolia	3	0
	Taiwan	3	0

As mentioned in the introduction, VOSViewer forms clusters or groups entities together, with different colours used to indicate different clusters. From Figure 2 to Figure 7 it can be observed that certain clusters of collaborators have remained relatively the same over the years, with certain clusters splitting among themselves. For example, while Sweden, Denmark, and Finland have had close collaborations over the years, Figure 7 shows that Sweden split away and formed its own cluster after 2015. Conversely, Canada, China, United Kingdom, and the USA have grown closer over the years in terms of close collaborations with each other while Singapore has shown a trend to form its own cluster among south-east Asian countries such as Vietnam and Malaysia while being distanced away from American and European collaborators. This may reflect a difference in geographic agendas and requires further investigation in future work. From Table 1 and Figure 7, it can also be observed that among the top 6 contributors to the CDIO Knowledge Library, Sweden and Singapore have become very independent CDIO hubs which maintain good collaborations within their respective geographical areas.

An interesting observation is that the contributions and collaborations from China to the CDIO Knowledge Library have reduced drastically after 2015. While the results of individual year-wise co-authorship have not been displayed in this paper, it has been observed that the contributions from the USA have reduced to a great extent after 2013. Alternatively, the findings of Meikleham et al. (2018) show China and USA as the major contributors within CDIO and engineering education which implies that Chinese and American authors are increasingly publishing papers in databases external to the CDIO Knowledge Library. This is an important finding and could potentially signal an area of future intervention for CDIO leadership to bring these researchers back into the fold. Additionally, countries such as Russia, Portugal, Columbia, and Chile have steadily increased their contributions to the CDIO Knowledge Library as shown in Table 1 and Figure 7, but their collaborations with other countries are minimal, and as a result their appearance in the VOSViewer visualization is reduced in comparison to the findings of Meikleham et al. (2018). This is an indication of the presence of localized CDIO communities around the world which may receive additional benefit through co-authorship collaborations outside of their country or regions.

VOSViewer Analysis - Co-authorship analysis based on author

Visualizing author networks in VOSViewer was a difficult task. Our initial analysis yielded unexpected results wherein significant authors were not visible in the analysis, which was similar to the findings described in Meikleham et al. (2018). The final cleaned up results of the co-authorship analysis based on author names are shown from Figure 8 to Figure 13.

The co-authorship analysis based on authors in VOSViewer showed consistent results wherein researchers tend to collaborate with the same people frequently and over a period of time. Additionally, there are many clusters of researchers who tend to publish independently. This is consistent with the findings of Meikleham et al. (2018), wherein a dispersed and flat cluster distribution of authors was identified. These clusters can also be seen in Figure 8 to Figure 13. Co-authorship mapping between 2015 and 2018 shows the emergence of new networks of co-authorship. However, these new co-author clusters are from the same geographical area, often with the same affiliation. While they are contributing to the CDIO initiative, they do not seem to integrate with the global CDIO community, rather forming local CDIO clusters. Tracking and documenting the key individuals in these network clusters is important because these groups have very real impacts on how other authors will interact with the initiative. Active members often act as "gate-keepers" within their institutions, responsible for a main fraction of a certain university's external CDIO collaboration.
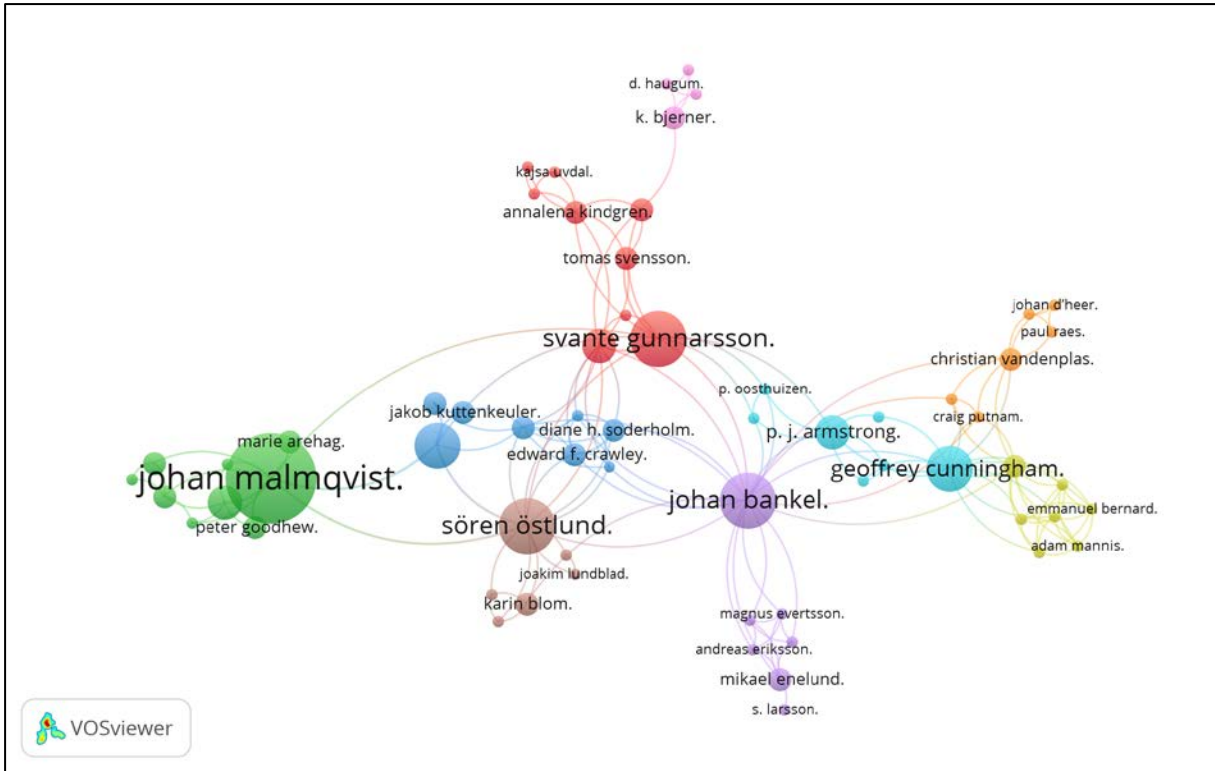
Figure 8. Authors with co-authorship links from 2005 to 2007, 224 authors, 63 relevant authors
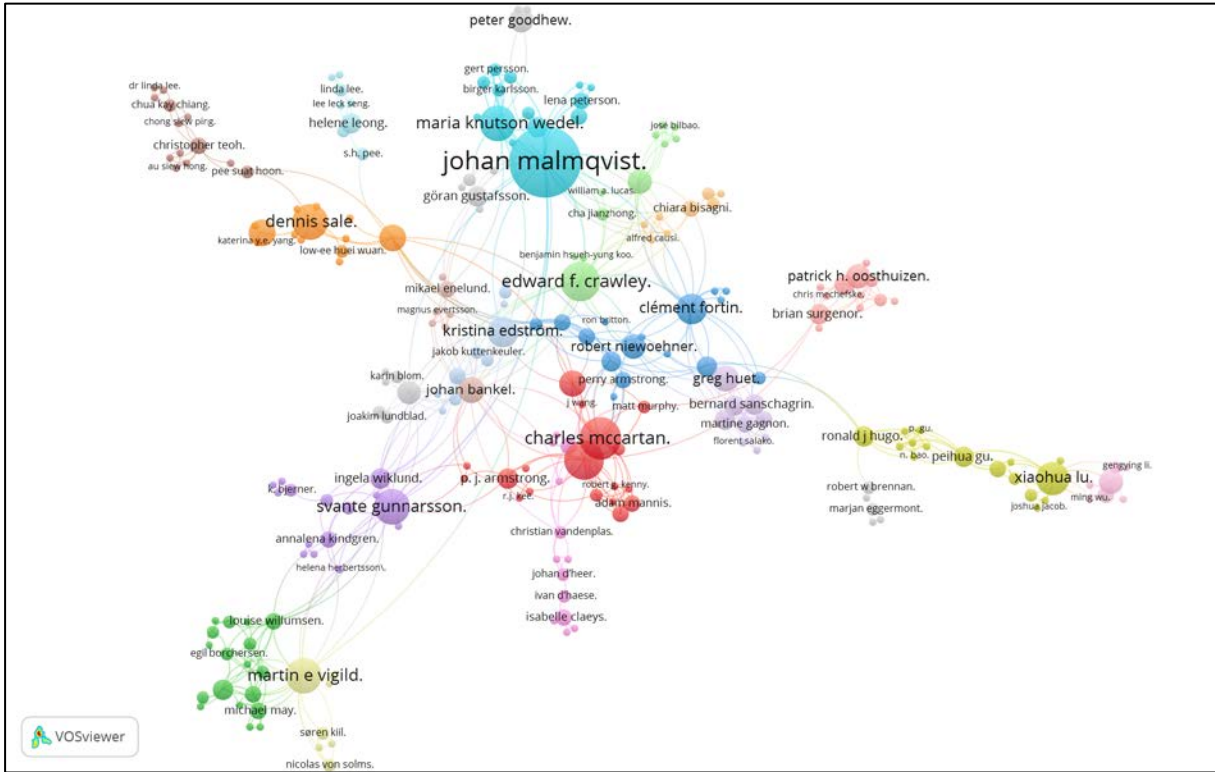
Figure 9. Authors with co-authorship links from 2005 to 2010, 605 authors, 237 relevant authors
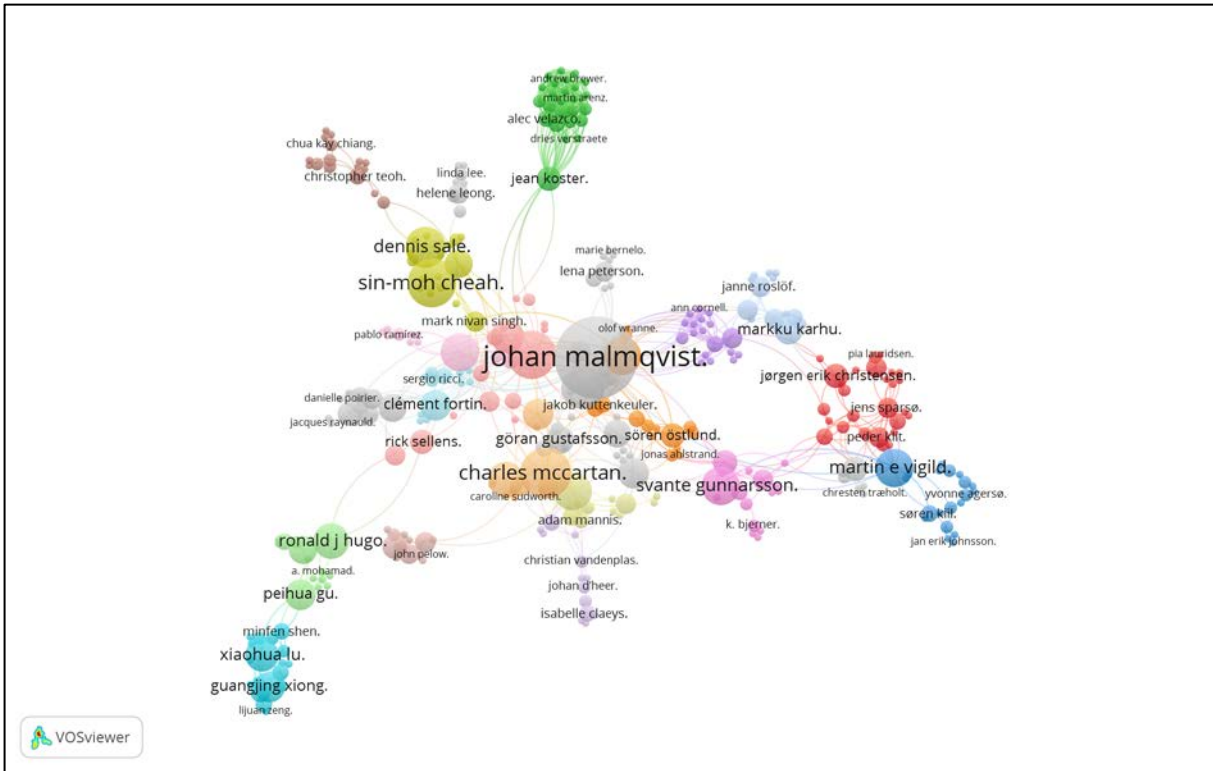
Figure 10. Authors with co-authorship links from 2005 to 2012, 980 authors, 353 relevant authors
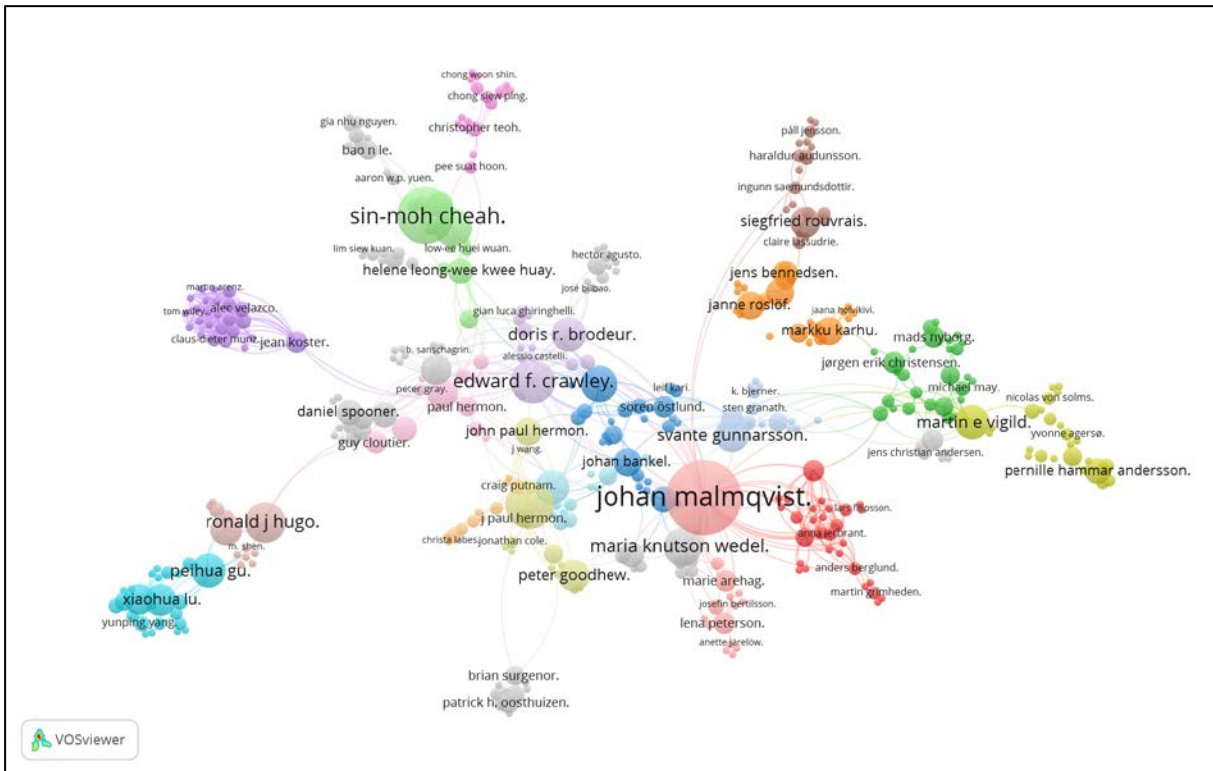
Figure 11. Authors with co-authorship links from 2005 to 2014, 1271 authors, 414 relevant authors
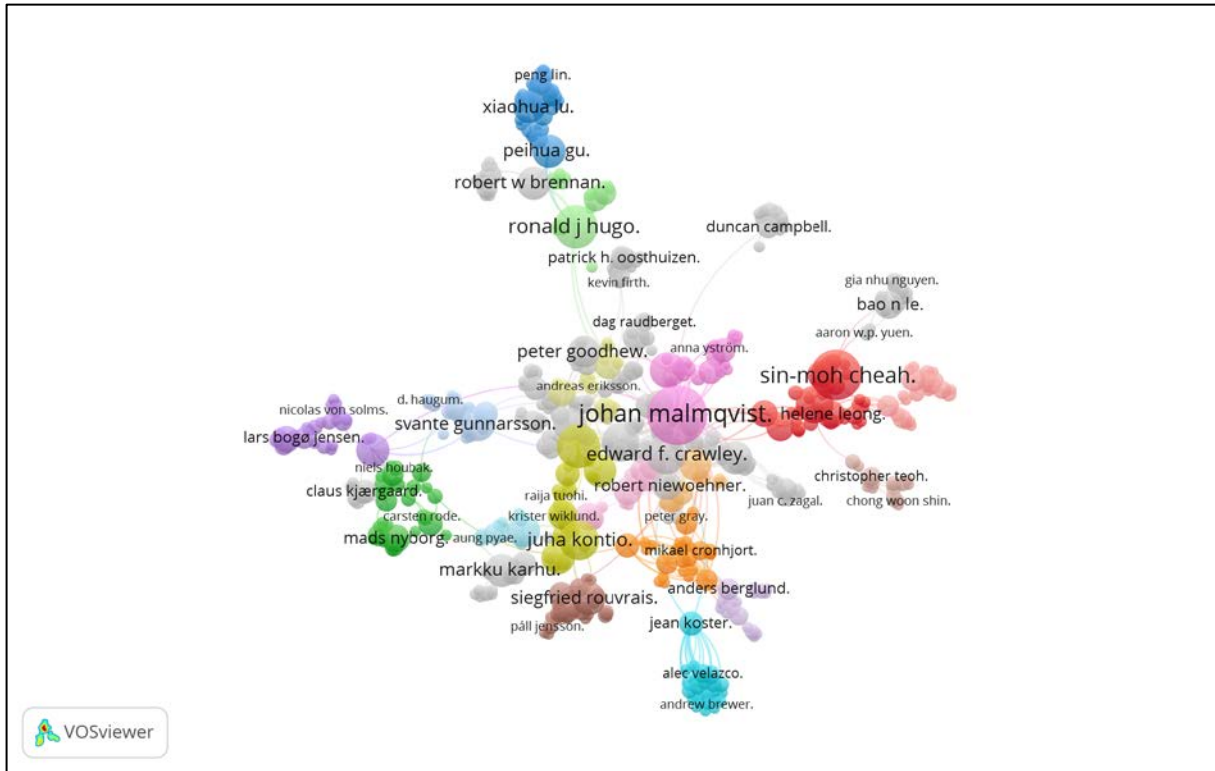
Figure 12. Authors with co-authorship links from 2005 to 2016, 1608 authors, 571 relevant authors
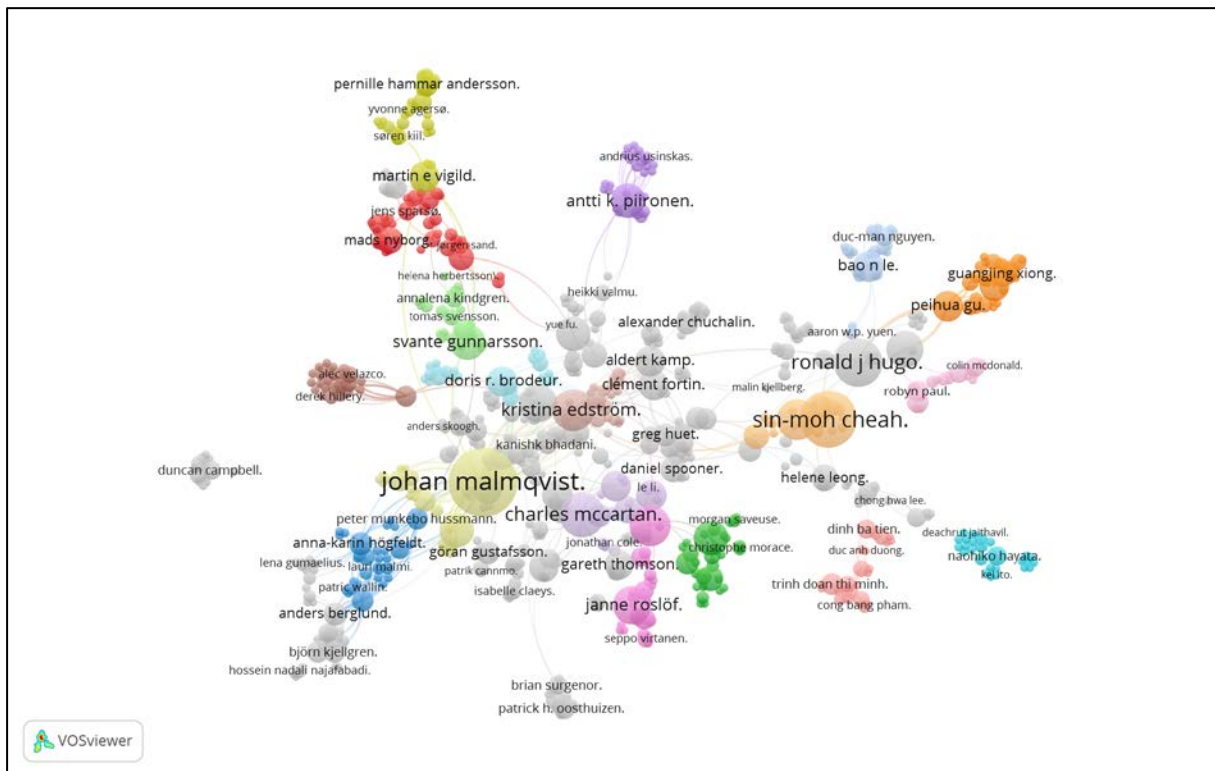
Figure 13. Authors with co-authorship links from 2005 to 2018, 1957 authors, 730 relevant authors
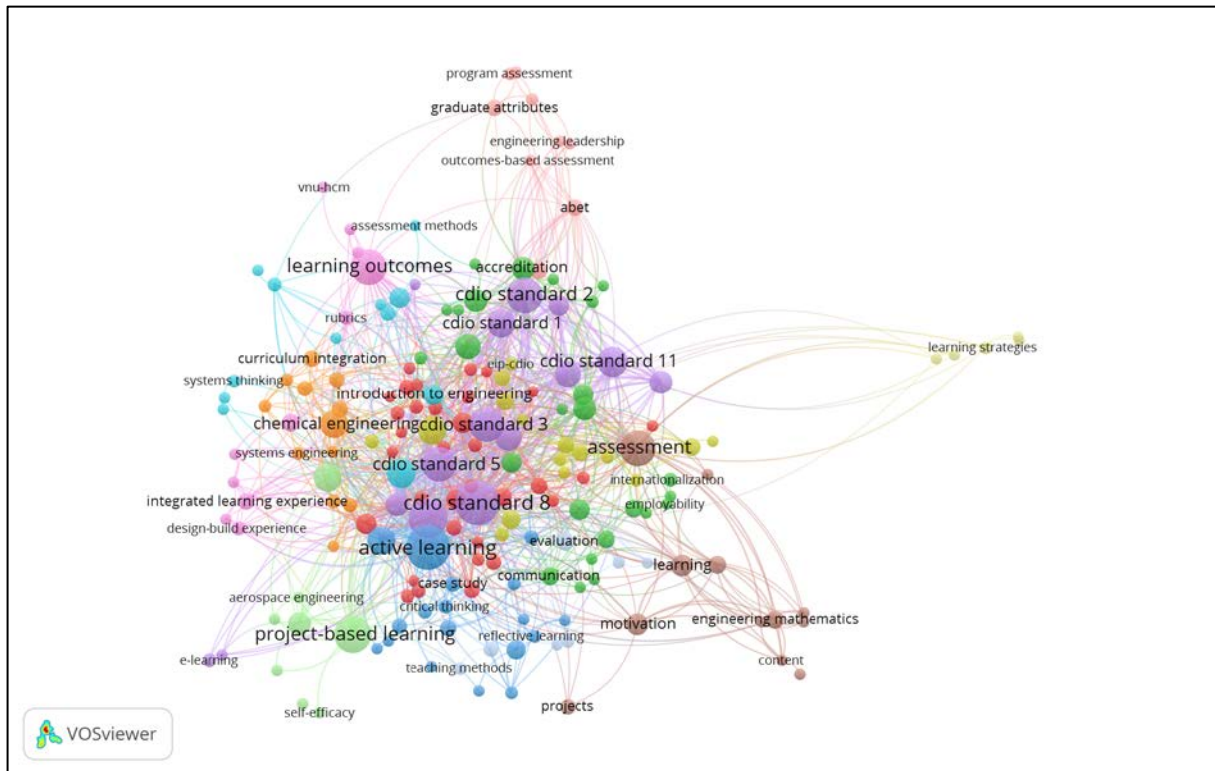
Figure 14. Author specified keyword co-occurrence map from 2005 to 2014

Keyword Analysis

From the year 2014, it was observed that CDIO Standard 8 - Active Learning and CDIO Standard 7 - Integrated Learning Experiences were the most frequently used author-specified standard keywords. Project based learning, active learning, assessment and learning outcomes were the most frequently used keywords by authors. It can be noted that there is a strong connection between Standard 8 and project-based learning. Figure 14 and Figure 15 show the keyword occurrence network before and after the year 2014, respectively. The close density of all the entities also shows that the relationship between keywords is very strong.

Due to the high frequency at which CDIO Standard 8 is used, it almost impossible to generate an image where the other significant keywords are highlighted. Comparing the author specified keywords from 2005 to 2018, the most frequently used keywords are active learning, design projects, and evaluation. These keywords are obtained by removing CDIO, CDIO syllabus, and engineering education from the keyword analysis.

Chemical engineering and civil engineering appear quite frequently in the keyword analysis, which also indicates that much of the active learning and design projects may be focused on fields such as civil or chemical engineering. These fields of engineering also feature in the analysis of Meikleham et al. (2018) as well as the ranking survey by Malmqvist et al. (2015). While chemical engineering and civil engineering rank far behind mechanical engineering as shown by Malmqvist et al. (2015), the keyword analysis from 2005 to 2018 shows that chemical engineering is followed by civil engineering and then mechanical engineering as the most used keywords for an engineering discipline.
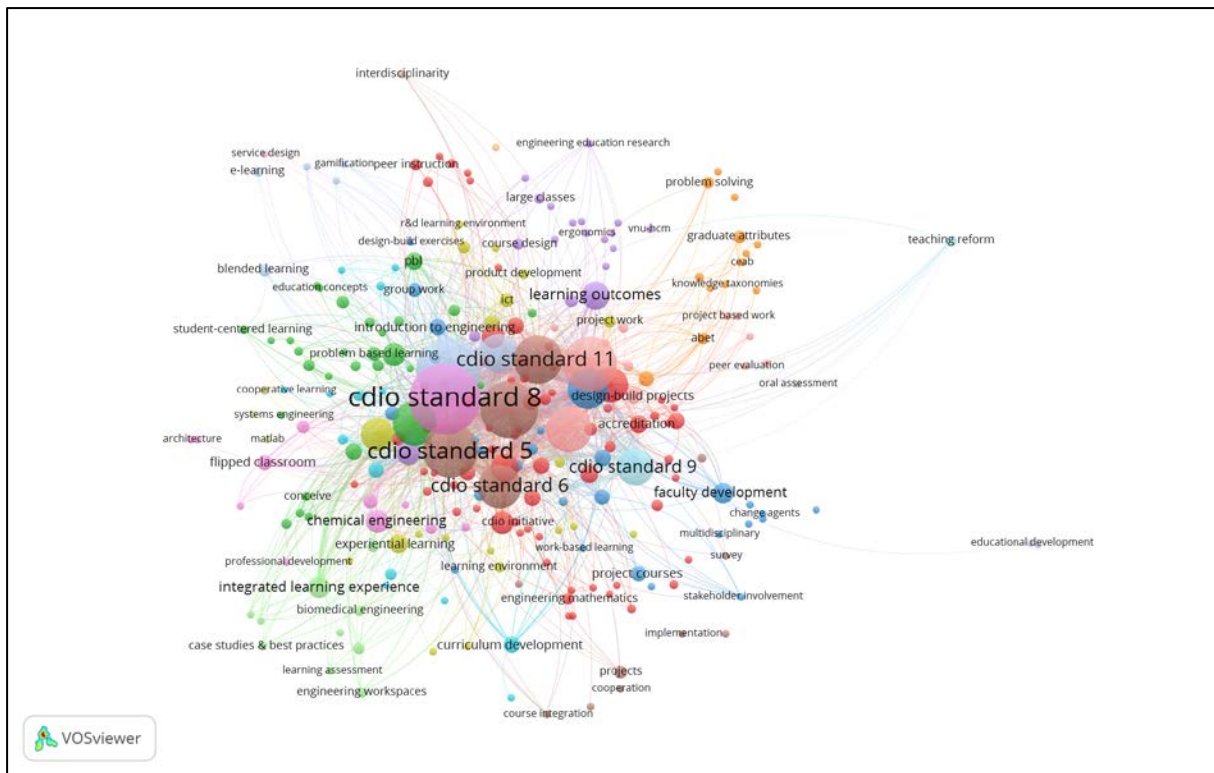
Figure 15. Author specified keyword co-occurrence map from 2005 to 2018

A possible explanation is that authors that have applied CDIO to mechanical engineering have considered this to be the default, whereas authors active in civil or chemical engineering have had a motive to mark their discipline in their keywords in order to make the paper stand out. This may indicate an area of opportunity for adding clearer instructions or constraints for authors when having them self-report data upon submission of their CDIO papers. Being aware of the differences in user reporting tendencies will be important if CDIO plans to leverage data more heavily in the future.

According to Figure 14, the CDIO standards that are most prominent are Standard 8 - Active learning, Standard 7 - Integrated learning experiences, Standard 3 - Integrated curriculum and Standard 5 - Design-implement experiences. Comparing these standards to the period from 2005 to 2014, it can be concluded that the focus of the CDIO initiative has largely remained unchanged throughout the years. Many of the findings of keyword usage by Meikleham et al. (2018) are consistent with the findings from the keyword analysis of the CDIO Knowledge Library. For example, literature efforts within CDIO concentrate on teaching, student learning and teaching assessment. Learning outcomes has been used frequently throughout the years.

The year 2018 saw a peak in the number of participating authors as well as countries. Projects and experience for students were the main keywords extracted from the title field with at least three occurrences of the same keyword for the year 2018. The main author keywords were CDIO Standard 8, Standard 7 and Standard 3. There is a risk of diluting the uniqueness of the CDIO initiative if the perceived focus begins shifting solely towards project-based learning (Meikleham et al., 2018).

The author keywords and title-based keywords are almost the same for 2016, 2017, and 2018. It will be interesting to analyze the proceedings of the 2019 conference to examine if the CDIO

initiative is following a trend of similar publications that have been evident since 2016. Since the CDIO Knowledge Library is comprised of over 1000 archived papers, the co-authorship networks and keyword networks created in VOSViewer are huge. Thus, the images generated from VOSViewer shown from Figure 2 to Figure 15 are only indicative of the entities that appear on the screen. Certain significant entities may get hidden under the bibliometric network cloud generated by VOSViewer. For example, in the co-authorship links based on authors, certain significant authors/entities who have a huge number of contributions to the CDIO Knowledge Library may be missing in the images shown from Figure 8 to Figure 13. However, these entities can be viewed by zooming in on the bibliometric network cloud in VOSViewer. Additionally, since these entities are separated into clusters, the exact visualization of the clusters can only be gained by zooming in on the cluster within the bibliometric cloud. Thus, certain results have been reported based on such individual visualizations within VOSViewer, with only the most relevant images being used in this paper.

CONCLUSIONS

The CDIO initiative has grown and influenced many educational institutions around the world. As of 2018, 47 countries have been part of the CDIO initiative, with 2018 witnessing the maximum number of conference papers in the annual conference. However, the number of publications per year have been relatively constant in the period after the initial peak of 2011. Sweden has been the major contributor to the CDIO initiative with the maximum number of publications and has strong collaborations with various countries. Denmark and Singapore are the second biggest contributors to the CDIO initiative followed by Canada, Finland and China. While China has made significant contributions to the CDIO initiative, there has been reduced participation by China after the 2015 CDIO conference in China. Similarly, the Japanese contribution to the CDIO initiative peaked during the 2018 CDIO conference in Japan, coinciding with the CDIO conference being held in Japan. Thus, the geographical location of the CDIO conference has a great influence on the contributions to the CDIO Knowledge Library. Since 2015 there has also been the emergence of newer author networks who collaborate locally. This suggests the presence of local communities, which have not become fully integrated with the global CDIO community. The exact reason for the lack of global collaboration is unclear, however it was hypothesized that this finding reflects geographic differences in research agendas. This finding requires further investigation and could be investigated by future authors by conducting a thematic analysis of these geographic clusters and verifying whether the themes are convergent or divergent.

The CDIO Standards 8, 7, 3 and 5 are the most frequently cited in CDIO conference paper keywords, implying a strong focus on project-based learning.

The CDIO paper data available in the CDIO Knowledge Library is to some degree different from the Scopus and Web of Science data analyzed by Meikleham et al. (2018) and in this paper. One major difference is that Chinese and American authors are increasingly publishing their CDIO papers in Scopus-registered journals.

The findings from this analysis along with the findings of the analysis by Meikleham et al. (2018) can be used to identify areas of improvement for the CDIO initiative as well as in higher education. While this paper demonstrates how historical publication trends have changed over time within the CDIO community it has also provided insight into the potential to leverage existing internal data to provide leadership with insights that can support strategic decision-making for the initiative. While the analysis of this library data has provided valuable insights

that can be used to influence decision-making, it also demonstrates that there may be an opportunity to crowdsource new data points via the publication process which could allow the CDIO initiative to synthesize unique global community insights that were previously not possible. With the world moving towards globalization and sustainability, it is becoming necessary to collaborate with different countries around the world. The growth of the CDIO initiative around the world is testament to the outreach and the potential that the initiative has to transform higher education for a beneficial future.

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GENDER DIFFERENCES IN STUDENT SATISFACTION SURVEYS

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ABSTRACT

Engineering programs around the world strive to increase gender balance among their students and endeavor to encourage higher female enrollment. This paper aims to investigate and understand how current engineering students perceive their courses in terms of sufficient prior knowledge and overall general impression and if there are statistically significant differences among male and female students. The discussion on possible reasons for trends in responses will assist in taking actions to accommodate both genders.The study is carried out at the Chalmers University of Technology and focuses on courses in its Mechanical, Automation, and Industrial Design Engineering programs. This study is a continuation of previous work on variations of student satisfaction between CDIO project courses and "traditional" courses (Malmqvist et al. 2018) with the addition of an analysis of gender aspects. The present study will use the same methodology, namely a mixed methods approach and investigate both closed-form questionnaire responses and free text answers in course surveys. Quantitative methods for comparing means of survey questions and qualitative analyses of free text answers for selected courses are chosen to shed light on patterns of different gender's perceptions. Aspects of different course characteristics such as traditional, lecture-based vs. project-based and theoretical vs. applied are considered.The results demonstrate that statistically significant differences exist in how male and female students perceive some of their courses and how involved they are in answering course surveys, with this difference being more substantial at bachelor's level than at master's level. Possible reasons on why those differences exist and what measures, if any, should be taken to close the gap are discussed.

KEYWORDS

Student Satisfaction, Gender Studies, Standards: 4, 5, 10, 12

INTRODUCTION

Female student underrepresentation in engineering related programs constitutes an issue for universities and policy-makers, who try to achieve a higher balance between male and female students. Marginson, Tytler, Freeman, and Roberts (2013) identify in their report the benefits of increased participation and retention of females in the STEM (science technology, engineering and, math) field with their main point being the increased economic growth and competitiveness noticed when the gender gap is decreased. Based on a UNESCO (2018) working paper, the number of female students in the engineering, manufacturing and construction field was 27% on a global average with a study by Stoet and Geary (2018) arguing that the gap of female's engagement rises in countries with high gender equality, the so-called educational-gender-equality paradox. There have been several studies focusing on understanding why those trends emerge in engineering education (Hill, Corbett, & St. Rose, 2010; Marra, Rodgers, Shen, & Bogue, 2009) and providing suggestions towards more gender-balanced engineering programs. Suggestions include for example how to make engineering more attractive to high school female students (Milgram, 2011) or to understand the different experiences between currently enrolled male and female students in engineering programs and act upon them (Hassan, Bagilhole, & Dainty, 2012).

At Chalmers, the percentage of male students in 2017 was 61% whereas the female students constituted 39% of the student body. However, when specific programs are considered there are significant fluctuations with the highest percentage of female students being observed in the Industrial Engineering Design (61%) and the lowest in the Marine Engineering (8%). Chalmers's general policy aims to smoothen those trends and increase gender balance among students across all its programs. In our context, gender balance is defined as the representation of either female or male students in any study program not falling below 40 %. To facilitate and showcase the importance of this effort all statistical information provided by the central management is gender divided. Since the overall aim is to attract an equal number of male and female students, an essential step from Chalmers' perspective is also to assure gender inclusive programs by redesigning courses or programs where gender bias is identified (Mills, Ayre, & Gill, 2010).

In our study, we take the first steps towards understanding why those trends occur by investigating how male and female students perceive their education and if there are significant differences between them in different types of courses. Our approach is to explore if and to what extent student satisfaction surveys after each course can be of assistance to identify and explain those gender trends. This paper aims to:

- Compare course evaluations to identify if there are significant differences between the responses of male and female students. The courses are categorized based on their level (Bachelor or Master), their approach (traditional, lecture-based or CDIO, project-based), and the program they belong to. The sample of courses is from Mechanical, Automation and Industrial Design Engineering programs at Chalmers.

- Provide an in-depth study of selected courses that presented significant differences in the responses of male and female students.

We first outline the research methodology applied in the paper followed by the results chapter which contains a quantitative section based on data from the course evaluation questionnaires and a qualitative section based on case studies of the selected courses. A discussion and conclusions chapter complete the paper.

RESEARCH METHODOLOGY

The study is based on courses from Chalmers' programs in mechanical (ME), automation (AE) and industrial design engineering (IDE). Chalmers offers 3-year Bachelor of Science and 2-year Master of Science programs in these disciplines, including 5-year Master of Science in Engineering programs delivered in a 3+2-year format.

The data for the study was collected from Chalmers' course evaluation system. The questionnaires in Chalmers' system are based on 11 common questions. The common questions are chosen to reflect a constructive alignment view (Biggs & Tang, 2007) on education, *i.e.,* emphasizing learning outcomes, delivery of teaching and assessment, and to support cross-university quality enhancement. Seven of the common question are quantified on a scale of 1 to 5, reflecting very poor to excellent, disagree completely to agree completely, or similar. Four of the standard questions are free text, such as "*Is there anything that should be changed for the next round of this course, and if so: How?*" The students can also comment on the quantified questions. The responsible teacher and the students can also agree on adding additional questions for a specific course. The results of the questionnaires were subsequently divided by student's biological sex, which is automatically tagged to each survey response through our student database.

In our analysis, we used Independent Samples t-tests to compare the average values of students' responses to perceived/self-assessed prior knowledge and overall impression of the course. The tests were performed to identify if there are significant differences between male and female students and within male and female groups of students when the type or level of the courses changes. Each test produces a p-value, which indicates the probability that the difference is random (Student, 1908). The standardized significance thresholds of 5%, 1%, and 0.1% were used. The aim was to identify general patterns in the data, and together with descriptive statistics graphs, to depict differences in the survey responses between male and female students. These enabled us to select a subset of courses for a more in-depth analysis, where we also considered free text data. Independent t-tests and descriptive statistics were our first statistical approaches to analyze our problem, and more elaborate methods should be used as a subsequent step.

The exact phrasing in the questionnaire for the two questions we chose to analyze was for the question on perceived/self-assessed prior knowledge "*I had enough prior knowledge to be able to follow the course*" and for students' overall impression of the course "*What is your overall impression of the course.*" Prior knowledge was chosen as it can affect students' learning, satisfaction with the course as well as the teaching, while it can also be a point of action. The overall impression is a measure of the student satisfaction which is an important quality indicator of course quality, including teaching, structure, and learning, and useful feedback to the teaching staff and the department.

RESULTS

This section includes the results of the study. First, the quantitative results from the Independent t-tests are presented and discussed, followed by a more in-depth analysis of six courses where significant differences between male and female students were identified.

Quantitative results

Table 1 describes the study programs which were included in the analysis, whether they were at Bachelor or Master level, the number of courses considered from each program, and the share of female students in each program. Courses with six or fewer responses from either male or female students were excluded in order to increase data validity. In total three

Bachelor and nine Master programs were examined, and the data contained courses from the academic years 2015/2016 through 2017/2018.

Table 1. Programs at Chalmers considered in the analysis.

Code	Program	Level	Courses	Female Students (%)
TKMAS	Mechanical Engineering	BSc	30	25,6
TKDES	Industrial Design Engineering	BSc	22	59,8
TKAUT	Automation and Mechatronics	BSc	22	15,7
MPTSE	Industrial Ecology	MSc	11	73,5
MPSYS	Systems Engineering	MSc	10	14,5
MPSES	Sustainable Energy Systems	MSc	9	28,8
MPPEN	Production Development	MSc	13	18,9
MPPDE	Product Development	MSc	7	20,4
MPDES	Industrial Design Engineering	MSc	9	55,7
MPAUT	Automotive Engineering	MSc	2	5,7
MPAME	Applied Mechanics	MSc	12	15,4
MPAEM	Materials Engineering	MSc	5	20,7
		Total	152	

Table 2 includes the results for the Independent Samples t-tests regarding students' perception on course pre-knowledge and overall impression of the course when the courses were grouped into different categories, see the first column. The analysis of the Master level programs was omitted since the entries were insufficient to obtain accurate results. The N number refers to the total number of course entries for each gender for three academic years (2015/2016 to 2017/2018) which have at least six responses from both male and female students (out of 456 possible for 152 courses and three years) and fulfill the criterion in the 1st column.

Table 2. Independent t-tests for responses for academic years 2015/2016 to 2017/2018 ($*p=<0.05$, $**p=<0.01$, $***p=<0.001$).

	Perception on course pre-knowledge					Overall impression of the course				
	Male		Female			Male		Female		
	Avg	SD	Avg	SD	t-test p-value	Avg	SD	Avg	SD	t-test p-value
All programs (N=338)	4.33	0.36	4.25	0.49	t=2.463 **p=0.014***	3.87	0.62	3.77	0.68	t=2.033 **p=0.042***
Bachelor Level (N=184)	4.35	0.36	4.19	0.53	t=3.427 **p=0.001*****	3.82	0.69	3.69	0.73	t=1.698 p=0.900
Master Level (N=154)	4.31	0.36	4.32	0.43	t=-0.33 p=0.741	3.94	0.52	3.86	0.62	t=1.141 p=0.255
CDIO courses (N=28)	4.36	0.46	4.36	0.62	t=0.034 p=0.973	3.73	0.59	3.48	0.75	t=1.418 p=0.162
Mechanical Engineering (N=84)	4.33	0.32	4.18	0.54	t=2.18 **p=0.031***	3.82	0.60	3.67	0.68	t=1.490 p=0.138
Industrial Design Engineering (N=60)	4.41	0.34	4.29	0.41	t=1.790 p=0.076	3.83	0.70	3.71	0.69	t=0.910 p=0.365
Automation and Mechatronics (N=40)	4.33	0.46	4.08	0.65	t=1.973 p=0.052	3.81	0.87	3.71	0.88	t=0.493 p=0.623

From Table 2 we observe that the female students have a slight tendency to rate the overall impression on average 0.1 points lower compared to the male students, significant at the 5% level. However, when we break down the analysis into different groups, for instance on BSc and MSc level and program level, we do no longer distinguish a significant difference. Furthermore, we observe that female students on the BSc level rate their prior knowledge 0.16 points less compared to the male students. This finding is significant at the 0.1% level. At the MSc level, we instead observe that male and female students report similar results. When we conducted similar tests for the courses within specific BSc programs, the differences on the average responses for both the questions posed were not significant except for the Mechanical engineering program where female students on average rated their prior knowledge 0.15 points less than male students.

Table 3 describes the results for the Independent Samples t-test regarding students' perception of their prior knowledge and the overall impression of the course for male and female students separately, broken down on BSc and MSc levels.

Table 3. Independent t-tests including all the courses in the study for academic years 2015/2016 to 2017/2018
(for BSc N=184 and for MSc courses N=154, (*p=<0.05, **p=<0.01, ***p=<0.001)).

	Perception on course pre-knowledge					Overall impression of the course				
	Bachelor		Master			Bachelor		Master		
	Avg	SD	Avg	SD	t-test p-value	Avg	SD	Avg	SD	t-test p-value
Male	4.35	0.36	4.3	0.35	t=1.327 p=0.185	3.82	0.69	3.94	0.52	t=-1.8 p=0.073
Female	4.19	0.53	4.3	0.43	t =-2.348, **p=0.019***	3.69	0.72	3.86	0.61	t=-2.3, **p=0.022***

From Table 3 we observe that for male students there is no significant difference in the prior knowledge perception or the overall impression between the BSc and the MSc levels. However, we can observe that there are significant differences in female students. Female students on MSc level rate their prior knowledge on average 0.11 points higher than they do on BSc level. They also rate their overall impression of the course on average 0.17 points higher on the MSc level compared to the BSc level. In both cases, the level of significance is at the 5% level.

Table 4 describes the results for the Independent Samples t-test regarding students' perception on their prior knowledge and overall impression of the course for male and female students separately, when they rate traditional (lecture-based courses) and CDIO (project-based) courses.

Table 4. Independent t-tests including all the courses in the study for academic years 2015/2016 to 2017/2018 (for traditional courses N=310 and for CDIO courses N=28, (*p=<0.05, **p=<0.01, ***p=<0.001)).

	Perception on course pre-knowledge					Overall impression of the course				
	Traditional		CDIO			Traditional		CDIO		
	Avg	SD	Avg	SD	t-test p-value	Avg	SD	Avg	SD	t-test p-value
Male	4.33	0.35	4.36	0.46	t=-0.46 p= 0.645	3.88	0.62	3.73	0.58	t=1.24 p=0.216
Female	4.24	0.48	4.3	0.62	t=-1.198 p=0.232	3.8	0.67	3.48	0.75	t=2.387, **p=0.018***

From Table 4 we notice that for male students there is no significant difference in the prior knowledge perception or the overall impression between traditional lecture-based and CDIO project-based courses. However, for female students, there is a significant difference where they rate CDIO courses on average 0.32 points lower compared to traditional courses.

Case studies

Here we discuss in more detail some selected courses in which gender aspects are believed or found to be important. The courses range from basic and intermediate (BSc) level courses in programming, basic courses in Applied Mechatronics and Logistics to advanced (MSc) level courses in Productions systems and Finite Elements. The courses considered together with certain basic facts are given in Table 5.

Table 5. Description of courses in case studies for academic years 2015/2016 to 2017/2018.

Course Name	Program	Level	Type	Applied vs. Theoretical	Mandatory vs. Elective	No of answers (Response rate)
Object-oriented programming in Python	Mechanical Engineering	BSc	Elements of blended learning	Applied	Elective	Male=49 (40,6%) Female=24 (58,5%)
Production systems	Production Development	MSc	Traditional with labs, seminars, study visits	Applied	Mandatory	Male=81 (54,7%) Female=25 (69,4%)
Applied mechatronics	Technical Design	BSc	Traditional with labs	Applied	Mandatory	Male=25 (51%) Female=36 (49,3%)
Logistics	Mechanical Engineering	BSc	Blended learning	Applied	Elective	Male=56 (40,6%) Female=37 (59,7%)
Programming in MATLAB	Mechanical Engineering	BSc	Elements of blended learning	Applied	Mandatory	Male=164 (44,8%) Female=75 (60,5%)
Finite element method - structures	Applied Mechanics	MSc	Traditional with computer lab	Theoretical	Elective	Male=49 (43,9%) Female=24 (54,4%)

Table 6 includes the results for the Independent Student t-tests regarding students' perception on course pre-knowledge and overall impression for the specific course between male and female students. Each course is subsequently analyzed individually.

Table 6. Results for the independent t-test for the case studies.
(*p=<0.05, **p=<0.01, ***p=<0.001)

Course Name	Perception on course pre-knowledge					Overall impression of the course				
	Male		Female			Male		Female		
	Avg	*SD*	*Avg*	*SD*	t-test p-value	*Avg*	*SD*	*Avg*	*SD*	t-test p-value
Object-oriented programming in Python	3.82	1.24	2.67	1.52	t=3.452, **p=0.001****	3.65	1.13	3.21	0.96	t=1.638 p=0.106
Production systems	4.31	0.78	4.2	1.06	t=0.564 p=0.574	3.58	1.16	2.88	1.24	t =2.595, **p=0.011***
Applied Mechatronics	4.2	1.06	3.47	1.12	t =2.558, **p=0.013***	4.16	0.73	3.83	0.93	t=1.284 p=0.143
Logistics	4.57	0.90	4.51	0.79	t=0.330 p=0.742	4.18	0.91	3.7	0.98	t =2.415, **p=0.018***
Programing in MATLAB	3.37	1.48	2.57	1.30	t=4.032, **p=0.000*****	3.69	1.05	3.32	0.97	t =2.599, **p=0.01****
Finite element method - structures	3.83	1.10	3.49	1.36	t=1.146 p=0.256	3.97	0.94	3.4	1.07	t=2.921, **p=0.004****

Courses in programming

Several studies support that the female students consider themselves to have less and sometimes also insufficient prior knowledge in programming courses compared to male students, see (Butterfield & Crews, 2003; Rubio, Romero-Zaliz, Mañoso, & de Madrid, 2015). In our study, this is confirmed strongly in both the mandatory first-year introductory level course *Programming in MATLAB* which does not require any prior knowledge in programming, and it is taught at the very beginning of the study program and the elective third-year intermediate level course *Object-oriented programming in Python*, which has basic programming skills is a prerequisite.

A possible explanation of the responses in the *MATLAB* course is that male students, in general, have a higher interest in computer science and are more experienced compared to female students by having done some prior programming. However, in the beginning, and during the course, the teachers note no differences based on gender in students' programming skills. Female students perform just as well as male students and the average grades, as well as the share of students with grade 5 (the highest grade), are the same for both genders. The failure rate on the course is about 12% for both genders which is considered rather good for a first course in an engineering program. Even though female students rate themselves to have less prior knowledge at 0.1% significance level, on average 0.8 points, they perform just as well as the male students who rated themselves to have had sufficient prior knowledge. We also note that female students give a significantly lower general impression at 1% significance level, on average 0.35, on the course compared to the male students.

Considering that female and male students have taken the same courses before with the same results, they should have about the same prior skills in programming when entering the course for programming in Python. However, in the course questionnaire female students again rated their prior knowledge lower than male students at 0.1% significance level, on average 1.58 points. From a statistical point of view, we cannot claim that male students performed better in the course despite this - although the average grade of males is slightly higher than for females, it is not significant. This confirms the overall impression which implies that prior knowledge is rated slightly higher by the male students, although it is not depicted in their results. There are some studies on gender differences in the perception

of introductory courses in programming. Results are somewhat conflicting but in general male students are found to have a broader interest in computers, but it is also shown that female students have the same abilities in programming but less self-confidence (Cheryan & Plaut, 2010; Qian & Lehman, 2016). We argue that our results confirm this picture in that female students perform just as well as males but consider themselves to have considerably less prior knowledge, although teachers in the courses report no differences in prior knowledge.

Logistics course

This basic course in Logistics does not require any specific prior knowledge, which is also confirmed by both female and male students in the questionnaire, see Table 6. Regarding the impact of the course, female students perform better and have higher grades than male students. It is however interesting to note that female students, in general, give the course a lower rating on overall impression and, thus, are in general less satisfied with the course compared to male students. This rating is somewhat surprising since the subject itself is often considered to be more appealing to female students compared to more theoretical math- and physics-based courses. However, in our study based on course questionnaires at Chalmers, we do not observe this difference in female students' overall impression between theoretical and more applied courses.

The Logistics course has during the last three years transformed from being traditionally taught (lectures, exercises, and labs) to a blended learning format with online materials, short lecture film clips, quizzes, and interaction together with face-to-face classes in which lecturing has been replaced by discussing and tutoring. This can lead us to believe that female students are less satisfied with online teaching and blended learning. This trend is somewhat verified by free text comments in the course questionnaire where several female students express doubts about the value of blended learning. One female student expresses it as: *"I personally do not like this set of online lectures. I prefer regular informative lectures. I felt that I would rather prioritize my time on other than going to a discussion session when the lectures are online".* However, research shows no clear results on this. Some studies indicate no differences in students' satisfaction in terms of gender for blended learning while other studies show differences in terms of gender, see (Ekawati, Sugandi, & Kusumastuti, 2017) and references therein.

Finite Element Structures course

The course is an advanced MSc level course in finite elements. The course aims to provide a deeper knowledge and increased understanding of how to apply the finite element method (FEM) on advanced and nonlinear problems in solid and structural mechanics. The course requires prior knowledge in the mathematical background of the finite element method and its application to structural mechanics problems. Female students rate their prior knowledge somewhat lower than the male students, but the difference is not statistically significant. However, the female students perform as well as the male students in that they obtain the same average grade, the same share of grade 5 and about the same share that failed. While considering this, it is interesting to notice that the female students in average give a significantly lower value on the general impression of the course compared to the male students, see Table 6.

Production systems course

Production systems is a mandatory course given as the first course in the Master programme, and its purpose is to assure that all students have a similar level of knowledge when starting the Master programme in Production engineering. Therefore it does not have any specific requirements of prior knowledge (other than the requirements to enter the

Master programme). This is also confirmed in the questionnaire, see Table 6, where we could not find any significant difference between female and male students when answering the question about prior knowledge. It is therefore interesting to note that female students rate the course significantly lower than male students. In terms of performance, the female and male students perform almost the same. The character of this course is that it is a traditional basic course and it has several different guest lecturers. A theory is that female students may prefer more challenging courses.

Applied mechatronics course

The applied mechatronics course is a basic traditional course with lectures and labs given in the second year at the Industrial Design Engineering. In some ways, the program differs from other programs in that the required GPA to enter the program is significantly higher than for other engineering programs, and the female to male ratio is considerably higher with females constituting the majority of students. Just like in the programming courses described above, the female students rate their prior knowledge significantly lower than the male students. However, when it comes to this course, the male students perform better; male students' average grade is 4.0 while the female students' is 3.5. Though, when it comes to rating their overall impression of the course there is no significant difference; The average rating for both genders is around 4.0. One theory is that the male students, for some reason, do have better prior knowledge and that the course does not level out this difference (opposite to the programming courses, described above).

DISCUSSION AND CONCLUDING REMARKS

Our study is based on the analysis of student course satisfaction surveys from academic years 2015/2016 through 2017/2018 including 152 unique courses and, thus 456 courses in total. We also analyze six courses in more detail. Bryant, Mathios, Kang, and Bell (2006) argue that although online evaluation methods have lower response rates, the results do not seem to differ compared to paper-based methods if the sample size is not too low and therefore we included a threshold of a minimum number of responses. The respond rate of the female students in these surveys is much higher compared to the male students' respond rate (see Table 5) although in the majority of the studied programs the percentage of male students is higher (see Table 1). This is in agreement with literature where female students tend to participate in a higher degree compared to male students (Bryant et al., 2006; Thorpe, 2002). However, we could also argue that this trend could also be amplified by the fact that entering engineering program is a more conscious choice by female students since at many occasions they need to justify their choices and consequently they are more interested in the quality of their education than male students. This is somewhat supported by the fact that the drop-out rate in the first year is higher for male students than female students at Chalmers Mechanical Engineering program.

Further, we observe that female students underestimate their prior knowledge in theoretical and, in particular, in programming courses while they perform as well as male students in programming and theoretical, math- and physics-based courses (with the Applied Mechatronics being a single exception). We also observe that female students perform slightly better than male students in general system-oriented courses and CDIO courses. However, it is also noticeable that the female students give those courses a lower general impression compared to more discipline-oriented theoretical courses. For male students, we cannot observe this difference. Moreover, our results indicate that female students are less satisfied with courses using blended learning than traditionally delivered courses while we again cannot observe this difference among male students' preferences. From our study of post-course student satisfaction questionnaires, we cannot discern any critical

circumstances why female students may not choose or may not remain in engineering programs. Potential circumstances that lead to this situation could be examiners who are not always equipped to manage gender diversity in their courses creating possible gender bias (as discussed by Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012), the lack of female role models and female teachers that are missed in the classroom as well as in the educational materials and gender stereotypes (see also Wang & Degol, 2017). However, what is evident in our study is a constant trend wherein almost all tests the average responses of female students are lower compared to the male students even when differences are non-significant.

Based on these results a couple of points emerged for further investigation. The first point is the perceived prior knowledge of the female students at Bachelor level and how it can become equal to the male students, especially since their performance is similar and this difference does not further exist at Master level. A first step can be that low rated courses in the pre-knowledge scale may develop a rubric to detect gender differences early in the course and provide the necessary support. The second point is the overall impression of the project-based CDIO courses. The reasons for this high difference should be investigated while considering among others the team formation and the role of the female students in their team.

From this study considering three "mechanical" programs and more than 150 courses, we conclude that female students perform as well or better compared to male students and that we need to act to convey this fact to the public to increase the female applicants to engineering programs. We also need to take measures to make current male and female students understand that there is no difference in abilities and skills between genders. However, McLoughlin (2005) argues that interventions to increase female comfort in engineering fields should avoid putting the female students on the spotlight and that should be considered in our planning. Finally, Stoet and Geary (2018) support that increased female engagement in STEM fields requires a multifaceted approach that considers a person's competencies across different areas and presents the career value of the field compared to the others. Our results are limited to Chalmers where the surveys took place, and there might be bias since the female students considered are the ones that are already enrolled in the engineering programs. However, we argue that they can provide insights into other engineering programs that aim for gender-balanced education.

ACKNOWLEDGMENTS

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HELPING STUDENTS TRANSITION FROM GROUP WORK TO INDIVIDUAL PROJECTS

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ABSTRACT

Previous research conducted at Aston University revealed that students found it difficult to transition from a group, CDIO-based projects in earlier study years to working independently on their individual final year projects (FYPs). The aim of this study was to explore whether the required skills that we try to develop through group CDIO projects can be sufficiently recognised by students and whether their confidence levels match staff perceptions regarding those skills. Over two academic years, students in their final year of study across our Mechanical Engineering degree programmes completed questionnaires at the start (QNR1, n=109) and end (QNR2, n=74) of their year in order to obtain their confidence levels in skills related to the CDIO standards. Students were also evaluated on skills by their academic project advisors at the end of their FYPs (n=84). The results show that in almost all cases, students were more confident in their own abilities than staff perceived their abilities to be. The greatest differences were found in 'Leadership' (50 % difference) and 'Critical Thinking' (41 % difference). Results from QNR2 (2016/17 and 2017/18) showed a reduction in confidence levels by the students, indicating that their self-evaluation of skills had reduced following individual FYPs. This academic year we have attempted to prepare students more for the challenge of the final year and bring their expectations and preparations more into line with the academics' perspectives. The results show that student confidence levels were lower this year in QNR1, reflecting what may be a more realistic outlook on their abilities. We also explored what other factors affect student confidence and abilities, including their active use of the CDIO process. We conclude that students find it difficult to transfer skills to their FYP and that staff intervention can bring their expectations and confidence to a more realistic level, and assist the transition.

KEYWORDS

Skills development, Project-based-learning, Problem-based-learning, Mechanical Engineering, Standards: 1, 2, 3, 5, 7, 8, 10, 12.

INTRODUCTION

Students in Mechanical Engineering and Design at Aston University have a unique learning and teaching environment, where the CDIO philosophy is discussed, and the acronym employed, by staff and students from week 1 of study. The Conceive-Design-Implement-Operate process is put into place for students to work through in a series of mini exercises that build into four major project modules over the first two years of study. Then, in the final year of study, students work individually on their own projects, named Final Year Projects (FYPs), with an academic advisor to help guide them.

Independent learning and students' abilities in this skill has been debated in the UK higher education sector and beyond (Hockings, Thomas, Ottaway, & Jones, 2018). Research has shown that students struggle with the transition from School to University, particularly in terms of their ability to learn independently (Thomas, Hockings, Ottaway, & Jones, 2015) and they have high expectations of the levels of academic support in their learning (Lai, Yeung, & Hu, 2016). Previous work at Aston identified that students struggled with the transition from group projects to their individual FYPs, feeling ill-prepared (Leslie, Gorman, & Junaid, 2018). Confidence levels dropped during the final year and students felt that although their FYP was their responsibility, they relied on their advisor throughout the project phases.

The aim of this research was to determine how students rate their abilities, how this may differ from the staff perspective and to identify key factors related to skills confidence. This was achieved through the following objectives:
- Asking students to rate their confidence in a range of CDIO related skills
- Asking staff to rate their students in those skills
- Comparing the staff-student confidence
- Identifying key skills/attributes which were linked to performance
- Equipping students with the mindset and realistic approach to independent work

METHODOLOGY

Over the academic years if 2016/17, 2017/18 and 2018/19, two questionnaires, QNR1 (n=109) and QNR2 (n=74) were completed by three cohorts of students. QNR1 was delivered at the beginning of the students' final year of study, and QNR2 towards the end of the academic year. These QNRs coincided with the students embarking on their individual FYPs and after submission of the FYP dissertation.

The QNRs were designed using a combination of multiple-choice 5-point Likert scale statements and open-ended questions, allowing the student participants the opportunity to provide qualitative comments that go beyond the scope of the questions. Questions and topics for the QNRs are shown below. Topics and skills were collated based on an analysis of the CDIO Standards (The CDIO Initiative, 2010). Also collected were data around student identity including gender and future plans, as well as FYP grades and final degree classification where possible. The following statements were included in the QNR as the key skills to measure in terms of their confidence levels:

- Type of planner (Always plan, Try to Plan, Always Run Behind)
- Use of logbook
- Time on FYP (Planned and Actual)
- Frequency of meetings with FYP academic advisor (Planned and Actual)

- Responsibility and Input from academic advisor
- Logbook use
- Target grade and confidence in achieving
- Use of CDIO process
- Confidence in skills
    - Knowledge discovery
    - Engineering reasoning
    - Apply engineering science in design-implement projects
    - Consider technology during product development
    - Professional ethics
    - Self-awareness of knowledge and skills
    - Problem-solving
    - Scientific thinking
    - System thinking
    - Creative thinking
    - Critical thinking
    - Work to professional standards in an organisation
    - Teamwork
    - Communication
    - Communication in foreign languages
    - Leadership
    - Project management
    - Develop conceptual plans
    - Develop technical plans
    - Develop business plans
    - Consider wider concepts during a project (e.g. enterprise, business and society)
    - Define customer needs
    - Consider regulations during product development
    - Create designs, i.e. plans, drawings, and algorithms
    - Transform a design into a product, process, or system

Focus groups with small numbers of students in each cohort were also conducted after submission of QNR2 by a member of non-teaching staff whom the students could speak freely with.

Statistical analysis was performed with Excel (Microsoft Ltd.) using Mann Whitney test and SPSS (IBM Ltd.).

Ethical approval was gained from the local ethics committee at Aston University.

RESULTS AND DISCUSSION

Students Confidence in Skills

Students' confidence levels in a variety of skills were self-assessed via QNRs, with the results showing a variety of confidence levels across the skillset. In the first two years of this study (2016/17 and 2017/18 respectively), confidence levels fell or stayed the same for 14 out of 25 skills during between QNR1 and QNR2, as shown in Figure 1. Most notably confidence fell for 'Project Management' (19 %) and 'Professional ethics' (10 %). Also, the students' confidence in achieving their desired grade fell between QNR1 and QNR2 (Figure 2). The data that

indicated this fall in confidence was reinforced by the findings of the student focus groups, with student discussion frequently indicating a perceived academic step change from heavily supported group work in years 1 and 2 to their individual FYPs. Overall, many of the students indicated that they found themselves ill-prepared for this independent working style.

However, students increased in confidence overall for 11 of the 25 skills, with most notable increases in 'Scientific Thinking' (20 %) and 'Consider Regulations' (14 %). It is argued that the skills that were most used during their FYPs may have improved their confidence. It is also contended that the added effect of time lapse between skills actually being used could also have impacted on confidence. This could explain why there was a drop in confidence regarding 'Teamwork' due to a lack of team-focused projects in the final year, despite their CDIO experiences in the first two years of study. Research by Ericsson et al. highlighted the need for what he calls 'Deliberate Practice' to build expertise, which includes the importance of regular and focused practice (Ericsson et al. 1993; Nandagopal & Ericsson 2012). This may go some way to explain why confidence levels varied across the skills. Further analysis of individual responses may help, however, it is beyond the scope of this study. Furthermore, despite the differences observed, they were not statistically significant and therefore would require further qualitative analysis.
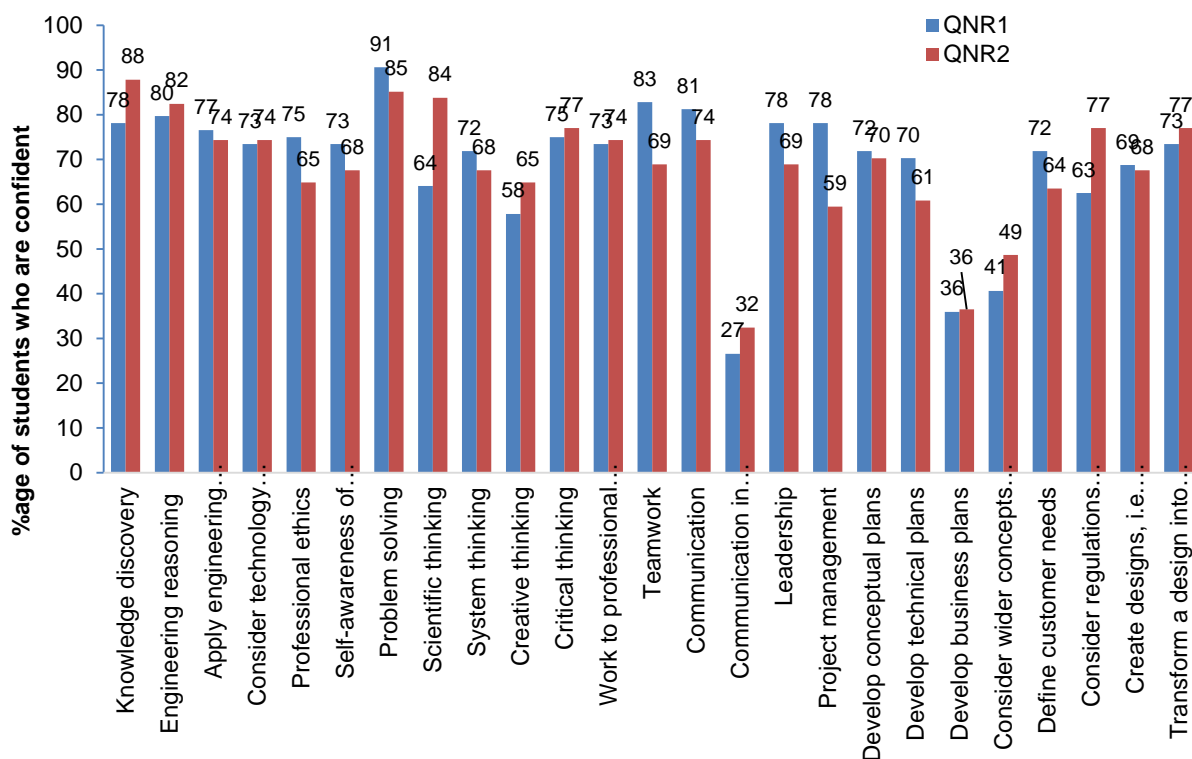

Figure 1. A graphical representation of the percentage of students with confidence in each skill listed in both QNR1 and QNR2 (data from 2016/17 and 2017/18).
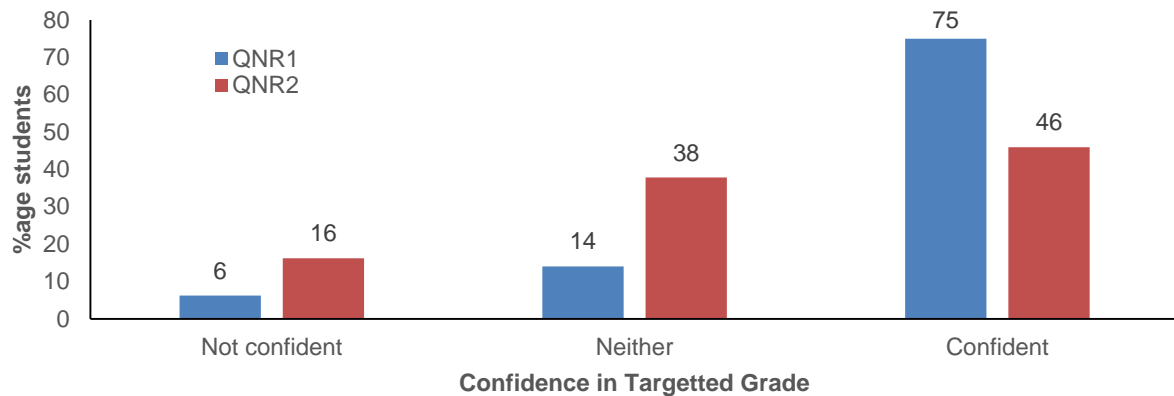
Figure 2. Student confidence in achieving target grade. Results from QNR1 and QNR2. Results show students have less confidence at the end of their FYP than at the beginning.

Staff Confidence in Skills – A Comparison Study

Comparing the confidence levels from the students' answers to the academic advisor's perceptions showed significantly contrasting data ($p < 0.05$), with staff predominantly showing less confidence in students' abilities (Table 1) in the majority of skills listed. The greatest differences between student and staff confidence levels were found in 'Leadership' at -50 %, 'Critical Thinking' at -41 % and 'Problem Solving' at -36 %. Whilst these are only perceptions of skill levels, it was interesting to observe the differences between staff and student evaluations. These findings, combined with data from our focus groups, provided additional evidence to support the theory that students were often not prepared for the level of skills required for their FYPs. However, it may also be possible that the supervisors may place higher expectations than should be expected for engineering students.

There is a growing body of work that explores the interplay between confidence and competence. Noel Burch's Conscious Competence Ladder (Burch, 1970) identifies four stages of competence: unconsciously unskilled (being unaware of what you don't know), consciously unskilled, consciously skilled and unconsciously skilled (being unaware you have a skill). Using this model to explain the results of this study, two theories emerge. The first: it is possible that more students transition from an unawareness of their skills to an awareness of their skills level, which impacts on their confidence levels (Figure 1). An additional theory is that the supervisors themselves may be unconsciously competent and may, therefore, be unaware of the learning journey needed to acquire some of the skills listed. It is perhaps difficult for a highly skilled person to retrospectively recall the process of learning a skill, particularly with the accumulation of time and experience. This may be reflected in the difference in confidence (Table 1). It may be a combination of these two possibilities, however, it is beyond the scope of this study and would need to be explored further.

Table 1. Difference in confidence between students and supervisors in the skills list from the QNRs. Large differences in confidence are shown for most skills.

Percentage Difference in Confidence	Skill
4.2	Knowledge discovery
-18.8	Engineering reasoning
-25.3	Apply engineering science in design-implement projects
0.8	Consider technology during product development
-12.9	Professional ethics
-30.5	Self-awareness of knowledge and skills
-35.6	Problem solving
-33.3	Scientific thinking
-24.1	System thinking
-17.7	Creative thinking
-40.6	Critical thinking
-14.1	Work to professional standards in an organisation
-24.6	Teamwork
-22.5	Communication
-49.9	Leadership
-33.5	Project management
-12.4	Develop conceptual plans
-11.4	Develop technical plans
0.0	Develop business plans
-6.5	Consider wider concepts during a project (e.g. enterprise, business and society)
-16.5	Define customer needs
-3.1	Create designs, i.e. plans, drawings, and algorithms
-5.4	Consider regulations during product development
-10.3	Transform a design into a product, process, or system

Identifying key skills/attributes which were linked to performance

In order to identify key skills and attributes associated with performance, a number of cross tabulations were conducted from the results of the QNRs using SPSS.

Students are offered a number of FYP titles prior to the project, however, it is often not possible for all students to be given their first choice due to over popularity of certain projects. Data from the QNRs compares whether being given a first choice of FYP affects both the students' confidence in achieving their grade and the degree classification they actually achieved. Table 2 shows that students who were given their first choice of FYP were more confident at the end of the FYP about achieving their grade. However, Table 3 shows that there was very little difference in the actual degree classification achieved between students tackling their first or second choice of FYP.

This mismatch between confidence and attainment could also be linked to the students' self-evaluation of skills, with students only feeling confident in areas they are more familiar with and not having full realisation of the transference of skills between project themes.

Table 2. Cross tabulation of students who received their first choice FYP topic and their confidence in their target grade.

QNR	Project Choice	Target Grade		
		1st (70+ %)	2.1 (60-69 %)	2.2 (50-59 %)
QNR1	1st choice	80.0 %	20.0 %	0.0 %
	2nd choice	75.0 %	22.5 %	2.5 %
QNR2	1st choice	58.0 %	38.0 %	4.0 %
	2nd choice	33.3 %	62.5 %	4.2 %

Table 3. Cross tabulation of students who received their first choice FYP topic and their achieved degree classification.

Project Choice	Target Grade			
	1st (70+ %)	2.1 (60-69 %)	2.2 (50-59 %)	3 (40-49 %)
1st choice	23.1 %	38.5 %	30.8 %	0.0 %
2nd choice	23.8 %	33.3 %	23.8 %	9.5 %

Table 4 compares the type of planner students identified themselves as with the degree classification they achieved, showing that 'Planners' achieved better degree classifications than those who are always running behind. This suggests that the ability to plan and project manage was a key skill and that those who recognised this as a strength were more likely to attain a higher degree classification.

Table 4. Cross tabulation of the type of planner students identified themselves as and their degree classification.

Type of Planner	Target Grade			
	1st (70+ %)	2.1 (60-69 %)	2.2 (50-59 %)	3 (40-49 %)
Always Plan	26.1 %	34.8 %	39.1 %	0.0 %
Try to Plan	23.5 %	35.3 %	20.6 %	5.9 %
Always Run Behind	0.0 %	66.7 %	33.3 %	0.0 %

Students were also asked in QNR2 if they had used the CDIO process in their FYP. 84 % of students used CDIO to some extent (Figure 3). This is an indication of how the projects in earlier years have given the students a process that they can use through the CDIO method of working.
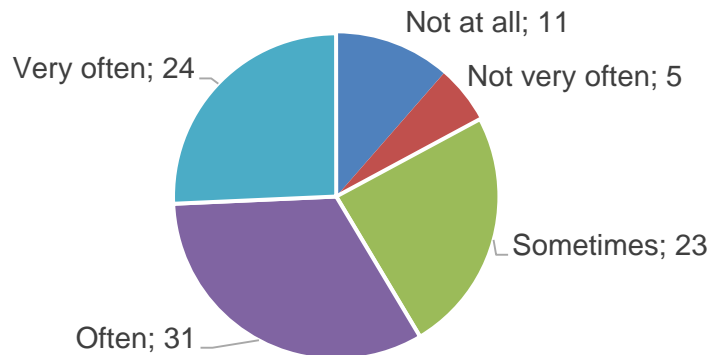

Figure 3. Students were asked in QNR2 if they had used the CDIO process in their FYP.

Equipping students with the mindset and preparing them for independent work

In the 2018/19 academic year, academic staff held a taught session aimed to help students identify the differences between group and individual projects and to emphasise the responsibility of the student in the FYP as opposed to in the previous group projects in earlier years of study. Figure 4 compares the confidence levels between the 2016/17 and 2017/18 cohorts, and the 2018/19 cohort following the intervention. The results show significantly lower confidence levels in 2018/19 ($p < 0.05$), which may be attributed to the 'skills' session hosted at the start of the FYP. This was intended to help students be better prepared for their individual FYPs and to have a more realistic evaluation of their own skills and abilities. In addition, the aim was for students to have a better awareness of how their skills could be transferred across projects.
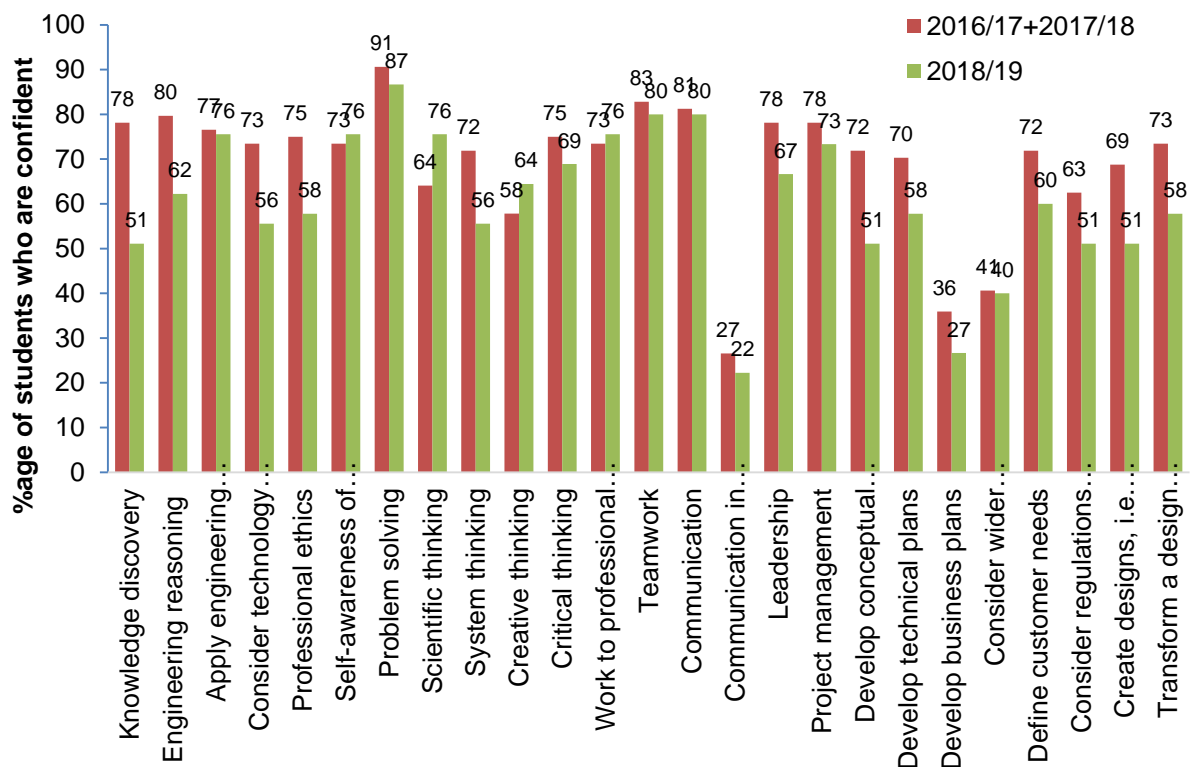
Figure 4. The percentage of students with confidence in their skills was higher in earlier years. Following the intervention of providing more detail and discussing the skills required for their FYPs in 2018/19, the confidence in skills at the start of the FYP is lower than in previous years.

CONCLUSIONS

The aim of this research was to determine how students rate their skills and abilities, how this may differ from the staff perspective and to identify key factors related to skills confidence. This was achieved through analysis of questionnaire results across 3 cohorts in their final year of study, focusing on the start and end of their FYPs, a major part of a students' Mechanical Engineering degree at Aston. An intervention was also carried out in order to aid students in

understanding the difference between group and individual work, and to appreciate how their skills could be transferred between different projects, enabling them to better self-evaluate their skillsets.

Key findings were as follows:
- Student confidence levels in their skills and abilities generally fell across the final year of study, indicating a drop in confidence when transitioning to an individual FYP
- There was disparity between the staff and student confidence in student skills, potentially indicating that students may be over confident in their abilities when facing an individual FYP, and perhaps staff may have high expectations on skill levels
- The key skill linked to performance is confidence in time management and the ability to plan
- Engaging with students to discuss their skills, the difference in types of projects and the transference of skills may be beneficial to students' appreciation of individual work and an awareness of how skills can be transferred between projects

Our conclusion is that the FYP can create a seemingly negative effect on student confidence, which we wish to avoid, through a more realistic self-evaluation of skill level and an appreciation of the different types of projects an engineer may face. An intervention can help students prepare for the differences in their FYP compared to previous group work and allow a more self-aware and self-reflective approach where individuals are better equipped to handle different projects and potentially increase success.

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THE INFLUENCE OF TEACHER CUES ON SELF-DIRECTED LEARNING IN MATH EDUCATION

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ABSTRACT

Increasing class sizes forces universities to change their education in ways that allow for independent learning for students. This study looks at a case where blended learning was introduced to alleviate some of the educationally negative consequences of large class sizes. Independent learning requires the students to become more self-regulated while at the same time they need efficient feedback from lecturers to enact these self-regulated learning activities. In this paper, we investigate whether at Delft University of Technology (TU Delft) student perceptions of lecturing behaviour is such as to stimulate student's independent learning and whether self-regulated learning behaviour results in more active engagement with the learning materials.

KEYWORDS

Curriculum Renewal, Mathematics, Blended Learning, Standards: 1, 2, 3, 4, 7, 8, 9, 10, 11, 12.

INTRODUCTION

In 2014 at TU Delft the "PRogramme Innovation Mathematics Education" (PRIME) was initiated in order to conceive a different approach to the math courses for engineering students. As a result of increasing student numbers group sizes in mathematics courses were growing. At the same time, this led to the desire to improve the quality of *active* learning. The premise was that large classes tend to reduce student engagement, to reduce student – teacher interaction, to reduce formative feedback, to diminish critical thinking and much more (Ramachandran et al., 2015). Blended learning was chosen as the solution to mitigate the negative effects of the large classes However, this requires more independent and self-regulated learning. Self-regulation is improved when reflection cues are added to the learning environment (van Laar, 2018). We have investigated the perception of the students on the role of the teacher in providing cues to students in monitoring and scaffolding, and hence in self-regulated behaviour.

PRIME

At TU Delft about 48 fte staff members are involved in over 150 courses in interfaculty education: teaching math to engineering students. At the moment the courses under review of PRIME are basic Calculus, Linear Algebra, Probability & Statistics for first and second year Bachelor students in Engineering programmes, like Civil Engineering, Mechanical Engineering, Aerospace Engineering and more. The goals of PRIME are to improve academic success, to improve the connection between mathematics and engineering and to increase student activity and participation in the math courses. The topic of this paper is mainly concerned with this last goal. We investigate whether active student participation in maths increases if the student perceives receiving stimulating cues to self-regulate their learning behaviour.

The organisation of PRIME

The initial project team consisted of a group of six dedicated lecturers from Delft Institute of Applied Mathematics (DIAM), an e-learning developer, an educational advisor and a project leader. The project was supported by the Executive Board of the university. After two years of running the project, the team has expanded into a team of a senior project leader, two coordinators, 16 instructors, an educational advisor and more than 10 student assistants.

The initial assignment was to develop a lesson plan with learning outcomes, which was then used to develop educational material: pre-lecture videos, lecture slides, online and book exercises, context examples (meaningful examples from the specific study programmes). Also, an overview graph of topics for each course and their interrelationship in terms of prior knowledge and connectivity was developed. The courses all have a blended design. The blended learning cycle as developed for PRIME distinguishes three phases in student activity: Prepare, Participate, Practice as illustrated in Figure 1.
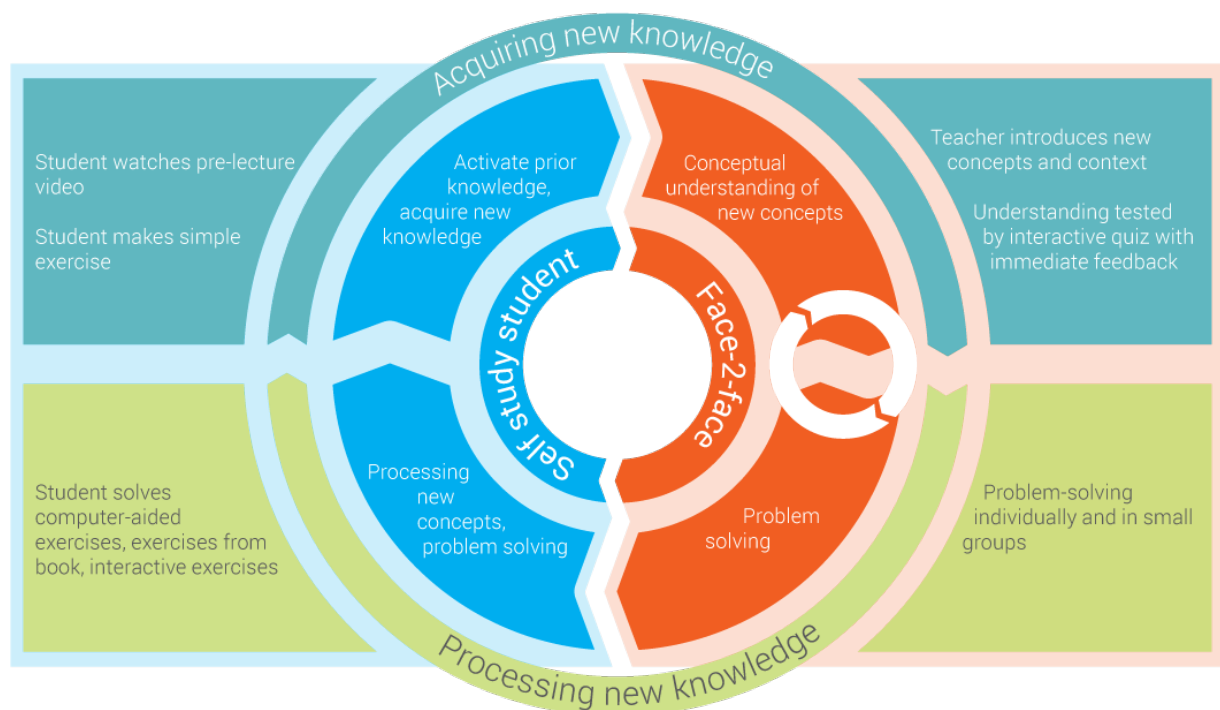

Figure 1. The blended learning cycle developed in PRIME

The student prepares before coming to class by watching a video, doing exercises from the book and/or doing exercises on an online exercise platform (with automated feedback). In the second part, during the face-to-face session (one session of 2 times 45 minutes), the student actively participates by answering interactive quiz questions about the pre-lecture activities. After this, the lecturer typically explains some new theory for say 20 minutes, there are a few other interactive quiz questions and time to work in class on exercises from the book. After the session, the student is supposed to practice. For this, an online exercise platform is made available in the collaborative learning environment (Brightspace at TU Delft). The platform provides exercises at different levels with feedback and dashboards for reference of level and understanding. Also, exercises from the book and old exam questions are on the to-do list for the student. This whole procedure requires an active and self-regulated attitude from the students in order to be successful.

It is important to know that the lectures are given by 8 to 13 teachers in parallel, to groups of 40 to 80 students, depending on the size of the Bachelor programme in question. The "teachers" involved are dedicated lectures, but also other academic staff (assistant, associate and full professors). The lecture slides developed in PRIME therefore also ensure uniformity of the content taught in the different groups.

THEORETICAL FRAMEWORK

Introducing blended learning makes the capacity for self-regulated learning more critical to student success as the students need to take more initiative, to plan, to seek help and to organise their study environment. Equally, the role of the teacher becomes more important in providing the relevant formative feedback, which helps the student to engage in a process called assessment for learning. Assessment for learning is focused on continuous formative feedback, where teachers actively observe and scaffold the next learning activity, building on students strengths and weaknesses. The teachers help students to find out what they already know such that more valid (tailored) learning can take place. When students in this context focus on the final programme outcomes, have time to internalise the materials offered, without necessarily being tested incrementally and take responsibility for their own learning process, more active involvement in the learning process may occur. The premise thus being that active involvement by staff and stimulation of students to be responsible and engaged may result in better learning results. This involves dialogue, trust and participatory relationships on top of feedback provided (Azevedo & Aleven, 2013). The argument is that modern higher(engineering) education, should move beyond the system of marking and grading to dialogic processes which assure standards of learning by sharing tacit and theoretical knowledge through active involvement in understanding the learning process and its outcome standards in the discipline or professional field.

Pat-El (2013) argues that assessment for learning builds on the alignment of instruction in support of learning. Support of learning is divided into two parts (1) Scaffolding: Supporting students managing their own learning process and (2) Monitoring: Stimulation of self-regulation of student's progress. Scaffolding by the teacher allows students to achieve a task beyond unassisted efforts and to progressively grow towards greater independence (van Laar, 2018). Scaffolding and monitoring require interaction between the teachers and the students. Bennet (2018), shows that students must evaluate their understanding of the learning task and the learning environment by picking up appropriate cues which help them to make judgements about their goals and plans of action to actively engage with the study material available. Equally important is the role the teacher has in stimulating students to engage (with the

available cues), to seek help or to ask feedback. The teacher gives guidance and assists the students and points out the critical pitfalls (strengths and weaknesses) which help students to realise monitoring activities of their own learning process (Kzric et all, 2018). After the initial teacher supported scaffolding and monitoring, the support materials in the blended learning environment should provide further scaffolding and monitoring opportunities self-regulation of the learning process.

RESEARCH QUESTIONS

Firstly we investigate what the student's perception is of the teachers' cues on monitoring and scaffolding in the PRIME learning environment. Secondly, we look into its relationship with the level of engagement with the study materials available in the courses under investigation as described above. Lastly, the contribution of separate activities with the learning materials on the reported engagement with the course material is considered.

The hypothesis is that reported engagement with learning materials is significantly enhanced by perceived monitoring and scaffolding cues from the teacher. If this hypothesis turns out not to be supported by the data, can we construct a better model?

RESEARCH METHOD

The monitoring and scaffolding questionnaire is based on the assumption that there is often a mismatch in perception in what teachers think they convey and the cues students perceive in supporting students' (self) evaluation of their learning (Pat-El, 2013).
A validated questionnaire from Pat-El (2013) was used: this includes the monitoring and scaffolding constructs and a five point Likert scale measuring the extent to which the perceived behaviour was applicable either to the teacher stimulating the students or to the students themselves when the questions start with "I". Finally, seven questions were included in the survey about the active engagement of students with the learning materials in the blended learning environment. Discriminating background variables were gender, math and physics grades at the end of secondary school, level of highest obtained diploma and discipline.

The survey has been distributed among 800 1st year students from Civil Engineering and Mechanical Engineering doing their 1st year calculus course. The learning materials offered are equal in each group. The students were taught in 22 groups by 16 different teachers. The response rate was 39% (316) of which 14 were non signed and 14 signed but not filled out. The final number of forms that could be used was 300.
A reliability analysis showed that the reliability of the questionnaire across the 40 items had a Cronbach's alpha of .88. Cronbach's Alpha is used to establish the reliability of the construct monitoring and scaffolding. A score of between .70 and .90 on Cronbach's alpha is generally considered as a sufficiently reliable score of the consistency within the sub-scale (Field, 2013). The Cronbach's alpha for the Monitoring construct was 0.88 and for the Scaffolding construct 0.80. These indicate that the constructs are reliable enough to pursue further analysis.

The responses were further divided between 245 males and 55 females which is equal to 81 % and 18% respectively. The overall population has slightly more girls in their programme (30 %). The sample under study is reasonably representative of the total population.

The average age of the respondents is between 18 and 19 years old. Around 99% is in the 1st year of their bachelor studies. Of these respondents 98% has a VWO diploma, which is a diploma at the highest level of secondary education, preparing pupils for university level education in the Netherlands. 90% is of Dutch origin. Other countries represented in the sample are Belgium (3), the Dutch colonies (2), US/UK (2), the Arab world (2), Italy (1) and Kenia (1).

Math and Physics grades were on average 7.8 (SD= 1.06) and 7.5 (SD= .85) respectively on a scale from 1 lowest to 10 highest at the secondary education level. It is noteworthy that the girls score significantly better in math (8.3 on average), than the boys (7.7 on average). For physics, there are no differences in the population. As there is a significant difference in math grades we decided to also consider the gender differences as one of the parameters to be studied. Gender differences tend to be persistent throughout STEM education and the teacher behaviour may be perceived differently by female or male students (Hofer & Stern, 2016).

RESULTS

Monitoring

The construct "monitoring" is representative for how students perceive the stimulation of the teacher to engage in self-directed learning with the learning material. In Table 1 we find the averages (standard deviation) for each score.

When comparing mean scores between men and women on the perception of the stimulation of the teacher to perform certain activities that support the students assessment for learning we note the following: On average lecturers do not perform all the feedback activities in class in such a way that students feel stimulated to reflect on their learning or demonstrate self-regulated learning. The lecturer typically demonstrates a teacher focused activity such as discussing assignments in class and by giving guidance to help understand the subject master (questions 12, 13). The lecturer tends to be more task focused by stimulating students on how they can improve and gives freedom in how to achieve that goal (questions 8, 5). This is a great start, yet there seems to be room for improvement. However, questions 14 and 15 show that the girls perceive the lecturers discussing the learning progress with the boys and not with them to a significant extent. Equally the improvement tips seem to significantly be less useful for girls than for boys. Although not strongly significant, differences are equally found on questions 1, 4, 10 and 11 (with a range from 0.05 to 0.09) where the girls consistently score lower than the boys. Apparently, there is less of a match between the views of the lecturers and the participating girls.

Table 1. Mean scores for monitoring for men and women

	Monitoring	Mean (SD) men	Mean (SD) women
1	The lecturer encourages me to reflect on how I can improve on my assignments	3.01 (.99)	2.7 (.95)
2	After examining the test results, the lecturer discusses the answers given to the test in class	2.86 (1.32)	2.7 (1.32)
3	Whilst working on my assignments, the lecturer asks how I think I am doing	3.20 (1.19)	2.94 (1.38)

4	The lecturer stimulate us to think about what we want to learn in university	2.94 (1.13)	2.65 (1.09)
5	The lecturer gives the opportunity to decide on my own learning strategies	3.90 (.819)	3.78 (1.07)
6	The lecturer inquires about what went well and what went badly in my work	2.90 (1.23)	2.75 (1.32)
7	The lecturer encourages me to reflect on my learning process	2.96 (.99)	2.73 (1.06)
8	The lecturer stimulates me to think about how to improve next time	3.22 (.97)	2.98 (1.15)
9	The lecturer shows how to find my strengths concerning my study skills	2.52 (.96)	2.29 (.97)
10	The lecturer shows how to identify my weaknesses concerning my study skills	2.48 (.99)	2.20 (.97)
11	I am encouraged by the lecturer to improve my learning process	3.34 (1.06)	3.05 (1.08)
12	The lecturer gives me guidance to assist my learning	3.47 (1.15)	3.35 (1.28)
13	The lecturer discusses assignments to help us understand the subject matter better	4.38 (.76)	4.24 (,90)
14	The lecturer discusses with me the progress I make	2.13 (.98)	1.7 (.97)
15	After each assessment the lecturer informs us on how to improve the next time	3.04 (1.09)	2.44 (.98)
16	The lecturer discusses how to exploit my study skills to improve my assignment	2.4 (.95)	2.33 (1.04)
	Monitoring Construct Cronbach's Alpha = .88		

Scaffolding

Scaffolding activities refer to the learner's autonomy and initiatives to realise growth and develop strategies in overcoming obstacles. The initiative is not so much triggered by the teacher but rather by the perception of their own activities in response to teachers' suggestions. In table 2 we find the averages (standard deviation) for each score.

We found that question 21 shows a significant (.005) reinforcement of the monitoring questions 14 and 15, where the girls do not feel invited to share or show what they have learned. Almost significant are questions 24 (0.04) and 27 (.05), where the girls' report on their contribution and opportunities to ask questions turns out to be lower than that of the boys. Overall, however, question 24, 27 are scored rather high. It is unclear whether this is due to the fear of the girls or whether they feel less invited by the teachers' behaviour or whether they perceive fewer cues than the teacher would like to. The somewhat lower scores on question 18 and 26 might suggest students feel they get fewer pointers or pointers that do not help them to improve their work.

Table 2. Mean scores for scaffolding for men and women

	Scaffolding	Mean (SD) men	Mean (SD) women
17	I am aware of my weak point in the application of study skills	3.95 (.81)	3.90 (.67)
21	During class I have an opportunity to show or share what I have learned	3.41 (1.18)	2.91 (1.23)
28	I am aware of the criteria by which my assignment will be evaluated	3.98 (.93)	3.78 (.99)
29	When I receive an assignment it is clear to me what I can learn from it	3.86 (.90)	3.64 (1.04)
30	The assignments allow me to show what I am capable of	3.89 (.94)	3.89 (.93)
18	The lecturer offers strategies to improve my study skills	2.95 (1.09)	2.84 (1.03)
19	When I do not understand a topic, the lecturer tries to explain it in a different way	4.11 (.92)	4.01 (.99)
20	The lecturer provides me with hints to help understand the subject matter	4.02 (.86)	3.88 (1.04)
22	The lecturer asks questions in a way I understand	4.22 (.66)	4.22 (.71)
23	The lecturers asks questions that help me gain understanding of the subject matter	4.15 (.78)	4.12 (.84)
24	The lecturer allows for my contribution during the lesson	3.77 (1.06)	3.44 (1.19)
25	I have the opportunity to ask my classmates questions during class	4.33 (.77)	4.22 (1.05)
26	The lecturer makes me aware of the areas I need to work on to improve my results	2.78 (1.08)	2.51 (1.09)
27	There is an opportunity to ask questions during class	4.70 (.55)	4.53 (.74)
	Scaffolding construct Cronbach's Alpha = .80		

Engagement with learning materials in the course

Exploring the activities taken up by the students we found that different groups of students use different strategies to be actively engaged. In Table 3 the mean scores for the seven questions related to this topic are displayed.

Table 3. Mean scores for Active Engagement: total and per gender

	Active engagement	Mean (SD)	Mean (SD) men	Mean (SD) women
act3.1	I have watched the video before each lesson	2.55 (1.42)	2.60 (1.45)	2.41(1.33)
act3.2	I have watched the video after each lesson	1.79 (1.09)	1.81 (1.08)	1.75 (1.14)
act3.3	I have attended every class	4.61 (0.79)	4.61 (0.72)	4.56 (0.71)
act3.4	I have practiced with the online assignments	3.57 (1.30)	3.36 (1.42)	3.58 (1.45)
act3.5	I have studied the study material from the book	3.57 (1.30)	3.50 (1.30)	3.98(1.18)

| act3.6 | I receive ample attention from the teacher to support my learning process | 3.78 (0.98) | 3.81 (0.95) | 3.62 (1.05) |
| act3.7 | I am actively engaged with the study materials available in this course | 4.08 (0.88) | 4.09 (0.87) | 4.05 (0.87) |

Computing correlations for these questions (see Figure 2), controlled for gender, level of education, maths and physics grade, shows that watching the video before class, attending class, practicing the online assignment positively correlate with active engagement (corr. .175, .293, .176 and sig. .004, .000, .004). The video after class was particularly watched when class was not attended. Also, high correlations are found on watching the video before class, studying the material from the book and active engagement (corr. .175, .253, sign, 004, .000). This seems to imply that students choose for the online materials or for the book.

Figure 2. Correlation matrix for the active engagement questions
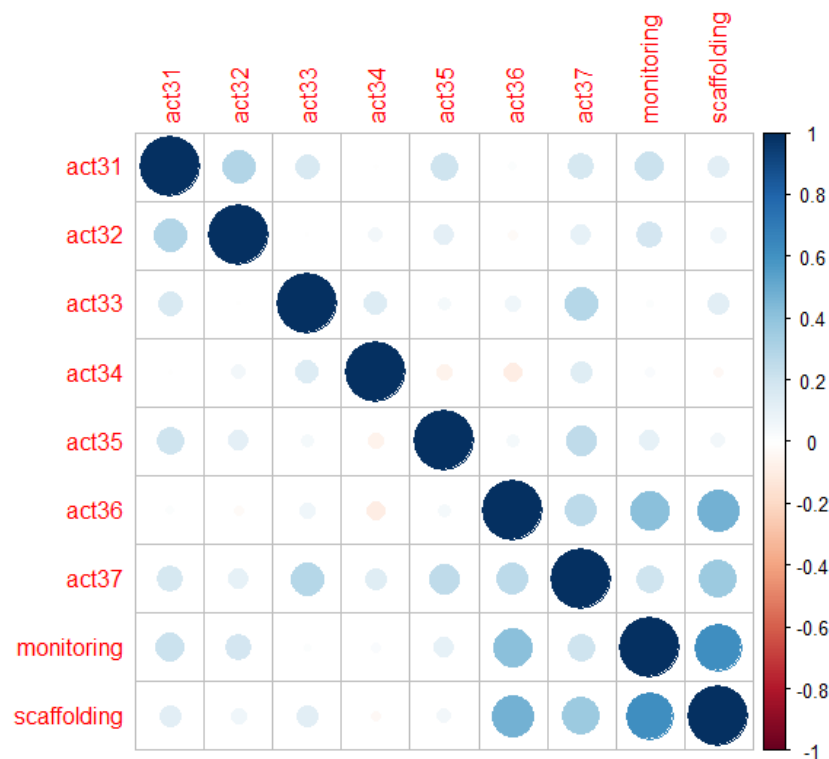
Negative or very small and insignificant correlations emerge for using online materials and studying the book. Students tend to do either one or the other. In the group who is more focused on studying the book, we found fewer correlations with attending class and teacher attention for the group. The highest correlational loading, however, is found on receiving ample attention of the teacher to support the learning process and monitoring (corr. .41 sign. .000). And on receiving ample attention of the teacher to support my learning process and scaffolding (.48 and sign. .000). Another high correlation is seen between monitoring and scaffolding (corr. .62 . sign. .000). Meaning the teacher may be the most important factor in stimulating students to monitor (or self-direct their learning), with the high correlation between monitoring and scaffolding showing the importance of the teacher to have students do the right things.
To test the hypothesis of the positive impact of monitoring and scaffolding on the reported engagement with educational course materials, we performed a multi-variate linear regression

taking act3.7 (" I am actively engaged with the study material available in this course") as the response variable and the construct monitoring and scaffolding as explanatory variables. The first analysis showed that perceived scaffolding cues are of significant influence on the engagement, but the perceived monitoring cues are not. The coefficient for the scaffolding construct in this model is 0.69, meaning that any unit increase in perceived scaffolding construct results in a 0.69 increase in the student's self-reported engagement with the material. However, the explained variance for this model is only 13%.

The following model turned out to be a better one: taking act3.7 as the response variable, and adding watching the video before the lesson, attendance in class, studying the book, getting ample attention from the teacher as explanatory (dummy) variables increased R-squared to 23%, with the largest significant contribution to the outcome from the attendance: the higher the score on attending every class, the higher the students reported engagement with the material. Second highest influence comes from studying the book, attention from the teacher only contributes significantly for students appreciating this attention with the highest score.

Finally, the best model we were able to fit turns out to be the one constructed from the above model by adding scaffolding cues: in this case, R-squared increased to 29%, with attendance and scaffolding cues having the highest impact on self-reported engagement with the materials.

CONCLUSIONS

In this paper, we have examined whether monitoring and scaffolding activities have a positive impact on the level of self-reported engagement with study materials in the PRIME set up. Furthermore, we have looked at differences in the perception of girls and boys with respect to monitoring and scaffolding cues.
Self-reported engagement with study materials available in the course is significantly explained by watching the video before the lesson, attendance in class, studying the book, getting ample attention from the teacher and scaffolding cues. Monitoring cues were not found to give a significant contribution.

Perceived monitoring of students is influenced by the attention of the teacher and watching the video before class. Perceived scaffolding is related to teacher attention, class attendance, active engagement with the materials and monitoring capacities. The teacher seems to play a crucial role in helping students acquire appropriate self-regulated learning activities.

We have found that girls perceive the lecturing behaviour stimulating capacity or confidence building as significantly less supportive. Indeed other studies have pointed out that teachers evaluate the performance and capabilities of girls in physics education lower than of boys. It turns out that in general they give boys more attention, provide them with more challenging questions, and call more often on boys and addressing them more often in general (Hofer & Stern, 2016). This may mean girls need to be addressed in a different way to experience the same level of support or that teachers may need to acquire a different attitude, or insight in what cues are relevant to create learning success.

This study gives an impression of possible relations between the teachers' behaviour and perceived cues by students and their active engagement. The teacher does make a difference in stimulating self-regulation and how independent and actively engaged students are. Yet many questions remain and need a follow up. These concern among others why apparently

there is little engagement with the online materials, why do girls and boys perceive the cues of the teacher differently and which of the scaffolding/monitoring activities are the most salient. Furthermore, the next steps will consist of interviewing the teachers that were involved in the teaching of the course under consideration about their monitoring and scaffolding activities.

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BIOGRAPHICAL INFORMATION

Annoesjka Cabo is an associate professor in statistics and a lecturer of mathematics at TU Delft. Since August 2016 she is the director of studies of interfaculty education at the faculty of EEMCS. She is the leader of PRIME: Programme Innovation Mathematics Education, a university wide initiative to innovate mathematics education for engineering students. As such she is involved in developing learning material, researching data from the project and coordinating a growing group of staff involved.

Renate Klaassen is a programme coordinator and researcher, working at the 4 TU Centre for Engineering Education at TU Delft. She has been heavily involved in educational advising on the innovation of the BSc in Aerospace Engineering, and various other curriculum reforms at TU Delft. Consultancy activities include assessment (policy, quality and professionalization), internationalisation of university education and design education. Areas of research interest pertain to content, language integrated learning in higher education, conceptual understanding in engineering education and interdisciplinary learning.

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THEORY, PRACTICE AND REFLEXIVITY: THE NEXT CHALLENGE FOR CDIO?

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ABSTRACT

The 'Conceive-Design-Implement-Operate' (CDIO) movement of engineering education reform emphasises project-based, experiential learning and the development of professional skills such as teamwork, collaboration and design. As well as disciplinary theoretical knowledge, implementation of the CDIO educational agenda calls for expertise in both engineering design practice and teaching practice. This agenda, it is argued, involves fundamental epistemological and normative shifts and involves engineering educators, like it or not, in what Donald Schon called "the battle of the epistemologies". This paper situates the CDIO agenda within the wider context of current professional educational thinking. In doing so it argues for the need for engineering education to advert to a third epistemological dimension of reflexivity, beyond theory and practice, now long since embedded in health care, managerial and teacher education. The authors then outline how the reflective dimension has been embedded in the Civil Engineering undergraduate program at the University of Limerick. Examples of both teacher's and students' reflections are offered for consideration. Pedagogical practice, approaches to assessment and some challenges encountered in implementing the reflective dimension in an engineering curriculum are outlined.

KEYWORDS

Epistemology, CDIO, PBL, Reflective Practice, Standards 2, 3, 5, 10, 11, 2.

INTRODUCTION

The CDIO approach to curriculum design involves students engaging in the kinds of activities that characterise the industrial practice of engineering: designing, collaborating, presenting, leading and so on (CDIO refers to 'professional skills'). In so doing, CDIO addresses the problematic theory-practice tension that is a feature of engineering curriculum reform. It has been argued elsewhere that the source of this tension is at root epistemological (Cosgrove & O'Reilly, 2018) and some argue that history suggests that the tension is both persistent and ineliminable (Edström, 2018). Epistemology is the philosophy of knowledge, its possibility, nature, scope and validity. Educational reform raises fundamental questions: What kind of knowledge is valid and valuable? What competencies are and pedagogical practices are required to inculcate such knowledge? Such questions challenge existing practices and power

structures. In fact, philosopher and educator Donald Schön has called this theory-practice tension 'a battle of the epistemologies' (Schön, 1995).

Schön characterised practitioner knowledge as 'professional artistry', a kind of 'knowing in action' which may be made apparent in what Schön called 'reflection in action' (Schön, 1983, 1987). As he says:

> there is a great deal of critically important knowing-in-action that is not captured in research results as they are usually formulated in textbooks or published papers (Schön, 1995, p. 30).

This knowing includes what CDIO calls professional skills. Schön goes on to say that we can all reflect on our action, objectify it and consider how we might modify our approach. That is the fundamental argument for what Schon calls Reflective Practice [RP]: to learn from our lived experience as practitioners or budding practitioners (Walker, Keogh, & Boud, 1985). Therefore Schon suggests that all students of practice disciplines stand to gain from reflecting on action or engaging in RP. According to Schön, both the practice of and the teaching of practitioner skills involve a reflexive move. Schon's work has spawned a movement of reflective practice in professional education, especially in the health and caring professions and in teacher education where RP is now deeply embedded in curricula. Curricula that adopt RP typically require students to engage in reflective writing usually about practice placements. Educators who embrace RP now consider that truly professional practice is constituted as truly professional by its lifelong critically reflexive stance. RP then becomes a way of professional life often taking the form of Action Research [AR]. In fact, AR may be considered a form of RP. The RP movement now draws on many other thinkers in addition to Schön including Dewey, Freire and Brookfield (Brookfield, 2017; Lyons, 2006, 2010; Moon, 2004).

REFLECTIVE PRACTICE and CDIO

Engineering educators who adopt the CDIO approach sit astride the theory-practice divide in two respects since both engineering and teaching are practices in Schön's sense (Cosgrove & O'Reilly, 2018). If such educators research their own educational practice, it is argued that this also involves a reflective dimension. Both Dewey and Freire emphasise that educational enquiry requires a critical stance since neither institutional assumptions nor power interests are transparently apparent. Carr and Kemmis agree and they elucidate the epistemological and methodological shifts required to move beyond assumptions derived from the natural sciences and embrace a critically reflective stance in research that is educationally authentic (Carr & Kemmis, 1986). Furthermore, they insist that for research to be truly educational, it must be in the service of improved practices, and therefore it must involve as participants teachers and, as far as possible, their students.

This article considers engineering education and the CDIO movement in particular in the light of these ideas and suggests the need for a reflexive element in engineering education. The work reported here adopted the AR approach which is consistent with RP. While the research reported here relates to curriculum development, the epistemological shifts noted by Carr and Kemmis that distinguish theory, practice and critically reflective practice are outlined. Curriculum exemplars are described, including tutor and student reflections from the

University of Limerick undergraduate program in Civil Engineering. A number of educational benefits are argued for and some problematic issues are noted.

NATURAL SCIENCE AND POSITIVISM

Science searches for law-like regularities (correlations and causal relationships) among variables in systems with a view to explaining and predicting behaviour and in the case of man-made technological systems, facilitating control of system behaviour. Its theories are constructed incrementally and inductively and it proceeds by controlled experiment to test hypotheses. Epistemologists have characterised natural scientific knowledge as positivist (Giddens, 1978). Within academia the discipline of engineering is closely allied to the empirical natural sciences and engineers' assumptions about knowledge, their implicit epistemology and research methodology tend to mirror those of their natural scientist colleagues.

FROM POSITIVISM TO INTERPRETIVISM

In the 19th century, Auguste Compte proposed that the Social Sciences should adopt the methods of the natural sciences which he called 'positive science', hence the tile 'positivism' (Cohen, Morrison, & Manion, 2007; Giddens, 1978). The perceived, dehumanising effects of adopting positivist assumptions and methodology (Outhwaite, 1987, p. 6) in social science resulted in a reaction. The pioneering sociologist Max Weber declared: " the course of human action and human expressions of every sort are open to an interpretation in terms of meaning…" (quoted in Outhwaite, 1987). Thus, for example, no scientific experiment or analysis performed on coins can reveal the nature of or value of money. That can only be revealed by reference to complex social understandings, practices, rules and contextual conditions. Interpretivism, therefore, seeks an understanding of the subjectively held meanings in play in a social context. This, in turn, leads to the positivist charge that interpretive approaches are not objective (in positivist terms) and are therefore unreliable and invalid. Notwithstanding the early emergence of interpretive approaches, the tendency to import inappropriate positivist assumptions and methodology into the social sciences is still pervasive (Artigas & McCone, 2006; Bennett & Hacker, 2003; Hyslop-Margison & Naseem, 2007; Smit & Hacker, 2014; Tallis, 2004, 2014). Therefore engineers should pay particular heed to Borrego's warning about the tendency of engineering educators to transfer in an inappropriate way positivist assumptions into their educational research (Borrego, 2007). Contrary to systems examined by the natural sciences, social systems can often only be understood 'from the inside' by reference to the commonly held meanings of the participants.

TECHNICAL RATIONALITY AND EDUCATION

Engineers, informed by empirical science, often design systems by identifying the most efficient means to achieve a pre-defined end by a controlled manipulation of materials and processes (although engineering design artistry certainly involves much else besides (Cosgrove & O'Reilly, 2018)) . This approach separates the means from the ends and is called technical rationality (Dunne, 1993, 2005; Schön, 1995). Schön notes that this profoundly

reductive epistemology of technical rationality argues in regard to knowledge generation (research) in general:

> that if you can't name the variables and measure their values, and if you can't create control groups or manage random assignment of subjects to treatment and control groups, then you can't possibly generate valid knowledge. In the absence of these conditions… you're not doing rigorous research- (Schön, 1995).

Borrego's observation that engineers tend to transfer this kind of rationality (assumed as normative) into their educational research has been noted above. It is this hegemonic claim of technical rationality rooted in the causal categories of empirical scientific explanation that Schön contests and that is challenged here. Peters explains the conceptual error involved in such attempts to separate educational means from educational ends.

> Talk about 'the aims of education' depends to a large extent on a misunderstanding about the sort of concept that 'education' is….Education is not a concept that marks out any particular process…rather it suggests criteria to which processes...must conform. One of these is that something of value should be passed on… People think that education must be for the sake of something extrinsic that is worthwhile, whereas being worthwhile is part of what is meant by calling it 'education'. The instrumental model of education provides a caricature of this necessary feature of desirability by conceiving of what is worthwhile as an end brought about by the process…. (Peters, 1956) quoted in (Carr & Kemmis, 1986 p.77).

Or as Carr and Kemmis express it compactly 'educational "ends" are constitutive of educational "means" as educational' (Carr & Kemmis, 1986). If the means employed are not congruent with the avowed educational ends, then questions about instrumental efficiency do not even arise (Cosgrove & O'Reilly, 2018).

For those seeking to conduct research on their CDIO practice, the technical-rational prejudice must be challenged by acknowledging the valid knowledge category of practical-professional knowledge or artistry and asserting the ethical basis of education as a practice. Reflective Practice is one avenue to elucidating the nature of and nurturing the development of such professional artistry.

CRITICAL REFLEXIVITY IN EDUCATIONAL RESEARCH

Many educational researchers do apply interpretive methodologies in their research. However, education is a human social practice (Dunne, 2005) with its own ends and values. As noted above, practices (including engineering and teaching) involve aspects of what Donald Schön named 'professional artistry' (Schön, 1983, 1995). If research is to be characterised as educational, then its aims and values must be congruent with those of educators. A research approach, even an interpretive approach, drawn from the social sciences that seek to develop theoretical understandings and leave practice untouched cannot properly be called educational (Carr & Kemmis, 1986, Chap. 4). Furthermore, Carr and Kemmis point out that it is not sufficient simply to elucidate all the meanings at play in an educational situation, in an interpretivist mode:

> 'The subjective meanings that characterise social life are themselves conditioned by an objective context that limits both the scope of individuals' intentions and the possibility of their realisation. By adopting an epistemology for the process of self-understanding that excludes critically questioning the content of such understandings, the interpretive approach cannot assess the extent to which any existing forms of communication may be systematically distorted by prevailing social, cultural or political conditions (Carr & Kemmis, 1986, p. 135)'.

We need a critical point of view. The critical theorist Jurgen Habermas proposes that knowledge is constituted by three kinds of interests: the technical, the practical and the emancipatory. The technical interest is closely aligned with the natural sciences. The practical interest generates knowledge as interpretive understanding (Weber's '*Verstehen*') which can inform practical judgements about action. Because it informs action it has a necessarily ethical character. However, in addition to interpretive understanding we need to identify the forces that distort and render inauthentic educational practices. For example, whose interests are served by the 'hidden curriculum' of lectures divided into subjects, conducted in 50 minute time slices and assessed predominantly by end-of-semester written exams (Eikeland, 2001, p. 145; Schön, 1995)? A critical social science seeks to identify and provoke action to eliminate distortions in the interest of rational autonomy and freedom. This interest Habermas calls an emancipatory interest. The role of critical theory in social relations is analogous to the role of psychotherapy in individual living: to identify, articulate and reconfigure mistaken, oppressive or dysfunctional understandings, structures and relations that frustrate the flourishing of human life in all its potentialities. To this end, a critical social science asserts the need for a self-reflective understanding because we unknowingly reproduce in our practices the inauthentic patterns of our own experience.

So we see that teaching and learning practical or professional skills involves a reflexive move and researching our teaching practice also involves a reflexive turn. It is argued therefore that an epistemology adequate to these tasks must be further extended beyond theory (natural and social) and practice to include a critically reflexive category of meaning which we may refer to as '*interiority*' (Coghlan, 2010, 2016). For a more complete argument and account that expands on and situates such an extended epistemology in a wider philosophical and historical context see (Cosgrove & O'Reilly, 2018).

Participatory research to promote beneficial change is called Action Research (AR) (Carr & Kemmis, 1986 Chap.7). The essence of the process is ongoing cycles of planning, acting and reflecting conducted collaboratively in particular contexts with the practical end of improving current practice and this is the approach was used for the development work reported here.

The 'Conceive-Design-Implement-Operate' (CDIO) movement of engineering education reform emphasises project-based, experiential learning and the development of professional skills such as teamwork, collaboration and design (Crawley, Malmqvist, Östlund, & Brodeur, 2007). Problem Based Learning (PBL) shares many of the concerns of CDIO practitioners. Edström and Kolmos note that, while CDIO reform proceeds from outcomes (ends) and PBL reform proceeds from process (means) they are nevertheless complementary approaches that overlap in many areas (Edström & Kolmos, 2014). Therefore the examples cited here from Civil Engineering at the University of Limerick (CIVIL @ UL) which were originally informed by the PBL approach are as relevant for CDIO practice as they are for PBL. Both CDIO and PBL

are intended to provide many of the experiences of practice placements and as such can offer similarly rich potential for reflection.

REFLECTIVE PRACTICE IN EDUCATION

Given the character of both CDIO and PBL it will now be clear how such approaches include both theory and practice. The first author encountered the educational work of John Cowan (Cowan, 1998) in 2009. Cowan, a Civil Engineer, advocates the need for reflection for (prior to) as well as on (after) action (Cowan, 1998). For Cowan, reflection is concerned with any experience bearing on learning with a view to further development:

> Learners are reflecting when they analyse or evaluate personal experiences that have a bearing on their learning and attempt to generalise from that thinking. They do this so that in the future they will be better informed or more skilful or more effective than they have been in the past (Cowan, 1998).

He proposes a protocol for reflective writing that moves from a selective description of experience through the critical interpretation, evaluation and self-challenging to forward planning and metacognitive self-review (Cowan, 2013, 2014). It is distinct in emphasising anticipation (reflection for action) and in pivoting to the future after reflection-on-action. Because of its practical, developmental and ethical thrust and its expression in accessible language likely to be congenial to engineers, Cowan's model has been adopted and embedded in the problem-based program in Civil Engineering at the University of Limerick since 2009 (Cosgrove, Ryan, & Slattery, 2014), and with the support of John Cowan is currently undergoing development through Action Research. The preparatory research phase, to align practice with Cowan's model of reflection, lasted 3 semesters. The formal action research phase after receipt of ethical approval has involved 3 cohorts over 5 semesters and finished in the summer of 2018. Cowan summarises his key conclusion about reflective practice thus:

> I judge the introduction of self-assessment as the most powerful factor for change and development that I have yet encountered (Cowan, 1998 Chap.7).

Self-assessment is simply another name for the core of reflective practice.

IMPLEMENTATION IN THE UNIVERSITY OF LIMERICK

Reflection is required at a number of points throughout the UL program but just two are noted here: The first is a second year module, Design Studio (DS) where students are individually tasked to choose a problem (e.g. a design or organisational problem) or problematic situation of personal interest and examine possible measures to ameliorate the problem or improve the situation (Quilligan, Phillips, & Cosgrove, 2017). Problems proposed by students range from a design for real-time coach-player communication systems in non-helmeted sports to durable silage pit covers to the amelioration of binge drinking. The module is lecture-free and moderated by two tutors. Students typically spend some days off campus to help stimulate creative thought and they present periodically on their developing ideas. The second example

is a third-year group based Integrated Design Project (IDP) spanning 4 modules including Soil Mechanics, Structural Analysis, Reinforced Concrete Design and Professional Skills which requires groups to survey a site and design and present a whole-frame structural solution including foundations. Third-year cohorts (typically 30 to 40 students) include between 4 and 9 Chinese students newly arrived in UL and a small number (between 1 and 6) of American or European international students. Students carry out their own site survey and are supplied with a geotechnical investigation report including soil samples and Architectural planning drawings for a real project with planning permission on the surveyed site. Most subject lectures happen during the morning and moderated and unmoderated group meetings and workshops happen about twice each week over the 12 week semester.

ASSIGNMENT STRUCTURE AND WORKSHOPS

The reflective writing assignment used in CIVIL @ UL was developed in collaboration with John Cowan and is drafted so as to be generally applicable to many contexts. The reflective task is structured in 3 stages (see table 1) in order to motivate early engagement and 'get the ball rolling' with an unfamiliar mode of thought. Online feedback is provided by the tutor at stage 1, independently and confidentially by John Cowan at stage 2 and by a peer at stage 3.

Week no.	Stage	Content	Notes
3	1	Review experience to date; Anticipate 3 likely Demands/Abilities/Dispositions	Description of each chosen ability as performed in practice Personal plan to develop ability Kind of Data to be collected to demonstrate development in each ability to a prospective employer for work placement
6-7	2	Interim Reflection on Action :	Review progress and feedback to date. Make interim learning claim with supporting data
11-12	3	Final Reflection and Look Ahead	Final learning Claim with further data and implications for future development

Table -1 Reflection Stages

Submissions and feedback are administered through the UL online learning management system, SULIS apart from John Cowan's feedback which is emailed confidentially. Apart from noting that those that engage early and respond to formative feedback do better, it is not felt that a detailed analysis of development over the stages would yield important insights.

A variety of instructional documents have been developed for each stage of the process, emphasising a) keeping a journal or log of learning experiences, b) personal choice in the ability, skill or disposition chosen for reflection, c) a clear account of the skill or ability in performance, avoiding bland generalities, d) the specific kinds of data that would tend to support a credible claim of development in the chosen skill or disposition, e) an account of salient events or learning experiences (including learning from failure) with data relevant to the specific claim, f) a before-and-after comparison of capability g) a look forward to future implications for professional development. Workshops are held in advance of each submission stage to encourage i) identification of possible skills for reflection, ii) assessment of exemplar

texts and iii) self- and peer-assessment of draft submissions and iv) raising awareness of the relevance of self-assessment of professional skills for employment.

As each action research cycle of development has progressed, in the spirit of collaboration that animates AR, 3 prompts are tabled to students at the conclusion of each workshop as follows:

1. The most important thing you do when facilitating our workshops is to.........

2. You could help us more effectively if you would..........

3. It's not really helpful when you........

Responses are written on anonymous post-it notes. These responses allow modification in practice where that seems warranted by the comments. Similarly, anonymous post-it notes are used to gather responses to a wide variety of questions that arise during workshop discussions, for example, 'how many hours of study and meetings per week would be required to succeed on this project' or 'what is the most frustrating behaviour among teammates?' These answers can then be posted as feedback so students can gauge their own opinions and expectations against those of their peers.

WHAT THE STUDENTS WRITE ABOUT

Some 300 odd submissions have been stored in a database (NVIVO) that facilitates a comprehensive analysis of data in multiple formats. A first cycle of coding has been completed. This identifies the wide variety of themes apparent in the text by name e.g. presenting, time management, group work, feelings, learning by doing, confidence, motivation, creativity and so on. Further cycles of coding will allow consolidation of themes into related clusters of themes. Examining only final submissions (170), the most commonly presenting single word is 'time' (970 times). Abilities (or skills or dispositions) have been filtered from the themes identified in the first pass of coding and the most frequent 7 are shown in Table 1 together with the number of submissions in which they occur.

Theme	Occurrence
Teamwork	109
Communicating (not presenting)	96
Time Management	95
Presenting	92
Planning	73
Research	49
Interpersonal Skills	43

Table -2 Reflection Themes

It is apparent that some themes such as 'Time Management' and 'Planning' may overlap and further analysis is required in this regard. One theme, 'challenge of freedom' occurs predominantly in the Design Studio (DS) example (17 times) and only twice in the IDP where the required outputs are specified quite tightly. One DS student comments:

'Although I was allowed to choose any topic which suited my fancy, I was confounded by the choice, as I had not been given such freedom ever before in my academic life'.

Similarly, 'creativity' occurs 25 times in Design Studio reflections but only 4 times in the IDP. The link between freedom of choice and creativity is apparent in the following:

> 'to be handed a blank page and told to come up with your own idea/concept was very different. This process required creative thinking.'

One requirement of the Design Studio module is to consult end users or stakeholders related to the student's choice of topic. This develops further skills:

> 'Then once I had a possible solution I had to see if there was actually a demand for such a product (football vending machine) this led to multiple conversations with basically every football player in the course, the manager of my own local team, players from my local team and players from all other teams also. This was a major factor in my ability to develop my communications skills.'

The IDP spans 80% of all activity (4 out of 5 modules) in an entire semester. It is situated immediately before students go on their 8 month industrial placement and is designed with that in mind. Students must manage their time throughout the semester as 50% of the credits are for assignments completed during the semester. These assignments may be worked on in groups but each student submits individually. While there are a rich variety of experiences with a high potential for reflection, so far it has proved difficult to motivate students to keep a learning log or journal of salient experiences for later harvesting. Nevertheless, examples of competent and credible IDP learning claims occur with sufficient frequency to convince the authors that the effort is educationally worthwhile and two extracts follow:

> 'Communication (Verbal) - It has been over ten weeks since I started reading books to improve my vocabulary and so far, I have yet not seen any improvement. The feedback from my friends tells a different story. They tell me that I have no speech impediment …In week 5 we had a mock presentation…The video provided at the end of this presentation with the constructive criticism by my classmates helped me to better myself for the real presentation. They told me to look forward and keep eye contact with the audience and look less at the notes or have sticky notes instead. For the final presentation, I followed the same steps as I did in week 6. … There was a point when I went blank due to anxiety, but I was able to keep it together and finish my speech. This proved that the method that I chose was helpful and worked. Still, I had to practice more in order to completely overcome my anxiety.'

It is doubtful that the student would have engaged in such a focussed way and sought and received such effective peer support and feedback on an area that was problematic for him if the reflective assignment had not provided the motive and space to do so in such a conscious way.

> 'Working in Projects with Younger Members – Progression
> 'I offered an option to divide the work in the group and this has made a huge impact on my schedule as I didn't have to chase around for anyone and could manage my time and role in the project. One example was that we needed to get a group presentation done and they left everything to the last minute so I offered to work on other parts of the project and help them with that instead of getting involved in the last-minute pressure and it worked, … They were happy for me to get other parts done for them and I was happy to have them done this presentation, so distributing the work has worked in this matter and I also indirectly was able to develop some leadership skills. … I must respect whatever way a younger member of the team wants to do their work. This reflects their teenage moments in life and

I now understand because one day I was standing in their shoes.'

The above extract is from a stage 2 submission. A reading of all three stages shows a clear progression from frustration to action to resolution for this highly motivated mature student who learned how to work fruitfully with less well organised younger team members.

Since early on the first author has kept reflective notes and memos of salient events and has found Schon's conviction borne out: as teachers we need to reflect on practice in order to notice and understand what we do. We may be surprised at what insights can emerge that we may not have been aware of. One such example follows of a moment of classroom talk from my own workshop practice that would have been lost had it not been recorded shortly after the workshop:

> "**Paradox:** You must look in the mirror to reflect.
> [I modelled this physically with my hand as mirror]
> If your attention is distracted from your reflection by looking at assessment i.e. thinking about what "they" are looking for, you will then no longer be reflecting.
> So if you want to score high in reflection forget about the score!'

CREDITS AND ASSESSMENT

Assessment is by the first author using the assignment as a guide with an eye to the 7 points noted a) to g) above with particular emphasis placed on item d), persuasive data to support any learning claims of a kind likely to convince a prospective employer. Plagiarism checking software is used on submission. Grading is benchmarked each semester by sending a sample of graded assignments at C, B and A grades to John Cowan for cross-checking and sharing of judgements. In the DS module, the reflective work attracts 30% of the credits. In the IDP out of 400% across the 4 modules 35% is allocated to the reflective work, 10% from each of 3 modules and 5% from the fourth.

PRELIMINARY CONCLUSIONS

A significant number of students do learn how to reflect well and their efforts are both competent and credible, although many students find the task challenging and some submit narratives with unsupported claims of development.

Mature Students engage with reflective work willingly

Complex group based design projects makes many demands on students in the broad area of professional skills that are educationally valuable.

Reading students reflections opens up to the tutor a world of experience and learning, of educational life, that might otherwise go unnoticed and unrecorded. The teacher's own awareness, empathy and motivation can be significantly enhanced thereby. Furthermore, reflective writing allows tutors to access the student's experience in ways not allowed by other modes of educational engagement. This, in turn, provides an opportunity for educators to consider how the many kinds of valuable learning that are happening in CDIO type curricula, including the unforeseen yet valuable outcomes can become credit-bearing.

Each semester some students, without prompting, choose to write about the benefits they have derived from reflection in education and sometimes in their life generally.

Plans are being made to require students to update a learning log weekly on the learning

management system.

Consideration is being given to allocating a full 6 credit module to the reflective element in the IDP with the intention of requiring assembly of an employment-relevant e-portfolio to support learning claims.

Consideration is being given to including time-management as a mandatory element with explicit support as one of the three skills treated.

ACKNOWLEDGMENTS

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BIOGRAPHICAL INFORMATION

Tom Cosgrove is founding professor of the problem-based programme in Civil Engineering at the University of Limerick. He practised as a structural engineer for 28 years. He is a Fellow of Engineers Ireland and of the Institution of Structural Engineers. As well as his research in structural engineering he is currently pursuing action research on reflective writing in engineering education.

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Learning and Teaching Engineering Mathematics within an Active Learning Paradigm.

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ABSTRACT

The purpose of this paper is to report upon how using open-ended, ill-formed problems were used as a capstone project within a level 4 mathematics module to enhance students' higher order thinking skills and complement the competencies they develop through an active learning model. Specifically, it provided students with the opportunities to think mathematically, reason mathematically, pose and resolve mathematical problems, to use technology to model resolutions, interpret and handle mathematical symbolism and to communicate their resolutions to peers and staff.
The evidence from this investigation concludes that the majority of students found the experience challenging but worthwhile. They considered they had learnt important skills including the ability to form assumptions, persistence, time management, project management and enhancement of their mathematical skills in relation to engineering. Many students also thought it was a useful experience in their development as professional engineers.

KEYWORDS

Problem resolution, modelling, analysis, evaluation, synthesis, Standards:

BACKGROUND

An Active Learning paradigm has been at the heart of Mechanical Engineering and Design programmes for many years at Aston University.

Table 1, First-year Mechanical Engineering and Design programme.

YEAR 1	
Teaching Period 1	Teaching Period 2
ME1601 Engineering Science - 20 credits	
Forces and forces in structures, free body diagrams, Statics, mechanics, dynamics - plane and curvilinear motion	Basic fluids, Bernoulli, thermodynamics, heat transfer, heat and power cycles
ME1600 Electronic Engineering Fundamentals - 20 credits	
DC, charge, Kirchoff, Ohm, capacitance, op amps.	timers, binary, hex, microcontrollers
ME11EM Engineering Mathematics - 20 credits	
Arithmetic, eqn of line, logs, trig, complex no., vectors, calculus, introduction to MATLAB	Data, matrices, 1st order ODE, 2nd order ODE, fourier, vector calculus, MATLAB challenges
ME1501 Design and Experimentation - 30 credits	ME1502 Prototyping and Development - 30 credits
Design History File, creativity, erg & anthropometrics, package drawings, stress and design for strength, engineering drawings & geometrical tolerances	Wind energy, efficiency, power curves, user spec, PDS, aerodynamics, structural analysis, sankey & LCA, FMEA - CAD and Excel

[Type here]

Table 1 shows an overview of how the first year of the programme was designed. The programme comprises a series of major practical project modules which were developed in order to afford students the opportunity to learn engineering skills and knowledge of engineering processes in a more practical, experiential manner than the 'traditional' lecture approach. It was also recognised that, due to the nature of the students, underpinning theoretical concepts still needed to be taught. Due to this consideration, two theory modules, engineering science and engineering mathematics, were taught separately within the first year of the programme. The outcome from this approach was that students seemed to 'compartmentalise' their knowledge and skills i.e. the mathematics knowledge and associated skills they acquired were not necessarily transferred to other modules. Also, in many cases, students questioned the need to learn mathematics and its appropriateness for engineering. In order to ameliorate this situation, it was decided to align the engineering mathematics module closer to the approach taken in the practical project modules (Table 2). In other words, adopt a more active learning approach to the delivery of engineering mathematics. This alignment also resonates with the core philosophy of the CDIO syllabus. The CDIO syllabus states '…the three modes of thought most practiced by professional engineers are explicitly called out: Engineering Reasoning and Problem Solving, Experimentation and Knowledge Discovery, and System Thinking' (Crawley, 2001, p. 5). This has parallels with the Engineering Habits of Mind (EHoM) philosophy advocated by the Royal Academy of Engineering (Lucas, Hanson, & Glaxton, 2014). This report defines the EHoM as: Problem finding, creative problem solving, visualising, improving, systems thinking and adapting.

Table 2, Alignment of Design and Experimentation and Engineering Mathematics.

Stage	ME1501 Design and Experimentation – car project	ME11EM Engineering Mathematics – Matlab challenge
Conceive	Establish project scope and boundary. Specification for knowns. Assumptions for unknowns. Team dynamics. Project Management.	Establish project scope and boundary. Specification for knowns. Assumptions for unknowns. Team dynamics. Project Management.
Design	Apply appropriate mathematics and engineering science. Make design decisions. Develop prototype model.	Identify and apply appropriate mathematics. Make design decisions. Develop initial resolutions and produce Matlab models. Correct errors. Select final solution.
Implement	Produce engineering drawings. Produce manufacturing specifications.	Produce final solution.
Operate	Build and test.	Run Matlab model.

The implementation of 'engineering thinking' in a mainly practical module such as the Experimentation and Design, is reasonably straightforward but by no means unproblematic. Translating this approach to a theory based module such as engineering mathematics is challenging.

The report produced by the European Society for Engineering Education (SEFI) Mathematics Working Group (2013) was used as a starting point to identify the skills required by a contemporary engineer in terms of mathematical competencies. This report identified the key competencies as: thinking mathematically, reasoning mathematically, posing and solving mathematical problems, modelling mathematically, representing mathematical entities, handling mathematical symbols and formalism, communicating in, with, and about mathematics and, making use of aids and tools (p 14). This set of competencies enabled the process of developing an approach to 'engineering thinking' to proceed.

In order to start the process of acquiring these skills within engineering mathematics, it was decided to expose the students to open-ended, ill-formed problems (see Appendix 1 for an

example).   The students involved with this investigation were first-year undergraduate students studying Mechanical Engineering at Aston University.

The module was organised into three elements: semester one comprised of traditional lectures, tutorials and guided, self-directed learning on Matlab. Semester two took the form of the continuation of traditional lectures, tutorials and a problem resolution session.

For the problem (termed a challenge) resolution session, the students were organised into teams and told to select a challenge from a range of available briefs. Once they had selected a challenge they were expected to find and use appropriate mathematical formulae and procedures in order to develop an abstract model using Matlab. They were given talks on problem-solving and about working in teams. The assessment took the form of an academic poster which would be assessed by members of the Mechanical Engineering and Design faculty. Prior to the assessment day, the students were given instruction on how to design an academic poster. The staff members supervising the sessions were advised not to intervene at an early stage and let the teams struggle with the challenge.

LITERATURE REVIEW

Fundamental to engineering is the necessity for the engineer to be able to analyse a problem, identify the mathematics required to translate the physical scenario into an abstract model, interpret the results of the modelling process and communicate the resolution to managers and peers. The skills implicit within this process are known as higher order thinking skills and were identified in Bloom's Taxonomy (Forehand, 2005) as analysis, evaluation and synthesis. These higher order thinking skills are difficult to teach and for students to learn but are vital if the complex world of engineering is to advance. According to (Sazsin, 1998, p. 146) 'most engineering students think in terms of numbers rather than in terms of abstract concepts'. This 'attitude' towards mathematics tends to be encouraged at school or college where mathematics can be taught as a series of procedures analogous to a machine where one enters the inputs, performs a process which generates an output. At the other end of the spectrum, i.e. the professional engineer, the use of mathematical knowledge tends to be implicit. Engineers seldom apply the mathematics methods they learnt at university but frequently use the concepts when exploring engineering challenges (Treveyan, 2014). Whitfield (1975) makes the observation that the 'personality' of the engineer, when engaged in problem resolution, will be important, particularly the willingness and ability to form hypotheses and to tolerate uncertainty and risk. These attributes coupled with the ability to apply learned knowledge and skills enables the engineer to resolve the problem creatively. To expedite the process of moving from procedural knowledge to efficient and effective problem resolution and hence being able to employ the higher order thinking skills, engineering mathematics needs to foster the ability of students to explore a challenge and apply the knowledge and skills they have acquired and have the technical lexicon to discuss their resolutions. A word of caution is necessary when attempting a problem-based approach to the learning and teaching of engineering mathematics. In some cases, the pre-university learning culture of students is ignored. It should be born in mind that the students will come from a highly structured environment within which they are told what to learn, how to learn and when to learn. Genuine problem resolution is something very few, if any, have encountered before. These novice problem solvers, according to Sweller (1998) tend to employ a 'means-end analysis' approach (the approach often taught to students). In other words, they recognise the end goal (the solution) and use techniques to reduce the distance from the initial state (unsolved problem) to the end state by subdividing the problem into a series of sub-goals using problem-solving operators. This approach involves determining the end state, working backwards to identify sub-goals, identify operators and operations to be performed and then start from the initial state to solve the problem by working forwards towards the end state. Although this approach provides a 'safer' route to problem-solving (fewer dead ends and blind alleys) it does result in high cognitive loading. Sweller (1988) suggests that the processes involved at a cognitive level are: the problem solver must simultaneously consider the current

problem state, the end state, the intermediate goal states and the required procedures to reach intermediate goal states. In order to handle this amount of information, a huge amount of cognitive resources have to be used (particularly memory, recall of mathematical laws and procedures) which can result in the ability to learn schemas for problem-solving to be very limited due to lack of cognitive resources. This situation is further exasperated by the way in which novice problem solvers categorise problems; they tend to group according to the surface structures (Chi & Rees, 1982). In contrast to this, the expert problem solver is able to 'work forward' relying upon acquired schemas built upon the classification of previously solved problems based upon their solution mode.

The development of problem resolution schemas invariably means the student, at some point, will encounter an impasse ie. a point in the process which is unresolvable given their current knowledge and skills. These critical points can result in various outcomes. The student can, by means of trial and improvement resolve the impasse, seek help from those considered to be more knowledgeable, decide the current approach is inappropriate and start again or remain 'stuck' and become frustrated and ultimately disengage from the activity. This sort of behaviour is indicative of cognitive disequilibrium as described by D'Mello and Graeser (2010) In order to employ the higher order thinking skills and hence become competent problem solvers, students must be given the opportunity to develop schemas which enable them to efficiently, in terms of cognitive resources, resolve problems. The synthesis aspect of HOTS can be directly related to schema acquisition since, by definition, synthesis is the process of combining different elements to form a connected whole (related to the classification of problems). Analysis is the process of examining the problem in an organised way and evaluation is the process of determining the quality, effectiveness and efficiency of the problem resolution.

AIM AND OBJECTIVES

The question this paper seeks to address is: can the process of developing higher order thinking skills based on the acquisition of mathematical competencies be initiated within a first-year engineering undergraduate programme using mathematics as a vehicle? This question can be subdivided into:
   (a) Is there a process in which explicit knowledge can become implicit?
   (b) Can students learn to form realistic and sensible hypotheses?
   (c) Can students learn to tolerate uncertainty and take risks?
   (d) Can students learn to reflect upon there resolutions to offer a sensible solution?

METHODOLOGICAL APPROACH

At the end of the programme of study, the students were asked to complete a questionnaire about their experience of this approach to learning engineering mathematics. The questionnaire comprised of 25 questions broken down into sections on teamwork, problem resolution and learning mathematics. The questionnaire responses (a 5 point Likert scale) were analysed using IBM SPSS ver23 utilising a frequency of response analysis. Each week the investigator would keep field notes based on the questions asked by the students and on the outcome of discussions with each of the teams. Incomplete questionnaires were discarded. Ethical approval was sought and given for this investigation. 182 questionnaires were returned out of the 340 which had been issued (54% return rate). This mixed method provided the investigator with both quantitative and qualitative data which enabled him to cross reference the responses given in the questionnaire with the comments made by the students and with the observations. In this way, it was possible to achieve a realistic level of certainty regarding the validity of the data collected. This methodology was also based on work previously undertaken by the author (Peters, 2015; Peters, 2017)

KEY FINDINGS

Analysis of the questionnaire revealed that 68% of the students thought this approach improved their appreciation of the role of mathematics within engineering, 60% thought it made mathematics more interesting, and 77% thought it improved their mathematics knowledge and skills. Many students described their experience as 'challenging', 'rewarding', 'enjoyable', 'hard but fun', 'hard at first' and 'interesting'. Most of the students recognised that the skills they started to develop would help them on their journey to becoming professional engineers. The findings also highlighted that the majority of the students found it very difficult to make assumptions. They did not like the fact that they would have to find a starting point to begin the problem resolution process. Nor did they like the uncertainty around finding for themselves the mathematics they would need in order to resolve their chosen problem. They also found it difficult to cope with the notion of a problem being ill-formed with multiple potential answers. The idea of 'taking risks' and not relying upon a tutor to tell them what to do, again, was very challenging for many of them.

The students' resolutions to the following challenge illustrated some of the above observations.

Water Supply challenge:

> *'You have decided that you have had enough of living the 'rat race' culture prevalent in the UK. You have done some investigative work and decided to move to Northern Belize, buy some land and build a new life where you are in control. One of the first tasks, after building a shelter, is to build a water storage tank so you can have fresh water all year round.'*

The teams that chose this particular challenge soon discovered that they could use Torricelli's theorem to answer the initial tasks. When it came to them having to decide upon the initial conditions and the requirements they needed to take into account when designing their model, they began to struggle. For example, deciding upon an appropriate flow rate, deciding upon the amount of water they would require in addition to that required for drinking, how to collect the water and how to transport it to their dwelling.

The discussions with the students also revealed that they found it challenging when an impasse was reached in their investigation. In some cases, the impasse was resolved through group discussions, some groups would discard the resolution path they were following and restart the whole problem resolution process and others would 'give up' and seek help from a member of staff.

A subsequent cohort was asked about their experiences of working as a part of the team, problem resolution and how they thought this class helped them develop as professional engineers.

Team working.

The students were asked to describe their experiences of working in a team. In response to the question 'How would you describe your experience as working as part of a team?' the following statements were made: *it gave me insights into leadership and group dynamics, helped revise my maths knowledge, improved my social skills, helped me make connections, helped me to learn how to delegate, developed my logical thinking, taught me the difficulty in dealing with non-committed team members, built my confidence in speaking in public, developed my organisational skills and taught me to look at challenges in different ways.*

Development as a professional engineer (with regards to team working).

In response to 'How do you think this experience will have helped your development as a professional engineer?' responses included: *not much, sharing of ideas, empathy with others, accepting a consensus, learning to compromise, learning to cope with adversity, time management, improved organisational skills, importance of cooperation, childish and not useful, not to think people have the same mentality as yourself, made me feel better prepared*

for the future, learned to be creative and innovative, develop patience and improved my research skills.

Problem resolution

In response to 'How would you describe your experience of problem resolution?' answers included*: challenging, useful, value of research, tough, presenting results difficult, enhanced communication skills, rewarding, excellent, found it challenging to make assumptions, developed my critical thinking skills, found it difficult on deciding on appropriate maths to use, finding a starting point was difficult, fulfilling, quite an adventure, helped me develop trial and error technique, makes you really think and makes you think outside the box.*
Development as a professional engineer (with regards to problem resolution).
When asked 'How do you think this experience will have helped your development as a professional engineer?' responses included: *not very much, taught me to seek help when needed, to work in a team effectively, project management particularly the allocation of resources, maintained my interest in engineering, in gave me the opportunity to put maths into context, it allowed me to apply my knowledge to real world problems, it gave me something to speak about in interviews, help me develop thinking methods to overcome challenges, it taught me perseverance, it provided preparation for the workplace, helped me to develop initiative and taught me how to learn from my mistakes.*

DISCUSSION

Although from a preliminary reading it may appear that this approach does not reflect much of a change from a traditional engineering mathematics curriculum. One of the reasons the module was designed in this way was to ease the transition from the highly ordered learning environment of a school or college to one where the learner was expected to take more responsibility for their own learning. It was decided that if a purely problem-based approach to learning engineering mathematics was adopted then many of the students would be overwhelmed, with the net contrary result of inadvertently putting in place a substantial barrier to learning. The different elements of the module were designed with specific purposes in mind. The traditional lectures and tutorials were elements the students would expect from a university programme and thus feel they were being 'taught'. They also provided a means of the students enhancing their mathematical knowledge and skills. The guided, self-learning of Matlab afforded the students the opportunity to begin the journey of becoming autonomous learners. In semester two the students would then have a reasonable probability of successfully resolving an open-ended, ill-formed problem. Another reason this format was adopted was to focus on what was meant to be learned without imposing a huge cognitive load. In other words, once the students were confronted with their chosen challenge, they should have had various schemas in place, albeit in an embryonic form, so they would be able to focus and direct their cognitive resources to find a sensible, efficient and valid resolution to their challenge. The challenges themselves could be resolved with fundamental mathematics but also higher level mathematics could have been used if the teams were confident and competent in such procedures. The emphasis was very much upon the teams to decide the mathematical 'tools' they needed to resolve the challenge.
Although many of the mathematical competencies listed in the SEFI document are not explicitly recognised by the students, many of them are implicit in the process of developing a Matlab model to resolve a problem. Due to the nature in which the class was run, students had to think and reason mathematically without relying on a tutor to provide them with the 'answers' if they encountered difficulties. Many students found this extremely challenging to start with and asked questions like 'what equations do I need?', 'how do I code this in Matlab?', 'Is this assumption right?' Staff were encouraged not to intervene and encourage students to adopt the principles of problem resolution as detailed in the information they were given during the delivery of the programme. At the start, the students found this response difficult to deal

with since making assumptions, being allowed to make mistakes and having to find information for themselves was not something they were used to. After a few weeks, the students realised that the staff would guide them but not answer specific questions.

The students were also informed to use the problem worksheets as a guide and encouraged to develop the problem by posing 'what if?' type scenario questions in order to extend the problem to reflect the realities of providing a sensible resolution. Inherent in the problem resolution process is the need for the students to represent physical entities mathematically using conventional notation. This invariably involves them in handling mathematical symbolism and having to interpret the equations and expressions in order to apply them to their particular challenge.

Team working

It was apparent, from observations, the more successful teams set up a means of communicating outside of the scheduled class. They utilised such technologies as on-line chat systems and arranged meetings to discuss their projects. These teams also engaged in meaningful discussions about their challenge and in the main, settled on the consensus as to proceeding with their resolution. At times some of these discussions were quite critical and in danger of becoming very heated especially where one of the team members held strong opinions on how to resolve the challenge. There were some personality clashes in some of the teams which resulted in the alienation of certain members. The major issue with non-functional teams was around team members not attending the class or arranged meetings. This led to a lot of frustration for the team members who were committed to resolving the challenge.

Problem resolution

Observation of the teams revealed some of them were confounded by the prospect of not being given the equations necessary to resolve their challenge. Initially, the majority of the teams would ask what equations were required or the Matlab code they needed. The facilitators were informed not to answer these questions directly but to guide the teams in how they approached the resolution of their chosen problem. From a student perspective, especially those who had no or very little experience of genuine problem solving, this was a major challenge. They had become acclimatised to solving problems where there was only one correct answer and metaphorically speaking, using a mathematics machine where you inputted the values for given variables and the answer came out the other end. It seems the notion of trial and improvement was not a procedure they were comfortable with. A key comment was about the learning of perseverance. Too often, from observations, the teams would be ready to give up when they encountered a problem which they perceived as complex or impossible to resolve. This attitude diminished as the class progressed and their confidence and competence in problem resolution increased. This development was confirmed by comments such as 'helped me to develop initiative and taught me how to learn from my mistakes'.

It was also interesting to note the way the teams went about selecting a problem. Most of the teams selected a problem on their perception of how easy it would be to 'solve'. In some instances, this proved to be an erroneous process. For example, one challenge was to design a speed control hump to stop vehicles speeding through a built-up area. On the face of it, the students thought this would be straightforward but once they tried to mathematically model a speed hump they realised that it was not straightforward.

The assessment via a poster was introduced in order to afford the opportunity for students to discuss their work with members of staff. In the first instance, the students were expected to outline the problem, how they went about developing a resolution and how their particular resolution provided a good solution to the challenge. They were then asked specific technical questions about their resolution. Students found this method of assessment more challenging than they first expected but some commented on how the experience built their confidence for future presentations and how it taught them to prioritise information related to their resolution. The consensus from the students can be summarised by a statement made by one of them:

'It was a good idea to allow students to think and build their projects around their own assumptions and thoughts. Allow them to have a better insight on how to manage team and time.'

The different forms of assessment for this module were designed to assess specific aspects. The summative, terminal examination was designed to test the students' procedural knowledge, the Matlab model building their conceptual knowledge and the poster their communication skills and ability to work as an effective member of a team.

CONCLUSIONS & RECOMMENDATIONS

There is an inherent danger that current engineering education is producing graduates who can perform well in examinations but in reality, do not possess, what the RAE has termed, the Engineering Habits of Mind (EHoM) or what the CDIO syllabus refers to as Engineering Reasoning and Problem Solving, Experimentation and Knowledge Discovery. The outcome from this educational process is that many graduates are only capable of solving well-formed, closed-problems ie. the type of question given in an examination which only requires the application of a well-defined procedure. This situation, therefore, requires many companies having to invest in the extensive training of graduate engineers in order for them to be useful employees of the organisation.

This study has shown that the majority of students when they first arrive at a university are competent in applying their procedural knowledge of mathematics but when it comes to analysing and resolving a simple engineering problem, they find it extremely challenging to make assumptions, identify and select appropriate mathematical constructs in order to create an abstract model and interpret the outcomes from their model. It has also shown that their ability to ask the 'right' questions in order to work towards a problem resolution is limited. They also seem to lack fundamental skills in working within a team, communicating technical ideas, prioritising activities in relation to managing their time.

In a purely traditional model of teaching engineering mathematics ie. lecture, tutorial and examinations, the students are rarely given the opportunity to articulate their ideas and discuss mathematics. Most traditional forms of assessment take the form of class tests and examinations which, by their very nature, make it extremely difficult to assess HOTS and do not encourage teamwork or the ability to communicate technical information, particularly mathematics. Unfortunately, this adherence to a 'traditional' approach tends to be advocated by the Professional Bodies and many universities who are more concerned with the elimination of opportunities for students to cheat and plagiarise even though evidence (RAE, 2010) from reported conversations with professional engineers suggest that authentic problem solving, teamwork and the ability to communicate ideas are extremely important and more specifically: "industry … regards the ability to apply theoretical knowledge to real industrial problems as the single most desirable attribute in new recruits. …' (RAE, 2007).

In an ideal world engineering mathematics would be integrated within other technical subjects and hence eliminating the 'subject silos' of engineering programmes which are encouraged by a modular based system. A more project-based approach should also go some way to encourage students to become 'deep' learners rather than 'strategic' ones where they focus on passing modules in the hope of accumulating enough credits to pass the year. The totally project-based approach has numerous challenges, such as accreditation, assessment, moving away from a teacher-centric approach to a student-centred approach and the management of student and staff expectations.

Engineering schools who are actively looking for alternative ways to facilitate the learning of engineering mathematics must be cognizant of the entry profiles of their students. Universities who are considered to be high tariff institutions would probably attract students who are confident and competent enough to cope with a project-based approach whereas institutions at the other end of the scale, or who lower entry criteria for clearing, would have to ensure a

robust academic support structure was in place to provide a safety net for students who would struggle in such an environment.

By the end of this module, many students appreciated the opportunity to start to develop the skills required by an engineer in the 21st century. In terms of this investigation, the students started to develop the stated mathematical competencies and hence develop schemata whereby explicit knowledge became implicit. They also developed in confidence and learned to trust their own abilities with the realisation that they may not always be correct. They also began to develop a critical evaluation mindset whereby they were able, as a team, to look at their resolutions and decide whether they were sensible.

In order to continue the development of EHoM this approach of allowing students to tackle ill-formed, open-ended problems should be continued throughout their time at university and incorporated into the other subjects they study. This process will not produce engineers who are competent on graduation to resolve the many complex problems inherent in our modern world but it will give them a firm foundation and mindset on which companies can shape the engineers they require.

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APPENDIX 1

Applying Mathematics - Supplying Water

**Scenario**

You have decided that you have had enough of living the 'rat race' culture prevalent in the UK. You have done some investigative work and decided to move to Northern Belize, buy some land and build a new life where you are in control. One of the first tasks, after building a shelter, is to build a water storage tank so you can have fresh water all year round. In your investigations you found out that Northern Belize has a rainy season between June and November where, on average, 1524mm of rain falls. You decide upon a cubical tank with a water outlet at the bottom. Your initial 'guess' at the dimensions for your tank were: sides 3m

with a drain hole of diameter 0:1m. Unfortunately you can only find information on a cylindrical tank as shown in the diagram.

Initial Tasks
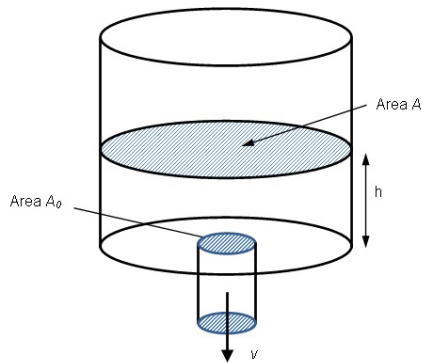
(a) Find a differential equation relating the height, h of the water at a time t. (b) Solve this equation for the initial conditions t = 0,h = 2. (c) How long, in minutes, does it take to empty the tank which is 2m full? (d) Decide how much fresh water you require per year and design an appropriate size tank.

Main Task

Using Matlab develop a mathematical model to investigate different sizes of tanks and different flow rates so you have access to water all year round.

BIOGRAPHICAL INFORMATION

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