DIGITAL DESIGN LITERACY IN K–12 EDUCATION

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PhD Dissertation 2019
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ABSTRACT

This dissertation addresses the introduction, sustainment and articulation of digital design literacy in K-12 education. It is the result of my four years of research in the FabLab@school.dk research and development project. Within this project, I have researched the topic through constructive design research experiments on both students' and teachers' experiences and competencies with digital design as new subject matter in K-12. The contributions presented in this dissertation are positioned within the emerging research field of making in education. The contributions concern new possibilities that making in education creates for K–12 students to develop competencies to design and critique digital technologies. The point of departure for my work was to explore how the implementation of maker settings and technologies might provide novel ways to combine constructionism, design and digital technology with the intention of having students develop digital design literacy. Hence, this dissertation is a response to the question of how to educate K–12 students to understand, use, critically reflect on, and design digital technologies through the emerging educational possibilities enabled by maker activities, maker settings, and maker technologies. The dissertation is comprised of five research papers and two reports framed by an overview that sum up the arguments made in the papers and the contributions from these come together as a whole.

The first contribution is a conceptual understanding of digital design literacy. I lay out a genealogy of traditional literacy toward new literacies to legitimize digital design as a new literacy in K–12 education. I contribute an understanding of how design and digital literacies are interrelated, can mutually benefit one another, and be synthesized and articulated holistically as integrated digital design literacy.

The second contribution are quantitative measures of the state-of-the-actual in terms of students' digital, design, and critical literacy and an assessment tool for quantitatively evaluating students' stance towards inquiry, which I argue to be an important competence of digital design literacy.

The third contribution is an understanding of three crucial aspects which must be considered when developing teachers' capability to teach digital design literacy. I point to impediments for such teaching and to existing practicing teachers' limited possibilities to meet demands presented by teaching digital design literacy. I contribute a framework for educating reflective design educators who can support students in developing digital design literacy.

The accumulation of these three contributions has resulted in what is the main contribution of this dissertation overview: The Digital Design Literacy Framework. The framework contributes a

legitmaziation, articulation and operational definitions of digital design as a new literacy and its underlying competencies.

RESUMÉ

Denne afhandling udforsker hvordan digital design dannelse kan introduceres, opretholdes og artikuleres i grundskolen og er resultatet af mine fire års forskning i FabLab@school.dk projektet. Afhandlingens emne er blevet undersøgt gennem adskillige konstruktive designforskningseksperimenter. Disse eksperimenter fokuserer på skoleelevernes og lærernes oplevelser og kompetencer med digitalt design som et nyt fag i grundskolen. Udgangspunktet for mit arbejde har været at undersøge, hvordan implementeringen af *maker settings* og *maker teknologier* kan bidrage med nye måder at kombinere konstruktion, design og digital teknologi med til henblik på at udvikle digital design-kompetencer blandt elever i grundskolen. Mere specifikt adresser denne afhandling, hvordan sådanne settings og teknologier kan stoette studerende i at udvikle kompetencer til at designe og kritisere digitale teknologier.

Afhandlingen adresserer spørgsmålet om, hvordan grundskolen kan forbedres ift. at uddanne elever til at forstå, bruge, kritisk reflektere over og designe digitale teknologier gennem de nye muligheder, som maker aktiviteter, maker settings og maker teknologier repræsenterer.

De bidrag, der præsenteres i denne afhandling, er placeret inden for forskningsfeltet, *making in education*, som er et fremspirende underfelt til Child-Computer Interaction og Interaction-Design and Children. Afhandlingen består af fem forskningsartikler, to rapporter og denne sammenfattende artikel, som opsummerer argumenterne i de enkelte publikationer og binder bidragene sammen. Samlet set bidrager afhandlingen med følgende indsigter:

Det første bidrag er en konceptuel forståelse af digital design dannelse. Jeg fremlægger en genealogi fra traditionel dannelse til nutidens udvidede forståelse af dannelse, for at legitimere digital design som en ny literacy. Bidragene omfatter definitioner af centrale begreber som færdigheder, kompetencer og dannelse og relaterer disse til kritisk tænkning, digitale teknologier og design. Jeg bidrager med en forståelse af den gensidige forbundethed mellem design- og digitale kompetencer, og af hvordan disse kan syntetiseres og artikuleres som digital design dannelse.

Det andet bidrag er kvantitative målinger af elevernes digitale, design og kritiske kompetencer og et værktøj til kvantitativ evaluering af elevernes tilgang til at løse komplekse problemer i samfundet vha. design (*stance towards inquiry*), som jeg argumenterer for at være en vigtig digital design kompetence.

Det tredje bidrag er en forståelse af tre vigtige aspekter, som skal overvejes, når skolelærere skal udvikle evnen til at undervise i digital design. Jeg fremhæver en række barrierer for sådan undervisning og læreres begrænsede muligheder for at imødekomme krav, der præsenteres ved at undervise i digital

design. Jeg bidrager med teoretiske og praktiske rammer for uddannelse af skolelærere, der kan støtte eleverne i at udvikle digital design dannelse baseret på teoribaserede forelæsninger og workshops kombineret med nuværende lærerpraksis i grundskolen. Dette bidrag overlapper med det første bidrag, da det informerer mine artikuleringer af digital design dannelse ved at pege på, hvilke kompetencer lærerene mangler og relaterer dette til teori om design ekspertise.

Sammenfatningen af disse tre bidrag har resulteret i *Digital Design Literacy Framework*. Modellen bidrager med artikuleringer og operationaliserer digitalt design dannelse som et nyt fag i grundskolen.

CONTENTS

1 INTRODUCTION

"If design is to become a third area in general education, a fundamentally different approach to traditional methods of teaching and the education of its teachers is needed." (A. Cross 1980, 205)

Children grow up in a world where digital technologies are omnipresent and shape their daily lives (see R1).[1] The computers and phones we communicate with, the cars and planes we travel in, the homes, schools, and universities that we inhabit, our food, clothes, entertainment, and medical care—all have been and are increasingly affected by new technological developments. Besides being the backbone of Western societies, digital technology is also at the root of complex challenges and problems faced on a global scale, such as online privacy and surveillance or design digital technologies that produce throwaway cultures resulting in environmentally damaging e-waste. This trend has also influenced the way students learn, play, communicate, and socialize. The rapid development and integration of new digital technologies into K–12 education and students daily lives have several consequences for future societal developments. This change is well-documented both internationally (Baller, Dutta, and Lanvin 2016) and in Denmark (Taenktanken Cevea and HK Danmark 2015), which stands as the backdrop for the work presented in this dissertation. Simultaneously, an increasing volume of digital technology that promises to enhance existing learning practices is moving into schools—a promise that often entices educators and politicians to prioritize investments in digital technologies. The interest in technology-supported learning has long been a topic of interest among researchers and professionals, and there is no shortage of digital technologies designed for K–12 education to scaffold learning of various subjects (see, e.g., Alpert and Bitzer 1970; Papert 1993; Resnick, Bruckman, and Martin 1996; Fulton 1998; Hew and Brush 2007; Blikstein 2013b). However, it is not always clear how best to incorporate digital technology in K–12. One promising way of integrating school activities associated with technology is *making* (Blikstein 2013a; Martinez and Stager 2013; L. Martin 2015; Iversen et al. 2015; Bevan 2017). Making involves hands-on design, construction, testing, and revision of a variety of artifacts, typically integrating digital technologies assembled with physical materials that allow for a range of practices related to disciplines such as art, design, engineering, craft, and mathematics. Making presents new ways to have students proactively engage with projects that involve technologies and materials in ways that make students creators rather than consumers of technology (Halverson and Sheridan 2014; Smith, Iversen, and Hjorth 2015; Giannakos, Divitini, and Iversen 2017). This dissertation is a response to the question of how to educate K–12 students to understand, use, critically reflect on, and design digital technologies

[1] The publications included in this dissertation are notated P(*n*) or R(*n*), where n is the number of the publication (see section 1.3).

through the emerging educational possibilities enabled by maker activities, maker settings, and maker technologies. Making in education has garnered widespread interest and support in research, policy, and education circles. It is the new promise for putting digital technologies into a meaningful service to advance educational practices, thus overcoming the lack of results regarding real change in teaching and learning with digital technology (Blikstein 2013a; Martinez and Stager 2013; L. Martin 2015; Bevan 2017). National and international literacy frameworks for the 21st century[2] mention creativity, critical thinking, problem-solving, and the competence to design innovative products as educationally valuable and are regarded as important compentencies (Voogt and Roblin 2012a, 309). These frameworks acknowledge that the rapid development of digital technology requires a new set of compentencies that go beyond the operational use of digital technology (Voogt and Roblin 2012a).[3] Hence, I claim throughout this dissertation that we need to educate and empower students to design and shape digital technologies themselves. A promising way to have students go beyond operational use of digital technology is the discipline of *digital design* (Hjorth and Iversen 2014; Bekker et al. 2015; Smith, Iversen, and Hjorth 2015), which stands as the overarching topic and catalyst for the research presented in this dissertation. Specifically, I investigate digital design as a *literacy—digital design literacy*, a concept not yet explored in the literature on making in education (see section 2.2 for an elaboration on the notions of skills, compentencies, literacy, abilities, etc.).

The purpose of this dissertation is to contribute knowledge and practices to understand better why and how to introduce, sustain, and articulate digital design literacy in formal K–12 education through making, specifically the *udskoling* phase in the Danish *folkeskole* (public municipal school).[4] The point of departure for my work with making in education was to explore how the implementation of maker settings and technologies might provide novel ways for students to develop digital design literacy. In contrast to the literature on other literacies, for example, language or media literacy, an understanding of digital design literacy is still not fully explored. One of the challenges in addressing making in education as a design researcher is the lack of a language for articulating what constitutes digital design literacy, whereas other paradigms such as STEM have well-developed vocabularies. In this dissertation, I align my studies according to these shortcomings. Hence, this dissertation is directed at gaining better

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[2] I restrain myself from using the notion of 21st-century competencies. It is impossible to know what competencies are important for the duration of a century.
[3] I use the notion of digital rather than ICT, but they are essentially referring to the same thing—competencies with digital information technologies.
[4] The Danish *folkeskole* covers the entire period of compulsory education from the age of 6 to 16, encompassing pre-school, primary, and lower secondary education. I have primarily worked with Danish adolescents aged 11-15 years old, which in the K-12 system roughly translates to (lower) secondary education.

understandings and articulations of how design education combined with new digital technologies and maker settings makes way for the exploration and teaching of digital design literacy. In exploring these topics, **I ask the following research question**:

How can digital design be introduced, sustained, and articulated as a new literacy through making in formal K–12 education?

The research question is at the core of this dissertation, which presents four years of research into digital design literacy education in K–12 maker settings. My interest lies in bringing design as a new liberal art of technological culture into K–12, exploiting the new educational potentials created by the introduction of making in education. The context of maker settings in schools provides advantageous settings for investigating the dissertation's research question, which is concerned with novel and distinct cases of introducing digital technologies and settings for design thinking (N. Cross 2007b, 2011). Making relies on digital technology, which also holds for design education, as design deals with the artificial, human-made world (Löwgren and Stolterman 2004). This framing allows me to investigate maker and design activities with maker technologies to develop digital design literacy among K–12 students. My research sheds light on the introduction of digital design and making in education from different but interrelated viewpoints. These viewpoints are elucidated along three trajectories, each with its own investigative perspective on digital design literacy: (1) conceptual, (2) measurement and assessment, and (3) educator. I elaborate on the three research trajectories in section 1.1.

The accumulation of the three trajectories has resulted in what is the main contribution of this dissertation, the *Digital Design Literacy Framework* (see chapter 4), which conceptualizes, articulates, and operationalizes digital design as a new literacy for K–12 schools that bank on making in education as being a promising mode of teaching and student competence development. Each of the included papers presents distinct research questions, findings, lines of argument, and contributions but are all motivated by my overarching research question, to which they provide partial answers. Not all contributions from the included papers directly inform the Digital Design Literacy Framework (see chapter 4), yet they are valuable and original contributions in themselves.

The contributions presented in this dissertation are positioned within the *turn toward making in education,* specifically the new possibilities that making in education creates for K–12 students to develop compentencies to design and critique digital technologies. *Making in education* encapsulates an emerging subfield of Interaction Design and Children (IDC) and Child-Computer Interaction (CCI)[5] that draws on the ideas and practices from the *maker movement, fabrication labs (FabLabs)*, and hacker cultures. Common to these cultures is a do-it-yourself (DIY) mindset, an interest in technology, hybrid making, and design. Exploring these various interests happens in *maker settings*. Maker settings are collaborative work spaces residing at schools, libraries, and other separate public and private facilities for making, learning, exploring, and collaborating. Maker settings are generally stocked with similar types of equipment and technologies such as digital fabrication machining, electronics, hand- and craft tools, 3D printers, and physical interaction technologies (Chu et al. 2015). The research presented in this dissertation has been undertaken in K–12 maker settings. I define maker settings that reside in K–12 as explorative educational settings that combine design thinking and digital technology with hybrid crafting to provide novel means of creating artifacts and creative expression meant to teach students to identify and design solutions to complex problems that exist in the world. Making opens new educational possibilities by focusing on the construction of artifacts and emphasizes the use of digital technology, both as a tool and a design material to be shaped (Hallnäs and Redström 2006). Technology is any intentional modification or design of the natural world done to fulfill human needs or desires (Löwgren and Stolterman 2004). With this interpretation of technology, I subscribe to the argument that technology, by being produced as artificial, is to be contrasted with the natural (Ihde 1990); a tree is natural, but the saw to cut branches is technology brought into the world by humans.[6] Digital design encompasses creating, shaping, and deciding on the use-oriented qualities of digital technology. The result of a maker or digital design process is digital artifacts, which can be referred to by terms such as systems, programs, innovations, or products. Thus, making in education provides students with new opportunities and means to shape their own technology and practices, which resonate well with IDC's ambition to enhance children's ability to understand, reflect on, and act critically in a digitally mediated world (Hourcade 2015).

The academic field of making in education emerged from a focus on STEM education, based on a renewed interest in Papert's constructionism (Papert 1993) and the new possibilities with digital fabrication technologies such as 3D printers and physical interaction technologies such as Arduino (Blikstein 2013a; Dittert and Krannich 2013; Blikstein and Krannich 2013; Walter-Herrmann and Büching 2013). These technologies are becoming more affordable, easier to use, and are often free/libre

[5] The "sister" venue of IDC.
[6] A detailed discussion on the concept of technology is beyond this dissertation, for such musings, I refer to Dewey's pragmatism (Levin 1956; Dewey 2007; Hickman 2017) and the postphenonmological perspective of Ihde (1990) and Verbeek (2005) on which my definition of digital technology rests.

software, which makes for easier collaboration, exchange of knowledge, and hacking of hardware and software[7] (Dougherty 2012; Blikstein 2013b; Walter-Herrmann and Büching 2013; Chu et al. 2015). Hereafter, I collectively define such technologies as *maker technologies*. Maker technologies refers to digital technologies and analog materials used in maker settings. Their design is primarily functionalist, giving its user the ability to make and design new artifacts, usually blending digital- and physical materials. Maker technology invites its users to tinker and create something of interest, which stands in opposition to more traditional consumer products such as videogames[8] or screen-based software that scaffolds students in learning subjects such as math or English.

The main contribution of this dissertation is a conceptualization of digital design literacy, articulated and developed as a framework that encompasses the contributions made in the included papers, intended for making in the education community the Digital Design Literacy Framework (see chapter 4). **This elaboration ties together the notions of design and digital literacy as articulated in the included papers, revisits of these, and new discussions on the issue found in this dissertation.** Moreover, the included papers are contributions in themselves, and while they all pursue different arguments and questions, they are all motivated by my overarching research question, to which they provide partial answers. The contributions presented in this dissertation are aligned along three research trajectories, each investigating the introduction, sustainment, and articulation of digital design literacy from three related perspectives that are essential for successfully bringing digital design as a new subject to be taught in K–12. In the next section, I outline the three trajectories that run through this dissertation.

1.1 Contributions and Research Trajectories

This section outlines how my research contributions can be traced along three intertwined trajectories that each partially answers my research question and contributes to the Digital Design Literacy Framework. Each of the three trajectories sheds light on the introduction of digital design literacy in K–12 from different but interrelated perspectives.

(1) Conceptual trajectory: This trajectory aims at providing a conceptual understanding of digital design literacy. I lay out a genealogy of traditional literacy toward digital design literacy in K–12, in that my focus is directed at legitimizing and articulating digital design as a new literacy in K–12 education. This includes defining central concepts such as skills, compentencies, and literacy and relate these to critical, digital, and design literacy. From this trajectory, I contribute a conceptual understanding of how design

[7] The Arduino microcontroller platform is a successful example of this.
[8] This is an oversimplification as video games might contain tools for “modding” https://en.wikipedia.org/wiki/Mod_(video_gaming) (accessed 20/11/2017).

and digital literacies are interrelated, can mutually benefit one another, and be synthesized and articulated holistically as integrated digital design literacy. In particular, I present a framework to articulate digital design literacy in the respect that I aim not only to use the concept to illuminate my work, as presented in the included papers, but also develop the concept itself by revisiting my papers and discussing how they contribute to answering my research question of how to introduce, sustain, and articulate digital design as a new literacy. The conceptual trajectory aims to be accountable to both theory on design expertise and exemplary practices that unfold when K–12 students engage in digital design in maker settings. Hence, I have sought to bridge what literature on design expertise argues to be important compentencies with the real-world examples of students and teachers learning digital design. The conceptual trajectory takes three perspectives, each of which highlight features of digital design literacy:

***(1.1) design perspective*:** This perspective focuses on understanding the design aspect of digital design literacy. Based on the literature of expert designers, I discuss what constitutes design competence, to what degree students and teachers have these compentencies, how the compentencies can be bridged with authentic exemplars of students practicing digital design in maker settings, and finally, how digital design can be articulated as a K–12 literacy. The outcome of this discussion, as well as my research findings, has led to the articulation of three important and challenging compentencies of digital design literacy. Specifically, their *stance towards designerly inquiry*, competence to *navigate complex design processes*, and *managing materials* used in design processes (see P1, P2, P4, and P5). My studies show that these three compentencies are challenging for students and teachers alike and create impediments for teaching digital design literacy. In chapter 4, I expand upon these findings and make further theoretical articulations on what can be considered important aspects of digital design literacy. The identified aspects of digital design literacy should be seen as proposed tools for questions, elaboration, and making informed choices when introducing digital design in making in education.

***(1.2) digital technology perspective*:** This perspective focuses on the use of digital technologies as a central part of K–12 maker settings. As part of introducing and sustaining making in education, I contribute a framework and language for analyzing the design qualities of four maker technologies, specifically, their *form properties* and the *coupling between user action and functionality feedback*. The main contribution of the framework is an expansion of design language to articulate design qualities of maker technologies. Such articulations are a fundamental element for people involved in a knowledge-constructing design culture. These analytical articulations include (1) reflections on form properties of maker technologies, (2) analysis of the relationship between user action and technology function (action-function couplings), and (3) how this relates to feedback when children use these technologies to design digital prototypes. Designers can use the presented framework to improve existing designs or prepare them for future designs. Researchers can use the expanded design language to analyze qualities of maker technologies. The framework provides a language to help students and teachers develop their language repertoire to talk about digital technology and better articulate, communicate, and make judgments on maker technologies in design processes. Finally, the examples chosen illustrate how maker technologies can be considered a particular genre of digital artifacts.

(1.3) critical perspective: From this perspective, I have theoretically explored the concept of critical digital literacy, investigated students' knowledge, experiences, and concerns in regard to online data tracking, and employed novel means of teaching critical digital literacy in K–12. As it is widely accepted that digital technology influences large parts of human life, in P5, I argue that a critical consciousness and the ability to reflect on sociotechnical phenomena and developments are needed. Critical digital literacy informs the concept of a digital design literacy with a critical perspective and points toward the need for students not only to create digital artifacts but also to reflect critically and retrospectively on how other digital artifacts are designed and used. Critical thinking is oriented backward, unlike design and making, which shape the future through the creation of artifacts in a forward-moving manner. I have empirically explored the critical perspective in P5, which did not involve maker activities. Instead, the workshop, which provided me with empirical data, was intended to explore and develop students' repertoire of examples and understandings that are exemplary of critical contemporary sociotechnical issues, in my case, online data tracking and surveillance. This repertoire construction requires an articulation language and understandings suited for describing and analyzing digital artifacts, systems, and their social impact. The designer can benefit from reconstructing thoughts and ideas that may have led to a specific design. Developing a solid repertoire of exemplars to draw upon is important (Schön 1984, 138–41; Löwgren and Stolterman 2004, 47, 166).

I consider the critical dimensions to be nested within digital literacy. Thus, when I refer to digital literacy, I also refer to critical digital literacy as a subset. However, there are instances throughout this dissertation where I need to refer specifically to critical digital literacy in order to map out the critical dimension of digital literacy in detail.

(2) Measurement and assessment trajectory: This trajectory aims at getting a quantitative understanding of the state-of-the-actual in terms of students' digital, design, and critical literacy. We live in an age of measurement (Biesta, 2010), and thus there is a need to develop tools for quantitative assessment of what we value instead of valuing what we can currently measure—in my case, a basic assumption is that digital design is valuable to K–12. This is especially true for the Danish context, where the educational policy requires evaluation tests to assess student development (Bryderup, Larson, and Quisgaard Trentel 2009). From this perspective, I have contributed knowledge on two levels.

(2.1) This level comprised two large-scale surveys, a baseline and a follow-up. The baseline investigated students' use, experiences, and understandings of everyday digital technologies. The follow-up investigated their ability to employ more advanced technologies as a means to create artifacts proactively. The two surveys also touched upon students' design compentencies and their critical thinking toward sociotechnical challenges. The baseline survey was intended to get an initial understanding of the state-of-the-actual regarding students' digital, critical, and design literacies through the implementation of design-focused making in education. The follow-up survey aimed to determine whether students' who had participated in the FabLab@school.dk project had further developed these compentencies. As reported in R1 and R2, students' self-perceived gains from implementations of making varied greatly between schools. The students' responses suggested that in schools in which students worked with their own ideas scaffolded around a diverse range of digital technologies and had their work structured around a generic design process model, had on average become better at imagining intentional change with technology, working proactively with technology, understanding how new technologies are coming into the world, and understanding how technology is affecting our lives as well as improving or worsening complex problems in the world. The survey results suggested that there is a potential and need for teaching digital design literacy in maker settings in formal K–12 education in Denmark. The contributions to this turn are especially evident in R1, as well as P2 and P4, which discuss the quantitative evaluation of the impact of making on students' digital design literacy.

(2.2) To accommodate the need for quantitative assessment tools for digital design literacy, I developed an assessment tool to gauge students' stances toward inquiry—an important aspect of digital design literacy. The Design Literacy (DeL) assessment tool presented in P1 consists of a qualitative survey question, a coding scheme for assessing aspects of a designerly stance towards inquiry, and a description of how I have validated the results based on findings from survey administration in K–12 education. Thus, I contribute a tool to capture and assess the state and development of K–12 students' stance towards inquiry. By applying the DeL tool, Danish K–12 students seem to approach wicked problems primarily as tame problems. That is, they do not approach wicked problems with a designerly stance towards inquiry. Instead, K–12 students seem to approach the wicked world with a stance of technical rationality, drawing on formalized solutions and routine expertise. The DeL tool is meant to provide educators, school leaders, and policy makers with strong arguments for introducing design literacy in K–12 schools, which function within an age of measurement.

(3) Educator trajectory: My focus on digital design education in K–12 calls for new pedagogical approaches to teach digital design literacy. Through a research-based master's course aimed at bettering facilitation and to support co-development of new teaching practices, I report on the challenges that teachers face when teaching digital design literacy to K–12 students. In P2, I conclude that there are three crucial aspects which must be considered when developing teachers' capability to teach digital design literacy: (1) understanding and navigating a complex design process, (2) managing digital technologies and design materials, and (3) balancing different modes of teaching involved in design and making in education. I point to impediments for such teaching and to existing teachers' limited possibilities to meet demands presented by teaching digital design literacy and argue why these three compentencies are essential to digital design literacy. From this trajectory, I have contributed a framework for educating reflective design educators who can support students in developing digital design literacy. Additionally, I have contributed an understanding of what compentencies teachers find challenging to acquire. The framework flows along three axes: (1) theory-based lectures and workshops, (2) peer-collaboration, and (3) teachers' practice in schools. This trajectory also overlaps with the conceptual trajectory, as it informs my notion of digital design literacy by pointing out what compentencies' teachers lack to overcome these three challenges.

The three trajectories are schematically illustrated in fig. 1. The dotted frame represents the turn toward digital design literacy that my research is situated in. The left-side arrows highlight the supporting and scaffolding role of maker technologies and teachers. The straight-lined square depicts the maker settings context. The Venn diagram shows how the (critical) digital and design literacies are intersecting and form a digital design literacy that this dissertation contributes an expanded understanding of.

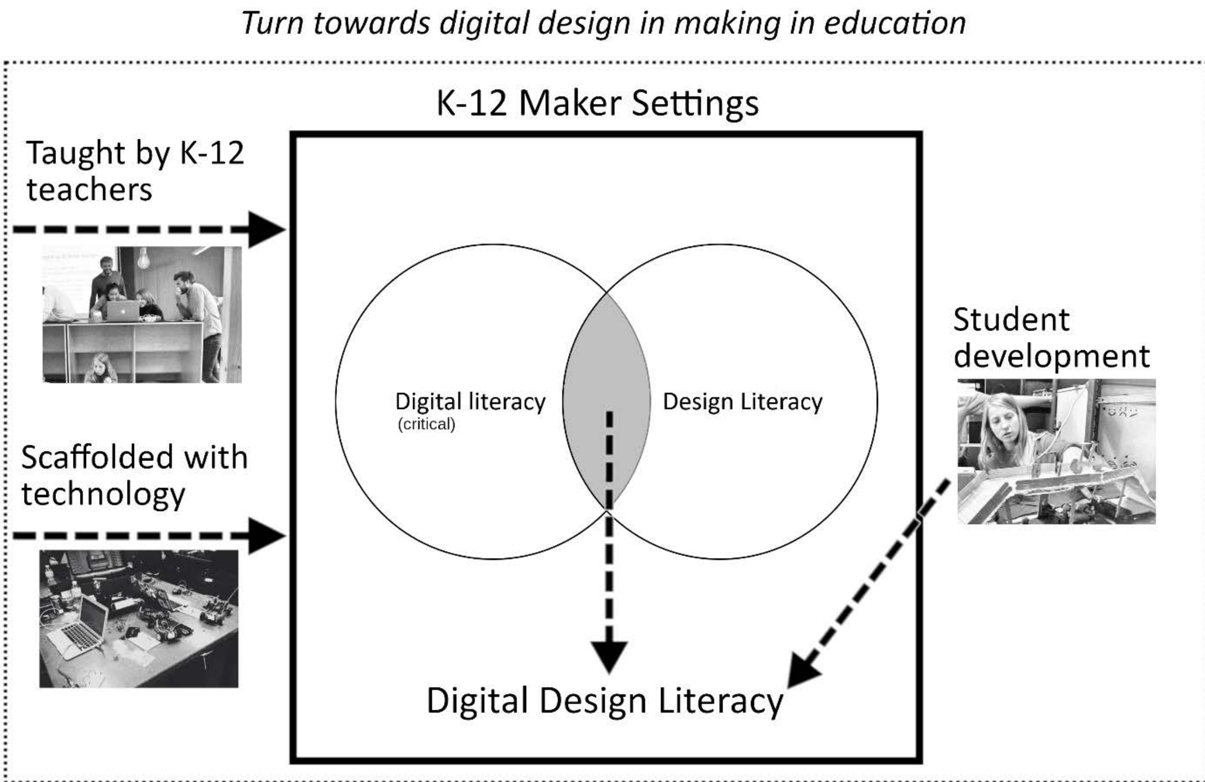

Figure 1—Research trajectories in my PhD project. Students are to develop digital design literacy in maker settings using maker technologies taught by local K–12 teachers.

The three trajectories are intertwined and have mutually influenced each other throughout my project to investigate the introduction, sustainment, and articulation of digital design literacy (fig. 1). The knowledge outcome from the three trajectories each provides partial answers to my overarching question. My contributions are fleshed out in text and by visualization, namely schemas (Nelson and Stolterman 2012). The schemas are diagrammatic presentations of theory or concepts and are intended to contribute to the written text rather than just visualize it. The schemas are designed in close association with my presented articulations and are original contributions in themselves. They are patterns for thinking about literacy in relation to digital technology, critical and design thinking, orders a cluster of ideas for guiding future research on digital design literacy in K–12 education, presents strategies for gaining knowledge with the purpose of acting in education and to give insights into how to give form to the idea of digital design literacy.

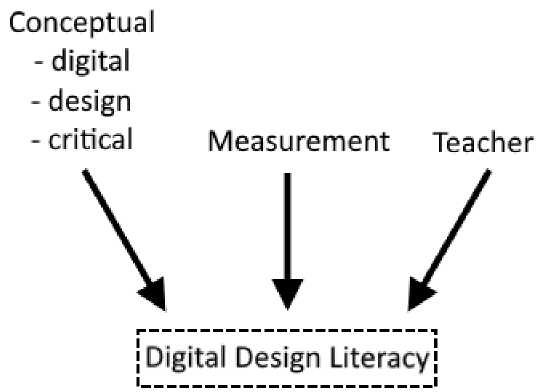

Figure 2—Each of the three trajectories have informed my conception of digital design literacy as presented in this dissertation.

The main contribution of this dissertation is a framework for introducing, sustaining, and articulating digital design literacy, based on a compilation of insights gained from the included papers and new theoretical reflections made throughout the writing of this dissertation (see chapter 4).

In the following, I will lay forth my motivation for undertaking my studies and the general research themes that frame this dissertation. I then outline an overview of the papers included in this dissertation and present a content preview of the chapters.

1.2 Motivation and Research Themes

The main motivation for doing this PhD is the idea of "design for the people," as a form of literacy that can serve us in our personal lives (Pacione 2010; Smith, Iversen, and Hjorth 2015). My exploration of research into a turn toward making in education highlighted the lack of knowledge about integrating design with maker settings and technologies but also its educational potentials and challenges. While digital technology can help solve problems, it also has the potential to increase the existing divisions of cultural capital, power, and wealth, thus creating more problems than it solves. Because most of human practice nowadays is affected by digital technologies, I find that one of the most promising modes for understanding the sociotechnical changes made by digital technologies considers the relationships between subjects and technology itself. Throughout this dissertation, I will argue that the production of transformative meaning can benefit from design practice and critical thinking centered around the digital domain. I adhere to modes of practice that set out to open things up, empower, foster civil engagement, identify power outcomes, and integrate technical and humanistic approaches. Critical engagement and design can and should go hand-in-hand if we as a society have an interest in educating future generations to be engaged, critical, and future-building citizens. Designing "things to think with" is a promising mode of critique (Ratto and Boler 2014; Pangrazio 2016) that can help give people tangible legibility of their ideas. It is recognized that digital technologies are important to integrate into K–12, not only instrumental usage such as how to print a text, but also more advanced usage such as interactive materials in design processes and the capability to critique digital technologies' role in the world (Voogt and Roblin 2012b; Coiro et al. 2014; D'Amelio 2018). As designers create new artifacts, they intentionally create what they view to be preferable futures (Löwgren and Stolterman 2004). The values underlying what the designers deem to be "preferable" changes our world, and thus it follows that the design of new technologies can have significant roles to play in society (Kolodner et al. 1998; Kolodner 2002). Design offers possibilities to participate in transforming the world by artificially shaping the future, to understand what choices are made in design processes and how critically to examine and reflect digital technologies and their impact on society, culture, and the world in general. It is imperative that students can reflect critically on digital technologies, as it helps develop a critical consciousness (Freire 1973) which can contribute important knowledge to students' design repertoire (Schön 1984) (see section 2.2.2 for a discussion of this concept). Janks argues that "*deconstruction without reconstruction or design reduces human agency"*(Janks 2000, 178) and that "*Design, without an understanding of how dominant discourses/practices perpetuate themselves runs the risk of an unconscious reproduction of these forms*" (ibid.), reiterating the ideals of the German *Bildung* tradition (Good 2007; Klafki 2011). Student development should focus not only on preparation to fit into the existing society but also on how to participate in envisioning and shaping the future of society. My work reflects this growing interest in bridging digital literacy, critical thinking with design thinking (Gainer 2012; Hinrichsen and Coombs 2014; Smith, Iversen, and Hjorth 2015; Hjorth and Iversen 2014; Pangrazio 2016; Iivari and Kuutti 2018).

The research presented in this dissertation was part of the FabLab@School.dk project carried out by the Child-Computer Interaction Group at the Department of Culture and Communications, Aarhus University, Denmark. The project was supported with a grant from The Danish Industry Foundation and the A.P. Møller Foundation. The FabLab@school.dk project is a collaborative network of teachers, students, politicians, designers, and researchers, as the project emphasized strong participation of stakeholders and encouraged a Scandinavian participatory design approach to establish making and design as a new school subject (Iversen and Dindler 2013; Smith, Iversen, and Hjorth 2015; Iversen et al. 2015). The goal of the project is to organize schools from different municipalities to establish local maker spaces[9] and facilitate the training of teachers to educate students in digital design. New Crafts and Design subjects or specific FabLab courses were introduced with a focus on creative work with design and maker

[9] Commonly called FabLabs among the stakeholders. However, I will use notion of "maker settings" instead, as it is more inclusive and has less emphasis on digital fabrication. Digital fabrication technologies are just a part of what constitutes maker settings, and in FabLab@school.dk, hybrid crafting was just as important as digital fabrication.

technologies. All school maker settings were based on common principles, guidelines, and equipment to facilitate knowledge sharing and teacher experiences both nationally and internationally. The project is part of the global FabLab@school initiative founded by Paulo Blikstein at the Transformative Learning Technologies Lab at Stanford University, California, USA. FabLabs@school.dk defines FabLabs as "*hybrid learning laboratories, which combine various digital technologies and analog materials combined with design thinking, with the aim of teaching students to create solutions to complex societal challenges*" (Smith, Iversen, and Hjorth 2015). The FabLab@school.dk project gave me the best opportunities to make research interventions and experiments in the unexplored territory of introducing digital design literacy in K–12 and support its development through making. This framing allowed me not only to investigate what maker activities, digital design literacy, and maker technologies might be but to engage with the processes, actions, and interactions, which take place when maker settings are used to develop digital design literacy. A central claim of this dissertation is that K–12 students should and can be empowered through design and making to gain the compentencies needed to shape technology development as well as to reflect critically on technology in their everyday life (I return to this in section 2.1.2 and 2.2). My research focuses on digital design literacy for the people as part of their formal K–12 education. Thus, my research interests and contributions are directed at this context.

My research address development rather than the concept of learning. This corresponds well with the use of the term literacy, which in the interpretation used here, has to do with more than content knowledge, skills, and compentencies to be learned and internalized. In summary, the interpretation of literacy that I adopt in this dissertation emphasizes holistic and humanistic development, including an understanding and critique of digital technology as not being neutral but always biased toward a particular desire—to develop critical consciousness that is rooted in recognition of technology design as a set of profoundly political processes and practices that can described in terms of issues of power, control, conflict, resistance, and that all discourse is political (Freire 1970; Fabos in Coiro et al. 2014). This interpretation is close to the concept of Bildung, which focuses on developing humans who can change and improve society, not just fit into what already exists, a passive spectator and consumer who lacks the competence to be reflective, participate in democracy, to be self-determined, and can understand the whole (Katterfeldt, Dittert, and Schelhowe 2015). In chapter section 2.2, I return to the discussion of what literacy, competence, skills and so on mean and how to use these terms to articulate and legitimize digital design as a new literacy.

The field of education is a highly politicized topic in the Western world as can be observed by the large number of education policy texts that discuss and define competencies and so forth for the 21st century (Voogt and Roblin 2012b). Teachers, designers, and researchers all take part in addressing issues and challenges that inevitably arise when introducing a new subject; there are many stakeholders interested in influencing the future of education, what is deemed important to teach, why it is important, how it should be done, who is it crucial to involve, and so on. One a major point of contention is the balancing between what is asked from industry, that is, what literacies students need to learn to be prepared for future job markets versus personal and cultural maturation of students from a humanistic perspective. However, that is not to say that the two cannot go together in unity and the two extremes are not harmonized in terms of what is deemed to be educationally valuable. Thus, this dissertation will also communicate with people outside academia, as the experiments and contributions presented in this dissertation are attempts at improving a small part of Danish K–12 education.

To address my research question, I have been involved in designing and conducting several qualitative and quantitative experiments. My involvement in these experiments have led to exemplary case studies (Binder and Redström 2006) of students and teachers working through design processes, using maker technologies and craft materials and critical investigations and group discussions on the issue of privacy invasive online data tracking.[10] These exemplary cases have been combined with statistical survey inquiries on aspects of design- and digital literacies. All my experiments have been concerned with either digital technology, design thinking, making, or critical thinking in mind, where development of digital design literacy stand as the backdrop. In undertaking the experiments, I took a constructive design research approach (Brandt and Binder 2007; Koskinen et al. 2011) through which I have participated in the making of workshops, concepts, courses, spaces, and training programs to obtain insights and an understanding of the object of study as the key means in constructing the knowledge presented in this dissertation (see chapter 3 for details on my research design and methodology).

[10] "*Privacy-invasive software is a category of software that ignores users' right to be left alone and that is distributed with a specific intent, often of a commercial nature, which negatively affect[s] its users.'* (Boldt 2007)

My research has been influenced by the Scandinavian participatory design school, which traditionally focuses on people, organizations, and their practices from a participatory perspective that focuses on democratizing workers' influence in design processes (Ehn 1988; Schuler and Namioka 1993; Iversen, Halskov, and Leong 2010; Halskov and Hansen 2015). From this perspective, stakeholders and users are not seen as people to design *for*, but as participates to design *with*. A goal of the FabLab@school.dk was to position the students as both co-researcher and designers rather than partners (see fig. 3) (Iversen, Smith, and Dindler 2017). This is concretized in my constructive design research methodology that positions research activities as interfacing between people and society at large to explore and shape potential futures while generating new knowledge and practices for understanding digital design literacy.

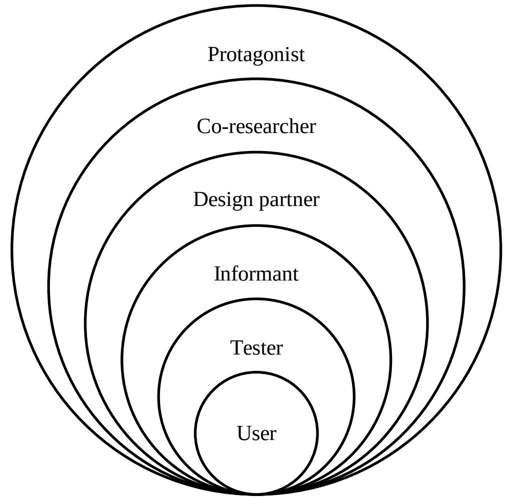

Figure 3—Development of child roles in IDC, (Iversen et al. 2017), extension of Druin's (2002) "onion model" for understanding children's role in participatory design projects.

In the following section, I outline each of the included seven publications' contributions, how these contributions have informed the Digital Design Literacy Framework (see chapter 4), and how the papers and the Digital Design Literacy Framework collectively answer the question of how to introduce, sustain, and articulate digital design as a new literacy.

1.3 INCLUDED PUBLICATIONS

This dissertation is structured around five research papers and two reports. These writings in combination in with the Digital Design Literacy Framework (see chapter 4) represent the collective contribution of this dissertation. The two reports do not present any self-standing academic arguments but are included to provide data as supporting evidence for some of my claims. Each of the included research papers presents distinct problem framings, findings, lines of argument, and contributions. All publications are motivated by my overarching research question, to which they provide partial answers. The papers are tied together by a consistent set of research considerations. However, composing this dissertation has offered me the opportunity to revisit my papers and place them along three trajectories that run through this dissertation in order to establish a foundation for understanding the relationship between my individual studies. Considering the magnitude of my research interest, my contributions do not, by any means, provide an exhaustive account. On the contrary, my interests have been my main stem of reference that has guided my research and has led me toward concise contributions within the field of making in education.

In the following, I outline the content of the included papers to show where the claimed contributions can be found, how they have informed the Digital Design Literacy Framework, and how they have contributed with answers to this dissertation's research question (see chapter 4). The papers are finished works in themselves and have been published in academic journals and conferences. Four of the seven papers have been reviewed and accepted in technology, design, and education-related journals (P1, P2, P3, and P4). P5 is submitted and under review. I also include two reports that are part of my ambition to develop ways to quantitively measure what we value instead of valuing, what we already know how to measure (R1 and R2). While interrelated, each paper takes a different perspective and thus presents and discusses its own questions, arguments, and contributions. The papers also represent an ongoing and changing exploration of how to bring the teaching of digital design literacy into K–12 education. At the time of this writing, making in education was still an emerging field of research, and thus there were no well-established publication venues. Accordingly, accepted papers have been published in design, education, and child computer interaction journals and conferences, all fields that have taken an interest in studying making in education. I reference these papers throughout this dissertation and will use the notation P(*n*) or R(*n*) when referring to these works.

What follows are summaries of each publication included in this dissertation, their individual findings and how they have contributed to the Digital Design Literacy Framework and the overall arguments made in this dissertation. In chapter 5, I discuss how the combined contributions of the included papers have helped to fill the knowledge deficits on digital design literacy in making in the education community and in turn how they have answered my overarching research question. I advise readers to have this section in reach for reference in the coming chapters.

Paper 1 (P1)—Christensen, K. S., Hjorth, M., Iversen, O. S., & Blikstein, P. (2016). Towards a formal assessment of design literacy: Analyzing K–12 students' stance towards inquiry. Design Studies 46, 125–151.

This paper investigates the possibility of measuring what we value in education in an age of measurement in which there is a strong tendency to attribute value to what is easily measured (see section 2.2). In this paper, I present an argument for the value of design literacy and a tool for quantitative assessment—the Design Literacy assessment tool (DeL tool). The DeL tool is designed to assess students' stance towards inquiry when asked to describe what steps they would take when confronted with a wicked problem. The assessment is quantitative but is based on a qualitative survey question. I discuss the turn toward design in K–12 education and why a designerly stance towards inquiry is an essential competence to develop as part of digital design literacy. I argue that without a designerly stance towards inquiry, students get trapped in a technical rational stance. The main contribution in this paper is the DeL tool, accompanied by the argument that a designerly stance towards inquiry must be developed if students are to address complex societal problems through design. The DeL tool is also an answer to the question of how to introduce and sustain digital design literacy in K–12, a question that often relies on having a tool to do a quantitative assessment of student development. This paper contributes to the Digital Design Literacy Framework (see chapter 4) by pointing to a designerly stance towards inquiry as being a central competence of digital design literacy, which in turn help to articulate digital design literacy. Findings from using the DeL tool suggest that the participating students' generally take a technical rational stance when asked to engage with a wicked problem.

Paper 2 (P2)—Hjorth, M., Smith, R. C., Loi, D., Iversen, O. S., & Christensen, K. S. (2016). Educating the Reflective Educator: Design Processes and Digital Fabrication for the Classroom. In FabLearn Europe (pp. 26–33). Stanford, CA, USA: ACM.

This paper presents an analysis of a teacher master course designed to train teachers in educating students in digital design. The main contribution of the paper is a discussion of how to create a framework for educating reflective design educators who can support students in developing competences related to digital design. The master course was based on a framework that allowed me to investigate K–12 teachers' development of core competencies for introducing digital design literacy to K–12. I uncover three challenges that teachers experience when trying to teach digital design to K–12 students: (1) their ability to navigate a complex design process, (2) managing digital and analog design materials, and (3) balancing different modes of teaching. The first two are specifically linked to design competencies, whereas the third relates to pedagogical challenges. Challenges (1) and (2) are of particular interest to my framing and articulation of digital design literacy. To address the pedagogical challenges, I demonstrate how a combination of design theory, in-school practice, and peer-to-peer learning created a framework toward educating teachers to co-development of new teaching practices. Insights from this paper contribute to the Digital Design Literacy Framework (see chapter 4) by providing an understanding of what competencies teachers need to develop to teach digital design literacy successfully to K–12 students. I discuss these insights against a backdrop of the literature on design competence and expertise. I point toward the competence of understanding and navigating design processes and to appreciate and manage different design materials as being essential to digital design literacy, both for teachers and students. The contributions presented in this paper all elucidate the introduction, sustainment, and articulation of digital design literacy in K–12. The teacher-training framework contributes to introducing and sustaining digital design education, as it demonstrates how a combination of design theory, in-school practice, and peer-to-peer learning created a teacher training framework. The study shows how the framework can facilitate and support the co-development of new teaching practices, which is valuable for teachers who are to introduce digital design as a new school subject. The developed teaching practices can in turn help sustain digital design education. In sum, the paper contributes new insights into what challenges educators have when teaching digital design literacy to students, how these challenges are central digital design competencies, and how to support teachers in developing new pedagogical practices to teach these competencies.

Paper 3 (P3)—Christensen, K. S., & Iversen, O. S. (2017). Articulations on form properties and action-function couplings of maker technologies in children's education. Entertainment Computing 18, 41–54.

This paper contributes a framework to support the development of a design language to make articulations on form properties and feedback of four maker technologies commonly found in K–12 maker settings. I argue that form properties of maker technologies, the relationship between action-function couplings, and how this relates to feedback when K–12 students use maker technologies to design prototypes are important aspects to consider when used to design prototypes. The articulations presented in the paper can benefit designers, researchers, and teachers involved in work within maker settings in K–12. The language can be used to describe and analyze qualities of maker technologies and their impact on their design process and products. This in turn adds to repertoire development (see chapter 2.2.2). As shown in P2, material management is an essential digital design competence. Navigating a design process requires the designer to be competent in managing materials. Managing materials requires a design language to articulate and communicate qualities of digital artifacts. As maker technologies are central design materials in K–12 maker settings, it contributes a language of form and feedback qualities and that may support students in developing a repertoire, an articulation language, and a sense of quality, and may help students be prepared for new design situations and communicate their design ideas. In this sense, the presented articulation framework is abstracted to such a degree that the articulations on form properties and action-function feedback couplings apply to other digital technologies that students might use in their design processes. In combination with the findings on material management in P2, this paper contributes to the Digital Design Literacy Framework by pointing toward maker technologies as an essential toolset to manage in design processes. The contributed articulation framework might help sustain digital design literacy in K–12 by exposing students to design exemplars. Such exposure can support student development of a rich material repertoire that might help them to bring experience to bear on new ultimate particulars.

Paper 4 (P4)—Christensen, K. S., Hjorth, M., Iversen, O. S., & Smith, R. C. (2018). Understanding design literacy in middle-school education: assessing students' stances towards inquiry. International Journal of Technology and Design Education, 1–22.

This paper follows up on P1s measurements of stance towards inquiry as an aspect of digital design literacy by assessing this competence among students who had received training in digital design. The assessments presented in this paper were brought forth by applying the DeL tool assessment instrument, as well as by a range of questions regarding students' experiences with making and knowledge of design processes. My analysis shows that students who had received some design education in K–12 maker settings had internalized basic knowledge about design. However, the same students had, generally, not developed a designerly stance towards inquiry to a degree that is statistically significant and measurable by the DeL tool when compared to students who had not received digital design education. Instead, students seemed to approach wicked problems as tame problems, regardless of whether they had been doing digital design in maker settings. I discuss how these results could be attributed to a lack of adaptive experts, since most of today's formal education is designed to produce routine expertise, making students less prepared to learn from new situations, and they may suffer from over-application of previously efficient schema learned through "banking knowledge." In combination with P1, this paper contributes to the Digital Design Literacy Framework (see chapter 4) by pointing toward a designerly stance towards inquiry as being a central digital design competence. P1 and P4 suggest that stance towards inquiry entails critical/retrospective reflection. Hence, digital design literacy necessitates critical thinking to engage and solve wicked problems, which requires the digital designer to engage critical thinking, which I explore in P5. Furthermore, the paper shows that design education in K–12 maker settings can improve students' stance towards inquiry.

Paper 5 (P5)—Christensen, K. S., & Iversen, O. S. (n.d.). "I don't want to know who is tracking me"—Critical digital literacy in Danish middle-school education. Submitted for the Journal of Literacy Research and is under review.

This paper describes a three-hour in-school lesson focusing on studying and developing critical digital literacy among a class of 40 students. I discuss the idea of critical digital literacy and contribute conceptual articulations on what critical digital literacy might constitute, its importance for digital design literacy, and how it can be taught in K–12. I report on a pilot investigation of the students' current knowledge, understandings, concerns, and experiences with online data tracking and surveillance. Additionally, I explore how the participating students articulated themselves critically on the issue. My findings indicate that students lack important aspects of critical digital literacy, that teachers are too constrained by a pre-defined curriculum, and that teachers themselves lack knowledge and experience with the issues of online data tracking and the digital domain in general. My study suggests that Danish public schools emphasize a very limited instrumental and instructional use of technology, whereas teaching related to critical reflections on epochal key problems brought forth by new digital web technologies are less apparent. I suggest that future curriculum should focus on developing students' conceptual models and knowledge of the Internet through properly articulated discussions based on students' personal experiences. This work is connected to the Digital Design Literacy Framework by pointing toward the importance of having a critical perspective on digital technologies and how this might be introduced in K–12. I present an argument for combining design and critical digital literacy by pointing toward critical consciousness, retrospective reflection, and the ability to critique digital artifacts as essential digital design competencies. In this sense, this paper also contributes to answering the question of how to articulate digital design literacy.

This paper has been submitted to the Journal of Literacy Research and is still under review.

Report 1 (R1)—Hjorth, M., Iversen, O. S., Smith, R. C., Christensen, K. S., & Blikstein, P. (2015). Digital Technology and Design Processes: Report on A FabLab@school Survey Among Danish Youth (Vol. 1). Aarhus University, Denmark.

The following two reports are not published in academic outlets but are nevertheless important in relation to this dissertation's arguments. The reports themselves do not contain or promote academic arguments. The reports should instead be seen as a form of appendix that helps to support some of the arguments presented in the included papers and this dissertation. Thus, the reports do not contain independent arguments.

The first report accounts for a baseline survey conducted as part of the FabLab@school.dk project. The survey on which the report is based was distributed among 1,156 Danish K–12 students aged 11–15 years and contained 227 questions. I present a snapshot of the participating students' use and knowledge of digital technologies, both in and out of school, about design and creativity and their perspectives on hacking, open data, and privacy issues. Findings from the survey generated a baseline from which my subsequent research interventions and experiment were inspired, that is, it was important to understand students' competences with maker technologies before designing interventions that would require students to employ these technologies in prototyping activities. The claims made in the report cannot be generalized to all Danish K–12 students, but only for the sample. I found that students are big consumers of digital media and technology, few students have knowledge of digital fabrication technologies, most students do not act on their creative ideas, and students lack knowledge of what is meant by a design process. This report and R2 (see below) are part of my ambition to develop ways to measure what I, as an advocate for digital design literacy, value rather than to attribute value to that which is commonly measured in the Danish K–12 educational system (e.g., PISA test ("PISA" n.d.)). Findings from R1 have contributed to the design of the Digital Design Literacy Framework by providing a quantitative understanding of students' competencies with and knowledge of design and digital technology. Furthermore, this report has, in combination with report 2, provided me with important insights that informed my qualitative experiments.

Report 2 (R2)—Hjorth, M., Christensen, K. S., Iversen, O. S., & Smith, R. C. (2017). Digital Technology and Design Processes: Follow-up Report on A FabLab@school Survey Among Danish Youth (Vol. 2). Aarhus University, Denmark.

To better understand the effects of the FabLab@School.dk educational program from 2014 to late 2016, a follow-up survey was administered to two groups: first, schools in which FabLab and design activities had been carried out in the FabLab@School.dk project at some point during a two-year period (FabLab schools) and, second, a control group of schools that had not been part of the FabLab@School.dk project and thus had not received any training in design in maker settings (control schools). The follow-up survey was conducted in the fall of 2016 among 246 students from FabLab schools and 203 students from control schools, totaling 449 students. I present insights into how students have developed aspects of digital design literacy: understandings and experience with a range of maker technologies, students found work with maker technologies motivating and that learning outcomes and motivation is very dependent on how schools integrate activities that touch upon digital design literacy. In short, report 2 shows that the FabLab@School.dk project has initiated digital literacies among students. R1 and R2 contribute to the Digital Design Literacy Framework by showing that digital domain knowledge as a knowledge set of digital design literacy is lacking among students and hence that digital domain knowledge is an essential competence of digital design literacy. One of the conclusions from the two surveys was that the involved students as a whole had not become digital design literate but that there are indications that the training of teachers (see P2) did help initiate digital design literacy among some students. In schools in which students worked with their own ideas with a diverse range of digital technologies and were supported by a teacher who had received training in digital design, students reported that they had on average become better at imagining change with technology, working creatively with technology, understanding how new technologies are created, and understanding how technology is affecting our lives as well as at solving complex problems. However, there was much difference in what education in digital design students had received.

Figure 3 is an overview of the included publications and their position along the three research trajectories.

	(1) Conceptual	(2) Measurement and assessment	(3) Educator
Paper 1	☑	☑	
Paper 2	☑		☑
Paper 3	☑		
Paper 4	☑	☑	
Paper 5	☑	☑	
Report 1		☑	
Report 2		☑	☑

Figure 4—Overview of the included publications.

1.4 Dissertation Overview

This dissertation consists of two parts. The first part is this dissertation overview that ties together findings from my four years of research. The second part is a collection of papers written throughout my four-year project.

The introductory chapter introduces the overarching topic of this dissertation, the issues discussed, my research question, and grounds my research in relevant fields to position my work. The chapter also summarizes the primary contributions of this dissertation and presents the structure, organization, and overview of the included article. Additionally, the titles of the articles on which the thesis is based are listed along with information on publication and how they fit together. This is followed by a review and discussion of literature related to making in education that pays attention to design, usage of digital technology, and how making can scaffold student development in various subjects. I review four fields of study to position my work and address the knowledge deficits that my research fills. Firstly, I review literature on the turn toward making in education, how it provides advantageous settings for digital design education. I show that making has mainly been studied in relation to the development of STEM competencies and that the turn toward design is just starting to emerge as a topic for research in the field of making in education. I review papers that present, analyze, and discuss technologies made or used in school maker activities—what I have termed maker technologies—and the few articles that discuss digital design as a new literacy. Secondly, I outline different conceptions of competencies, literacies, skills, and so on from a new literacy-studies perspective. I review new digital literacy studies to situate my PhD project within a larger educational discourse, education to legitimize the arguments made by design scholars, myself, my research groups, and the various stakeholders related to the FabLab@school.dk project. I discuss terms that describe the ability to do something well, successfully, or efficiently, as a result of experience and training, such as ICT skills, IT skills, 21st-century skills, information literacy, and digital competence. Thirdly, I review literature on digital literacies including critical thinking on sociotechnical issues. I review literature on basic and advanced aspects of digital literacy and argue how a critical and reflective mindset toward sociotechnical issues are central to digital literacy development and that a critical stance towards digital technologies can provide valuable domain knowledge for the students' design repertoire. Finally, I review literacy on the characteristics of design competence among expert designers and discuss what it means to be a designer, their competencies, their mindset, and approaches to solving problems.

Following my literature review, I discuss my research design and methodology on which my collection of empirical material is based. I describe the methodology of constructive design research and position my research within this approach. I then introduce mixed-method to articulate and ground further my research approach. I describe the FabLab@school.dk project and the specific contexts and experiments that I used to study students design work with digital technologies in maker settings among Danish K–12 students and how I have worked within the FabLab@school.dk project as a researcher, designer, and teacher. I discuss how this research approach was advantageous for investigating the dissertation's research question, which is concerned with novel and distinct cases of introducing digital technologies and settings for digital design.

Finally, I discuss how the insights generated from my discussions throughout this dissertation and the included papers have contributed new knowledge to the field of making in education. I synthesize my theoretical and empirical efforts and present the Digital Design Literacy Framework for understanding how design literacies and digital literacies can go hand-in-hand and be articulated holistically as a new literacy. The intention with this framework is to provide researchers, teachers, and other stakeholders with an interest in design and digital literacies with an expanded vocabulary to articulate and understand the concept of digital design literacy and what concrete competencies digital design literacy might include. These contributions are needed, as there does not yet exist any frameworks that conceptualizes digital design literacy and relates it to making in K–12 education. I conclude my research by providing an answer to the overarching research question of this dissertation and discuss how digital design literacy can lead to empowerment. Finally, I outline avenues for future research.

2 Field of Research and Related Work

In this chapter, I review literature related to the field of making in education and new literacy studies with interests in digital technology and making. I describe how my research builds on existing literature on making in education and the current turn toward digital design literacy to position my contributions. I outline how design and digital literacy have not yet been explored as an integrated whole in making in education research. Hence, this dissertation contributes new knowledge to research in IDC and making in education by providing an understanding of design education with digital technologies as a new literacy in K–12. In chapters 4 and 5, I discuss how the included papers and the Digital Design Literacy Framework have contributed new insights to the knowledge deficits that I will be outlining in this chapter. First, however, I go over the field of IDC to frame the emergence of making within a larger academic context.

In the 1960s and 1970s, researchers including the hackers and American computer scientists Seymour Papert and Alan C. Kay began exploring how to design digital technologies for children rather than military or scientific purposes. Their original focus was making computational thinking and programming accessible for children. A pioneering example of these efforts is the Logo programming language by Papert (1993) and Kay and Goldberg's Dynabook design concept (Kay 1972; Kay and Goldberg 1988). All three were fond of the learning and developmental theories of Piaget and Vygotsky, which have since been highly influential in the creation of IDC. From Piaget comes the concept of adaptation, with children forming knowledge structures as they experience the world. Papert would later build upon the ideas of Piaget to form *constructionism*, where the primary idea is that the best kinds of learning about computers happen when students are constructing physical or digital artifacts of interest (Papert 1993; Ackermann 2001). Their work has since influenced and inspired the design of digital technologies with empathy toward children, for example, programmable robots, visual programming languages, and new visions for the use of computers in K–12 education.

IDC is the premiere international community that focus on the promises and challenges of technology to enable children to participate in empowering experiences and bring children's voice and sentiments into the design process of new technology (Hourcade 2015). IDC is part of the Association for Computing Machinery Special Interest Group on Computer-Human Interaction (ACM SIGCHI),[11] which is the premier international community for professionals, academics, and students who are interested in human-computer interaction (HCI) with more than 20 sponsors and 40 in-cooperation groups including conferences, publications, web sites, and other resources. IDC brings together interdisciplinary

[11] https://sigchi.org (accessed 04/01/2019)

researchers, designers, and educators from disciplines such as cognitive and developmental sciences, human-computer interaction, interaction design, literacy studies, and educational philosophy. Members of the IDC community share the goal of exploring new digital technology from different aspects such as engaged learning among children (Giannakos, Divitini, and Iversen 2017), design for children with special needs (Börjesson et al. 2015), online safety considerations (Pangrazio 2013), usability and interaction design (Blikstein 2015), creativity (Thang et al. 2008), and so forth. IDC has run annual conferences since 2002 that include research papers, presentations, workshops, and panel discussions. IDC is attended by researchers, designers, and educators from the cognitive sciences, human-computer interaction, learning sciences, and creativity studies among others to explore new forms of technology, design, and development among children with the intention of getting input from outside academia as well as communicating knowledge to external stakeholders, for example, transferring knowledge so that teachers can operationalize it. The IDC community has turned toward studying maker practice and settings and how they present new opportunities for people to acquire competencies in subjects such as STEM, design, and art and provide researchers with new educational practices and contexts to study (Katterfeldt and Schelhowe 2008; Blikstein 2013a; Smith, Iversen, and Hjorth 2015; Kylie Peppler, Halverson, and Kafai 2016a). Research on making in education is explicated in the emergence of new conferences (e.g., FabLearn Europe, Denmark, Israel, and the Flagship Conference in the USA[12]), and special journal issues on the subject (e.g., Entertainment Computing: Special Issue on Maker Technologies to Foster Engagement and Creativity in Learning (Giannakos, Divitini, and Iversen 2017) and the International Journal of Child-Computer Education: Special Issue on Digital Fabrication in Education (Iversen et al. 2015)). Topics range from STEM (Blikstein and Krannich 2013; Johnson et al. 2016) to crafting with physical and digital materials (Buechley 2006; Lo and Paulos 2014) and is becoming increasingly popular to study across HCI, Interaction Design, IDC ,and CCI in relation to the future of education (Bean and Rosner 2014; Ames et al. 2014; L. Martin 2015; Cohen et al. 2016). Making in education aligns with the curricular demands of K–12, STEM, in particular, and innovation competencies such as in the P21 Framework Definitions for 21st-century skills (Ananiadou and Claro 2009; Voogt and Roblin 2012a; The Partnership for 21st Century Skills 2015). Making in education celebrates the new possibilities brought forth by new maker technologies, materials, and settings, as they provide new ways of designing and competence development (Bevan 2017). Making in education, as well as IDC, borders with the fields of HCI, interaction design (IxD), design studies, computer-supported

[12] https://fablearn.org/conferences/ (accessed 02/03/2018).

collaborative learning (CSCL), International Society for the Learning Sciences (ISLS), and new literacy studies, and I will, therefore, draw on theory from these fields as well.

The organization for the remainder of this chapter is as follows. First, I review literature on making and design in education, particularly the entry of the maker movement into K–12 education, the focus on STEM, making as emancipatory, the turn toward design in making. Finally, I offer a critique of the maker movement. Second, I review the literature on new literacy studies and its relationship with digital technology and design in K–12 education, what it is, how it is done, and why scholars find it to be an important field of research. I will argue why the turn toward digital design through making in education is relevant for new literacies that involve digital technologies, both as support material but also as a material with which to design, and how these new literacies can be taught in practice. Third, I discuss the concepts of design literacies and (critical) digital literacies, how they are connected, their relevance and educational value, and whether we want students to develop the competencies for transforming the world through digital design. Building on this review and its accompanying discussions, the remainder of the chapter outlines the academic context of my work and contextualizes my contributions within the field of making in education.

2.1 Making, Design and Digital Fabrication in Education

In this section, I review literature on the maker movement and how the advent of making aims at improving K–12 education, especially in regard to novel forms of student engagement with diverse materials including digital technologies, electronics, and materials such as fabrics, wood, plastic, glue, ink and so forth, enabling new opportunities for learning and development (Martinez and Stager 2013; Kylie Peppler, Halverson, and Kafai 2016a). Martin claims that the maker movement rests on three pillars (2015): (1) digital technology that enables advanced production of artifacts; (2) community, infrastructure and spaces, including online forums, spaces containing various technologies, like-minded individuals, and get-together events; and (3) the maker mindset, its values, beliefs and dispositions. In the following, I unfold these three pillars in more detail.

The maker movement can be traced back to the founding of *Make* magazine in 2005 and the first Maker Faire in 2006 (Dougherty 2012), but the basic activities of this new sociocultural phenomenon grow out of a longstanding tradition of DIY culture, including but not limited to woodworking, knitting, or tinkering with electronics. Dougherty claims that, while we all are makers, the maker movement "*has come about in part because of people's need to engage passionately with objects in ways that make them more than just consumers*" and define makers as "*enthusiasts who played with technology to learn about it*" (ibid.). Anderson (2012) defines the maker movement as "the fourth industrial revolution" and Hatch highlights the importance of artifact construction to the maker movement, which makes it distinct from the earlier modes of design with digital tools (Hatch 2014). Blikstein and Worsley (Kylie Peppler, Halverson, and Kafai 2016a, 1:64–79) argue, that the introduction and interest in making in education builds on four sociocultural underpinnings: (1) hacker culture at MIT, (2) maker fairs and *Make* magazine, (3) the rise of technology-rich informal education programs in, for example, museums, clubs, and after-school, and (4) a need for more and better STEM-oriented education. The accessibility of digital fabrication technologies such as 3D printers and laser cutters have been used for claims of a democratization of fabrication as well as education (Blikstein 2013a). Maker settings give students access to sophisticated tools for building and thinking that have been claimed to empower youth to engage in new forms of thinking and hands-on practices (Resnick and Silverman 2005; Blikstein 2008). The maker movement encourages people to get into programming, engineering, and creative projects to enable production rather than consumption—solve problems by producing tools rather than purchasing ready-mades (Gershenfeld 2007). The attention given to the maker movement owes much of its success to the excesses of current MIT-Silicon Valley economies, processes, and breakthroughs in digital fabrication and physical interaction technologies. The lowered costs of maker technologies have made them accessible to schools,[13] creating new educational possibilities, from kindergarten to university level (L. Martin 2015; Cohen et al. 2016), but the integration of maker technologies in formal education is still in its infancy. The lowered costs provide makers, hackers, and hobbyists with new modes of production not previously available to the general public. New materials such as e-ink and e-textiles have given new opportunities for the design of physical artifacts, making it distinct from the earlier computational and Internet-based design, which mostly happens on a screen (Anderson 2012; Hatch 2014). Papavlasopoulou et al.'s (2017) literature review shows that most maker technologies used in children's education are microcontrollers such as Arduino and Makey for physical interactions and Minecraft and Scratch for programming. However, there is only limited use of actual digital fabrication technologies in research related to making in education (Papavlasopoulou, Giannakos, and Jaccheri 2017). Instead, crafting materials and basic electronics are widely used (ibid.). Technologies that youth encounter in their everyday lives has a "black box" quality. Contrary to "everyday" technologies, maker technologies allow students to access the inner workings of digital technologies (Resnick, Berg, and Eisenberg 2000; Haskel and Graham 2016).

[13] To some schools, such tools might still be out of reach, but they were affordable to Danish schools, which were the context of this study.

The availability of maker technologies and materials and access to maker settings has broadened the view of digital literacy. The hype surrounding making can be seen in an increasing amount of coverage, investments, and new initiatives in maker settings by public libraries (e.g., the Makey Project in seven EU countries[14]), after-school clubs (e.g., Coding Pirates in Denmark[15] (Nørgaard and Paaskesen 2016)), science and technology museums (e.g., Tinkering Studio at the Exploratorium in San Francisco[16]). The US government has expressed interest in making through funding agencies such as the Institute for Museum and Library Services, National Science Foundation, Defense Advanced Research Projects Agency, and the White House, which hosted a Maker Faire in 2014 (Kalil 2010; Bevan 2017). Central to the current developments in making in education are initiatives such as the FabLab@school project at Stanford University and the FabLearn Fellows[17] program with members from Brazil, Germany, Denmark, USA, Peru, Italy, and more, who contribute to research about making in education and the development of teaching resources for their peers.

Making involves creating things, seeing how they "act in the world" and sharing them with others. Papert has shown that learning "*often happens especially felicitously when it is supported by construction of a more public sort "in the world"* (Papert 1993, 143). Martinez and Stager credit Papert as "the father of the maker movement," arguing that constructionism is the pillar that the maker movements stand upon (2013, 17). Multiple scholars claim that maker settings are the ultimate construction kit for students to do creative work by making, building, and sharing different projects (Buechley 2006; Blikstein 2013a; Dittert and Krannich 2013; Walter-Herrmann and Büching 2013). These claims are heavily inspired by Papert's idea of constructionism (Papert 1993), Piaget's constructivism (Ackermann 2001), Dewey's progressive education (Dewey 1916), and in some cases, such as in P5, Freire's critical pedagogy (Freire 1970; Blikstein 2008). The value of making in education aligns itself with the long-established argument that students' development is enhanced by playing, building, and externalizing ideas. Maker settings provide an environment to enable such teaching and learning (Kylie Peppler, Halverson, and Kafai 2016a). The centrality of materials-based investigations for motivating and advancing student development underpins the excitement surrounding making in education (Blikstein and Krannich 2013; Resnick and Rosenbaum 2013).

Another driver for the maker movement, as suggested by the appellation of "movement," is that the community spread across the person-to-person meetings in settings such as museums, FabLabs, and

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[14] https://makeyproject.eu (accessed 02/07/2018).
[15] https://codingpirates.dk (accessed 02/07/2018).
[16] https://www.exploratorium.edu/tinkering/about (accessed 02/07/2018).
[17] https://fablearn.org/fellows/ (accessed 01/02/2019)

hacker spaces, combined with events like the Maker Faire, the Chaos Communication Club, and as online communities such as ikeahackers.com, instructables.com, and gitlab.org. Participating in these communities happens, both in person and online, where people socialize, read, write, share projects, create and watch instructional videos, and engage in other forms of "geeking out" (J. Bardzell, Bardzell, and Toombs 2014; Maxigas 2014; Holm 2015)—a community of practice (Wenger 1999), which stands as the brick and mortar pillars of the maker movement. Without this community, maker technologies would not get the same traction in education, as the various guides and documentation are essential for creating a recursive public (Kelty 2008; Bazzichelli 2013). A recursive public describes groups sharing a moral order, common social norms of openness and freedom, which lives through hardware, software, networks, and protocols, and which shapes practices in their everyday lives. A recursive public works on developing, creating, and maintaining networks and, at the same time, is the network and the social infrastructure which geeks, hackers, makers, and so forth maintain. As Kelty points out, "geeks" share ideas, but they also build up the technology that allows the expression of certain ideas (2008), for example, those in the maker movement. A recursive public is one whose existence is possible only through discursive and technical reference to the means of creating this public. For instance, a FLOSS "maker technology project" may depend on some other kind of software or programmable interface, which may depend on particular open protocols or standards, which in turn depend on certain kinds of hardware that implement them (e.g., Makey, which is a fork of the Arduino). Similarly, K–12 students working with programming use informal peer support. An example of this is the online Scratch community, which allows students to learn by sharing their work and draw on the accumulated community knowledge, experiences, and remixes while operating within an established set of values (Fields, Pantic, and Kafai 2015). Various firms such as LittleBits Electronics or Lego also develop and push maker technologies, not to create a recursive public but rather to make a profit in a capitalist market.

The maker movement can be considered a shared social identity and community of people engaged in DIY, hacking, making, crafting, tinkering, designing, and so forth that allows for bottom-up projects for playful and useful purposes (Wang and Kaye 2011; N. B. Hansen, Nørgård, and Halskov 2014; Andrew Milne 2014; Ratto and Boler 2014; Ames et al. 2014; L. Martin 2015). The maker mindset or identity is said to be present in everyone, even though they do not necessarily identify themselves with the maker movement (Dougherty 2012). Hatch, co-founter of TechShop,[18] organized nine key elements of the maker mindset: make, share, give, learn, tool up, play, participate, support, and change (Hatch 2014). Following Dougherty and Hatch, Martin considered four elements to be essential to the maker mindset

[18] The original TechShop filed for bankruptcy on February 26, 2018.

and identity and their value for education: it is playful, asset- and growth-oriented, failure positive, and collaborative (L. Martin 2015). The maker mindset is playful which begets experimentation. It is tolerant of errors as stepping stones for further learning and competence development. Applying this way of thinking advocates growth, where, given effort, facilitation, and resources, anyone can learn the competencies needed to complete any project they can imagine (ibid.). Martinez and Stager (2013) describe the maker mindset as the "*act of creation with new and familiar materials*" where one takes control of their life and their learning. The maker movement's shared commitment to open exploration, intrinsic interest, and creative ideas can help transform STEM and arts education (K. Peppler and Bender 2013). Other works (e.g., Dittert and Krannich (2013) and Katterfeldt et al., (2015)) have added to this focus by analyzing how maker settings enable bottom-up ideation processes and allow children to grasp (*begreif*) digital technology better, which in turn offers new educational opportunities that make science and engineering more transparent and easier for K–12 students to understand. Making is also argued to be emancipatory and empowering for children, in that making is a mindset and identity rather than a set of skills. They also identify that making is not enough, but that a designerly approach is needed—this is the discourse in which this dissertation positions itself (Blikstein 2008; Iivari et al. 2017).

Much practice and research into the maker movement is interdisciplinary and cuts across multiple cultures such as hackerism (Raymond 2000; Wark 2004; J. Bardzell, Bardzell, and Toombs 2014; Lindtner, Hertz, and Dourish 2014) , do-it-yourself (Buechley et al. 2009; Andrew Milne 2014; Ratto and Boler 2014), critical and open engineering ("The Critical Engineering Manifesto" n.d.), critical design/electronic art (Dunne and Raby 2001; Dunne 2005), and FLOSS tools, software, and code libraries. Iivari et al. (2017) summarize a range of discourses within the field of making in education.

In the next section, I review literature on the development of STEM education through making and how this has led to a turn toward digital design and other non-STEM subjects.

2.1.1 A Focus on STEM and Making

The rise of the maker movement gained attention from research communities already engaged with education in, with, and through digital technologies such as computer-supported collaborative learning (CSCL), International Society for the Learning Sciences (ISLS), and Child-Computer Interaction (CCI[19]). Within these fields, block-based programming of robots (Papert 1993; Maloney et al. 2010), computational construction kits using physical interaction technologies such as the LilyPad Arduino (Buechley et al. 2008), and video games such as Minecraft (Love et al. 2016; Ringland et al. 2017) have

[19] The 'sister' venue of IDC.

been argued to stimulate the students' interest in STEM (Bevan 2017). Neil Gershenfeld argues that maker settings support students to uncover the "hidden core" of technology, revealing the model behind the black box—to use technology proactively, to concretize abstract concepts and make them more comprehensible (Gershenfeld, 2007). Gershensfeld's focus on educating students for careers in STEM is echoed in Blikstein and Krannich (2013), Eisenberg (2002), Martin (2015), and as shown by Papavlasopoulou et al. (2016), development of STEM competencies was by far the most common goal of making in education—especially computer programming (ibid.). A similar observation is made by Smith et al., who claim that making in education focuses primarily on "*the potentials of these technologies has mainly been on the support to STEM oriented learning goals*"(2016). STEM learning in making rests on Papert's constructionism, which outlines the idea of a technology-enabled, project-based learning environment and practice-based perspective, with the primary aim of developing students' STEM competencies to ensure the political goals and competitiveness of a nation (Iivari et al. 2017). This is also clear from Papavlasopoulou et al. (2017), who found that maker activities in K–12 focus mainly on STEM education, particularly computer programming. Making has been shown to be an effective way of teaching STEM-related competencies (Blikstein and Krannich 2013; Rode et al. 2015; Kylie Peppler, Halverson, and Kafai 2016a, 2016b) among boys and girls (Buechley et al. 2008) and for youth growing up in poverty (Blikstein 2008; Barton, Tan, and Greenberg 2017). However, topics such as democratic, critical, and educational empowerment needed to equip students to understand, change, and shape the world with digital technology remain unexplored from the STEM perspective—design and critical thinking are backgrounded. The lack of a critical dimension impacts the kinds of empowerment students can experience. Iivari and Kinnula (2018) argue that making in education, particularly STEM, encourages functional empowerment, whereas the critical and democratic empowerment is largely neglected. Making is, nonetheless, claimed to be a gateway for emancipation and empowerment. I outline these arguments in the next section.

2.1.2 Making as Emancipatory and Empowering

Strands in IDC community has placed importance on empowerment and emancipation of children and youth through the use and design of digital technology (Sawhney 2009; DuMont 2012; Read et al. 2017; Iversen, Smith, and Dindler 2018; Ribeiro et al. 2018). Similarly, advocates of the maker movement present the narrative of empowerment through making (Blikstein 2008; Ames et al. 2014; Iivari, Molin-Juustila, and Kinnula 2016; Iivari and Kinnula 2018). The claim is that making has the potential to empower everyone—developers and users, rich and poor, young and old, men and women—by transforming them from passive consumers to proactive producers (or designers) (Fischer 1998; L. Martin 2015; Iversen, Smith, and Dindler 2017; Iivari and Kinnula 2018).

It has long been an ambition of the CCI and IDC communities to improve children's capability to reflect critically and provide opportunities and means to shape their digital life. I join this effort to empower students; however, according to Kinnula and Iivari et al., it is not always clear what is meant by empowerment within making in education literature (Iivari, Molin-Juustila, and Kinnula 2016; Kinnula et al. 2017; Iivari and Kinnula 2018). They claim that to advance the field further, an awareness and critique of the various meanings and forms of "empowerment" is needed, and researchers need to reflect critically on which views of empowerment they assume: "*There are such huge differences in the views on empowerment and the discussion of those enables researchers and practitioners to make conscious choices as regards which form of empowerment they aim at*" (Kinnula et al. 2017, 17). Inspired by Hardy and Leiba-O'Sullivan (1998), Iivari et al. suggest five views of empowerment: (1) management/ mainstream, (2) critical, (3) democratic, (4) functional, and (5) educational/competence. Each of the five views differs in what perspectives to promote and downplay and has its strengths and weaknesses. These different views on empowerment are important to keep in mind when discussing and claiming the potentials of empowering through maker activities. These five views are not exclusive, but overlap and can be beneficially combined. Examples of research on the potential for empowering students through making can be found with Blikstein (2008), whose work with Freire's critical pedagogy shows that introducing computational technologies can empower people from a critical (empowerment as the oppressed combating the oppressors and achieving power this way), democratic (empowerment as people's right and ability to participate in decisions affecting their lives, empower people to forward their own agendas), and educational (people are empowered by offering them important skills and competencies) view. Blikstein argues that maker activities combined with maker technology can function as a tool or agent of emancipation that allows for mobilizing change in schools and empowers students, even in economically troubled communities (Blikstein 2008). From this perspective, learners can go beyond limiting situations and perceive oneself as an active agent of change in a mutable world—get emancipated (Blikstein 2008). Iversen et al. (2018) apply the concept of computational empowerment as "*the process in which children, as individuals and groups, develop the skills, insights and reflexivity needed to understand digital technology and its effect on their lives and society at large, and their capacity to engage critically, curiously and constructively with the construction and deconstruction of technology*." Ideas from the maker movement have seen an uptake in the participatory design community, emphasizing the potential as an educational resource for developing empowered individuals through education, design, and critical thinking. Iversen et al. (2017) introduce the concept of the child as a protagonist, in which children are empowered to shape technology and critically reflect on the technology in both their practice and society and culture at large. From both these conceptions of the empowered child, empowerment takes a functional and education/competence perspective on empowerment but also a critical perspective in that students should be competent in reflecting upon digital technology, life, and society. Building on the tradition of participatory design, an emphasis on democratic empowerment is also present, emphasizing empowerment by giving children access to the design process (Druin et al. 1998; Druin 2002; Iversen and Smith 2012; Iversen, Smith, and Dindler 2017; Read et al. 2017; Iivari and Kinnula 2018).

The majority of literature on making in education reviewed in this dissertation and the included papers, view empowerment primarily from the perspective of mainstream, functional, and educational/competence empowerment, whereas the democratic and critical views of empowerment are backgrounded. One takeaway from the literature referenced above is that the empowerment in making education can be enabled through making with the object of not only designing technology but for students to develop new insights, design competencies, and a critical consciousness and reflective stands toward technology through their engagement in design work. Furthermore, the maker movement seems to place less emphasis on "*encouraging people to critically reflect on technologies as part of their everyday life and practices*" (ibid.). I will return to this issue in section 2.2.3, arguing that the critical and reflective dimension of interacting with digital technology, as consumer or producer, is a crucial competence to develop as part of being digital design literate.

In chapter 4, I integrate the notion of empowerment in the Digital Design Literacy Framework, which I consider and claim to be at the highest level of outcome from digital design education. I suggest that future curricula should focus on developing students' critical and democratic empowerment as part of digital design literacy and that digital design education can provide avenues for such endeavors.

2.1.3 Turn Toward (Digital) Design

Several IDC authors have drawn on design research when suggesting methods and techniques for engaging children actively in the design of digital technology (Druin et al. 1998; Iversen and Dindler 2008; Fails, Guha, and Druin 2012; Fitton, Read, and Horton 2013; Frauenberger et al. 2014; Read et al. 2017). These methods and techniques are inspired by the Scandinavian participatory design tradition, but criticism of the application of participatory design research in CCI and IDC highlight that children do not necessarily influence the outcome here, and little emphasis is put on design as a mutual learning process as manifested in PD theory, thus being a reduced form of PD (Read et al. 2016; Iversen, Smith, and Dindler 2017). Design theory, particularly PD, has had a big impact in terms of understanding how children can be invited into the design process as users, testers, informants, or design partners (Druin 2002) but has since brought attention to enabling children to be designers themselves, not as partners but as autonomous agents of intentional change in the world (Landoni et al. 2016; Iversen, Smith, and Dindler 2017; Iivari and Kinnula 2018).

The field of making in education was initially focused on integrating constructionist pedagogy, physical interaction toolkits, and digital fabrication technologies into formal and informal settings to teach STEM. Drawing on the German Bildung tradition Klafki (2011), Schelhowe (2013), and Katterfeldt et al. (2015) have emphasized how maker settings in education had the potential to provide students with opportunities for developing their digital citizenship and enabling them to engage in complex problem-solving. Thereby, Schelhowe broadened the scope of making in education to include a design focus on maker settings: Children should learn to become digital citizens and designerly thinkers through making in education. In comparison to the PD approach, maker settings open an avenue toward educating students to become designers themselves, thus attaining educational/competence empowerment rather than democratic empowerment as in the children's right and ability to participate in design processes that ultimately affect their lives.

In the past five years, there was a beginning turn toward design with digital technology as a form of literacy and empowerment in the field of making in education (Hjorth and Iversen 2014; Smith, Iversen, and Hjorth 2015; Iversen et al. 2015; Paaskesen and Nørgård 2016). Among design researchers, the idea of integrating design in general education has long been suggested (Baynes 1974; Archer 1979; A. Cross 1980, 1984; Davis et al. 1997; Pacione 2010), and current literature argues that design thinking and practice offer major educational opportunities to support the new literacies needed for the 21st century (Balsamo 2009; Burdick and Willis 2011; Bekker et al. 2015; Smith, Iversen, and Hjorth 2015; Christensen et al. 2016; Gourlet and Decortis 2016; Giannakos, Divitini, and Sejer Iversen 2017). Schön argued that "*all of us make things out of the materials of a situation under conditions of complexity and uncertainty*" and, therefore, "*designing in its broader sense constitutes the core of practice in (…) everyday living*" (1992, 126–27). More recently, Nelson and Stolterman (2012) and Keirl (1999, 2006) have argued that design should be for everyone because the design of new digital technology has significant roles to play in empowering contemporary citizenship and democracy (Kolodner et al. 1998; Kolodner 2002) and design offers major educational opportunities to support the new literacies needed in the foreseeable future, both from the perspective of individual development as well as to accommodate the future job market (Balsamo 2009; Pacione 2010; Sheridan and Rowsell 2010; Burdick and Willis 2011; Smith, Iversen, and Hjorth 2015; Christensen et al. 2016; Iversen, Smith, and Dindler 2017). Designerly ways of engaging with wicked problems are examples of applications of design from which everyone may benefit when interacting with the world. The natural sciences rely on methods of induction and deduction for solving problems that are definable and observable, that pertain to the universal and absolute truth, what is denoted as tame problems in the terminology of Rittel and Webber (Rittel and Webber 1973). However, design is not based on scientific induction or deduction, and thus intentional change in the world cannot, therefore, be accomplished using a scientific approach or methodology. Instead, designers work with wicked problems, which are of a different nature in that they deal with a complex web of interdependent issues and concerns that cannot be exhaustively analyzed before the design process, and whose conditions may change during the process. Given the characteristics of wicked problems in design, the outcome of a design process is an ultimate particular: a response to the fundamental distinctiveness of the situation which is by consequence also fundamentally distinct itself. A design is expressed in the way things are brought together, how they are related and connected in ways appropriate to the ultimate particular conditions and intentions of the design situation. This implies that students should develop aspects of fundamental design competencies such as designerly inquiry, ideation, navigating a design process, good judgments and sense of quality, composing, connecting, and materializing ideas as externalizations and a developed language (see section 2.2.2 for details). Researchers in favor of design in general education argue that it is not enough to involve children as participants in technology design projects or teach simple instrumental/technical skills sufficient enough to become mere users and consumers of technology-rich society that other parties design for them (Fischer 1998; Smith, Iversen, and Hjorth 2015; Iversen, Smith, and Dindler 2017; Kinnula et al. 2017). Instead, there is a need and desire for students to learn that it is that they can make intentional changes in the world and challenge that which already exists, be they societal, cultural, political, or technological ones, and so on. Development of design competencies may lead to other forms of empowerment than what has been articulated within the application of PD in CCI and IDC, which are rooted in a democratic understanding of empowerment. Iversen et al. (2017) and Iivari and Kinnula (2018) have drawn attention to this issue; "*[Iversen et al.'s] objective [is to transcend] the goal of giving children a voice in design, and addresses more broadly how children can be empowered to shape technological development and critically reflect on the role of technology in their practices.*" (Iversen, Smith, and Dindler 2017). Iversen et al. (2017) suggest the concept of design protagonist, which concerns the empowerment of students in designing technology and critically reflecting on it. It is argued that children should become agents of change in the design process as they engage with authentic, real-world design problems, and it is suggested that, through their engagement in design processes, student develop competencies in designing and as well as critically reflecting on technology, which can empower them to make more informed decisions about technology in their lives.

According to these works, designerly ways of engaging with the world enable individuals to act as agents of change and creators of preferred futures, competencies that are echoed in descriptions of 21st-century competencies by organizations such as OECD's Partnership for 21st Century Learning (Ananiadou and Claro 2009; Voogt and Roblin 2012a). All of these define the competence to take on complex problems as being important in the 21st century, thus accommodating the need for developing students' knowledge and practices that may help them address and solve future wicked problems. Furthermore, the frameworks mention creativity, critical thinking, productivity, and problem-solving, all of which are traits of being a competent designer. This is reiterated by Burdick and Willies according to whom 21st-century skills "sound like designing" (2011, 546). Pacione's agenda-raising Interactions[20] article puts forth the argument that design should be "*put back in the hands of everyone*" (2010), a statement in line with those of Nelson and Stolterman (2012). Pacione suggests that we should not focus on educating the general public to levels of design mastery. Instead, Pacione describes "design for the people" as a form of literacy similar to that of mathematical literacy: basic skills and techniques that serve us in our daily lives. Despite the general popularity of design in various professional (and personal) disciplines, it is noteworthy that the studies offer understandings of experienced designers, and comparisons of the processes of novice versus expert designers who have an intrinsic motivation for learning design (e.g., (Ho 2001; N. Cross 2004)), but not of K–12 students (who might not have intrinsic motivations for learning design). In a comparative analysis of international frameworks for 21st-century competencies, Voogt and Roblin (2012a) claim that an operational definition for each of the 21st-century competencies is required to determine what should be expected from students to reach the defined competencies. Such operational definitions are crucial as they contribute to developing and broadening a pedagogical continuum (Voogt et al. 2011) for planning and assessing the learning of 21st-century competencies—in the case of this dissertation, articulations of competencies that make up digital design literacy. However, the field of making in education currently lacks an operational definition of digital design literacy to determine what to expect from students and teachers. In chapters 4 and 5, I return to this issue by demonstrating how the Digital Design Literacy Framework and my papers have contributed an operational definition of digital design literacy for K–12. Furthermore, Voogt and Roblin state that the connections between subjects and 21st-century competencies should be identified, both within and across subjects, thus making these connections stronger. In my studies, I have worked primarily *within* a specific subject that crosses multiple subjects: critical thinking, digital literacy, and design literacy. This crossover emerged in conjunction with a newly introduced focus on innovation, creativity, and digital technology, specifically in the subject Crafts and Design[21] in the Danish school system. In this subject, students are to work with design and crafting through processes of ideation, fabrication, production, and product evaluation, emphasizing the integration of new maker technologies. My work cut across subjects, exemplified in the

[20] http://interactions.acm.org/ (accessed 03/11/2018).
[21] http://eng.uvm.dk/~/media/UVM/Filer/English/PDF/131007%20folkeskolereformaftale_ENG_RED.pdf (accessed 17/01/2018)

included papers, for example, R1 focuses on the relationship between the critical, digital, and designerly, whereas in P5, I take an interest in critical digital literacy and in P3 focus on the students' use of maker technologies. Moreover, Voogt and Roblin argue that the interdisciplinary themes are dynamic and in continuous change, since they must reflect contemporary societal issues, many of which involve the proliferation of digital technology from the workplace reaching out and broadening in scope, ultimately resulting in digital technology moving into the classroom and other domains of everyday lives (Grudin 1990). Grudin claims that computers have moved from mainframes such as time-sharing systems to ubiquitous computing, namely that digital technologies have faded into our everyday surroundings, for example, ATMs, phones, and interactive urban media façades. N. Cross (1982) justifies design in general education, claiming, "*Design in general education is not primarily a preparation for a career, nor is it primarily a training in useful productive skills for "doing and making" in industry. It must be defined in terms of the intrinsic value of education"* and "*To be educated is of value in and of itself, not because of any extrinsic motivating factors or advantages it might be considered to offer, such as getting a job*" (ibid.). Cross lists three ways that design can be educationally valuable for the general public: (1) Design develops innate competencies in solving real-world ill-defined problems, (2) design sustains cognitive development in the concrete iconic modes of cognition, (3) design offers opportunities for development of a wide range of competencies and non-verbal thought and communication.

Cross's claim resonates with Klakfi's conception of *epochal key problems* (Klafki 2011) as they have to do with designing preferred futures. Epochal key problems are period, universal, and do not necessarily have a given answer in advance. Klafki argues that students should work with epochal key problems throughout their entire education, as they concern a large portion of humans on a global scale.[22] Examples of contemporary epochal key problems are climate change, overfishing, deforestation, biodiversity, and online privacy. In sum, a central issue in introducing a new subject in K–12 is the development of frameworks containing definitions of 21st-century competencies and strategies to support and regulate its implementation and assessment of students' competencies (Voogt and Roblin 2012a). In light of current developments in the turn toward digital design in making in education, an instinctive imperative is to ensure that fundamental competencies of digital design literacy are articulated.

[22] For a collection of epochal key problems related to environmental, social and economic challenges of the 21st century, I recommend readers to see https://21stcenturychallenges.org/ (accessed 20/5/2018).

Figure 5—One of the school maker settings from which my empirical material has been collected.

As my work deals with the introduction of making in K–12, I want to define making more specifically from the design perspective of Nelson and Stolterman. To Nelson and Stolterman, making is an essential aspect of design, in addition to its process of inquiry; it is its capacity to produce and give form to a design concept. An example of a palette for design production "*would include categories of the capacity "to make*" (Nelson and Stolterman 2012, 172). The focus is on material making and production as distinct from just description and explanation. Whereas making emphasizes the creation of personally meaningful objects based on personal needs, design processes are focused on the desires and needs of others—that is, the design brief that students have to work with. Additionally, by employing maker settings, we open potentialities for a design studio design approach (Schön 1985). As shown in (Smith, Iversen, and Hjorth 2015), maker settings such as school FabLabs offer opportunities to support what Schön defines as a reflective practicum (Schön 1987)—and such settings are essential if students are to engage successfully in design processes. Schön has argued for learning through a reflective practicum, in which an aspiring designer builds up a personal repertoire of knowledge through engagement in design projects (Höök et al. 2015). Hence, I consider K–12 maker settings as a reflective practicum. However, one crucial problem arises; K–12 teachers are not design experts and thus cannot engage in a master-apprentice relation, and students do not necessarily have an intrinsic motivation for learning design, as is the case of students who chose to learn design. Hence, K–12 teachers must develop new practices to integrate design and digital technologies into school maker settings and carefully balance explorative and iterative approaches to real-world problem-solving. However, there is a lack of knowledge on how to do this and address the accompanying challenges that emerge in training the reflective educator. Without competent teachers, design education cannot be taught successfully, a statement that Iivari and Kinnula reaffirm, "T*here are multiple challenges involved, and schools and teachers are seriously in need for help*." (2018).

In summary, the CCI and IDC research communities have moved from working with children as design partners, testers, informants and so forth to a focus on empowering children to be actors of change. Making and designing enable students to build or adapt objects by hand in order to understand a particular concept. However, there is a shortage of knowledge about how to introduce and understand digital design literacy in K–12. Thus, it is crucial to develop articulations that contribute to framing and intensifying central competencies of digital design as a new subject in K–12, as it is crucial to plan curriculum, make assessment, and make theory on digital design more accessible to K–12.

While the maker movement has received much praise and hype, both in and out of school, it has also received criticism. What follows is a review and discussion of the criticism that has been raised since the maker movement reached beyond geeky hackerdoms. It is easy to get caught up in the hype surrounding the novel means of teaching in K–12 maker settings, but one must not be so gullible as to "buy the fake diamond ring." Hence, it is necessary to make a critique of the movement and turn toward making in education.

2.1.4 Criticism of The Maker Movement

The narrative of empowerment through making has drawn attention within the IDC and CCI communities. While these arguments are indeed powerful and persuasive, a body of literature that criticizes the maker movement has started to emerge and gain traction (Ratto 2011; Sivek 2011; L. K. Hansen and Stephensen 2013; G. D. Hertz 2014). In a panel presented at CHI 2014, Ames et al. (2014) discuss the visions of the maker movement. Her criticism finds that making often falls short of its ideals, for example, technological empowerment and the openness of the maker community. Researchers have remarked that an overwhelming number of participants are white Caucasian males with a technical background and with plenty of disposable income, whereas the presence of women and minorities is low (Buechley 2013; Brahms & Crowley in Kylie Peppler, Halverson, and Kafai 2016b, 2:13–28). This is exemplified in Buechley and Hill's (2010) analysis of users of Arduino and LilyPad. Based on an analysis of customers by gender, they found that Arduino is predominantly used and bought by males, whereas LilyPad is used and bought predominantly by females. Another problematic development is the increase in the co-optation of the maker movement by mainstream consumer society and technology corporations, with the danger of becoming consumers of maker technologies and the accompanying trivialization of making. An example of such dangers is the “keychain syndrome” (Blikstein 2013a) where projects are instructional but at the time hyped among students and teachers since digital fabrication can easily generate materialized artifacts (load up the STL and press print on the 3D printer). Accordingly, educators should avoid teachings that are quick demonstration projects or a step-by-step guide to combat the triviality of making simple remixes of ready-mades (fig. 6 conceptually illustrates these concerns).

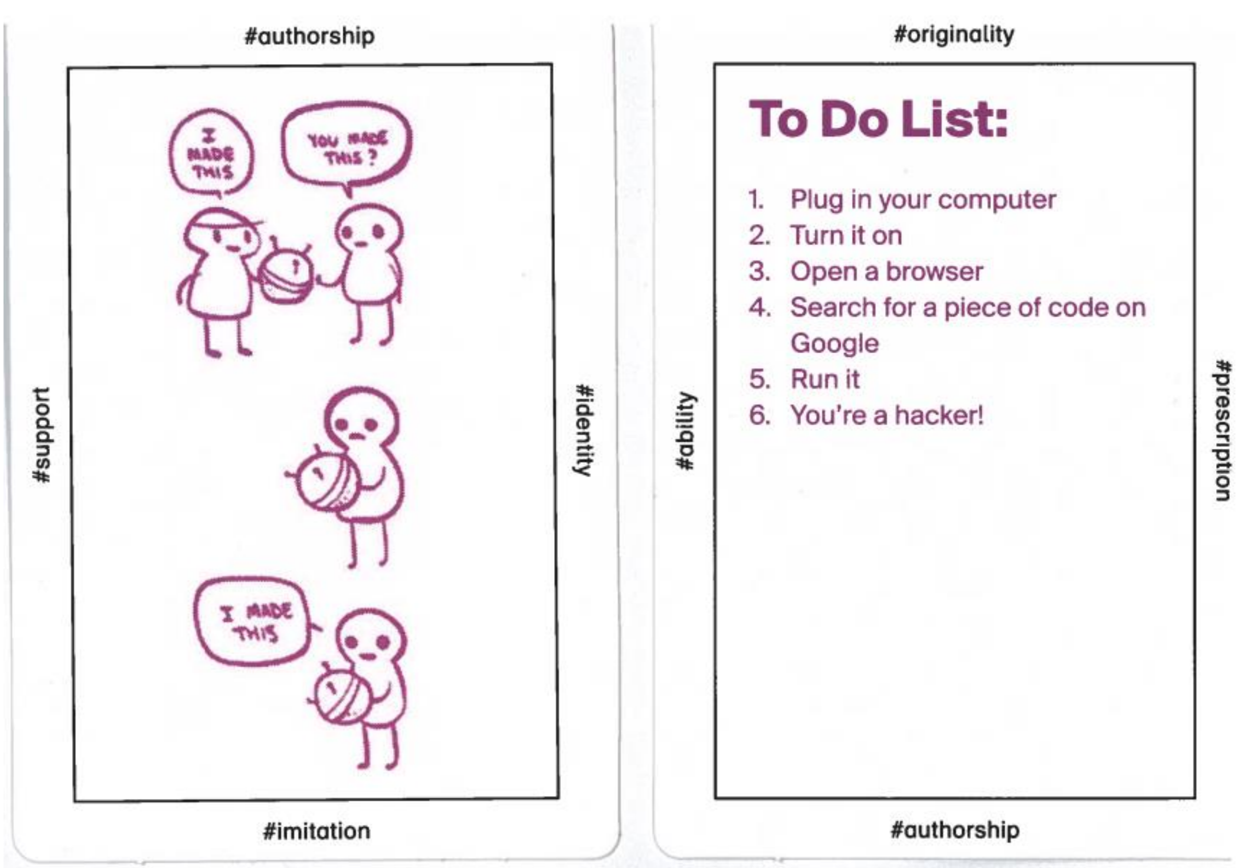

Figure 6—Two Unmaking cards that point toward “maker movement issues” similar to that of the keychain syndrome (Critical Media Lab 2016).

Presence of American corporations influence on making in education, its practices, technologies, and other resources might also have unwanted consequences (Lindtner, Hertz, and Dourish 2014). One potential danger of such influence can be observed in the monopoly that corporations such as Microsoft, Apple, or Google have in education in terms of software (e.g., Microsoft Office, “learn to Google,” or Apple iPad, all of which lock users into solely using wall-gardened services by being incompatible with all other options and in some cases spying on students (Alim et al. 2017)). This could potentially also happen with making in education (the FabLab Foundation has top-down criteria for what can be qualified as a FabLab).[23] Bean and Rosner (2014) criticize the maker movement as being articulated as a social movement, but that while a movement is typically understood to be a bottom-up phenomenon, brands usually originate from the top-down. The promises of the maker movement rest on digital utopianism with a solidly technological determinist bent (ibid.), exemplified in Anderson's description of digital fabrication as an industrial revolution (Anderson 2012)—note the use of industrial and not social revolution. So, "*While its leaders refer to making as a movement, we think it may be better understood as a brand*" (Bean and Rosner 2014, 27). To challenge the technological utopianism of the maker movement (Sivek 2011), a counterculture has emerged; *critical making*. Ratto uses critical making to describe his desire to "*theoretically and pragmatically connect two modes of engagement with the world that are often held separate—critical thinking, typically understood as conceptually and linguistically based, and physical "making," goal-based material work*" (Ratto 2011, 253). Critical making focus on simultaneous socially reflective and technical work through making, not to come up with solutions to a problem, but rather to facilitate praxis for critiquing contemporary sociotechnical issues and design of digital technologies to further critical knowledge through material production. The Free Universal Construction Kit (L. K. Hansen and Stephensen 2013; Free Art and Technology [F.A.T.] Lab and Sy-Lab 2012) can be viewed as an example of critical making: "*We are not a commercial company; we are artists, hackers, and activists. The Kit is not a product; it is a provocation. F.A.T. Lab and Sy-Lab, in cooperation with Adapterz LLC, (1) perform solely the service of publishing the Free Universal Construction Kit, (2) do not participate in any production, public manufacture or sale of the items displayed here, and (3) offer no opinion, warranty or representation as to the safety, quality or functionality of the Kit.*" (Free Art and Technology [F.A.T.] Lab and Sy-Lab 2012), fig. 7. Drawing on the ideas of hackerism, Hertz (2013) argues that *Make* magazine has sanitized making into a consumer-friendly format. Hertz claims that this "maker sanitization" ignores the values of hackerism culture, for example, reverse engineering as a civic activity or tactical media activism, and thus the maker movement distances itself from discussions on politics, activism, history, economics, and social issues. Hence, the underpinning for critical making is shedding light on the ideologies behind the digital technologies that inhabit our everyday lives.

[23] https://www.fabfoundation.org/ (accessed 20/01/2018)

Figure 7—The Free Universal Construction Kit 3D printed in plastic and an example of the interoperability between children's construction toys. CC BY-NC-SA 3.0 by F.A.T. Lab and Sy-Lab.

Making as an educational practice is seldom brought into a pedagogical tradition but, rather, caters to the idea of making as an educational practice in itself. However, this practice has emerged from the innovation and technological oppressed culture of the notoriously non-diverse MIT-Silicon Valley axis. That the maker movement has its roots in the ideologies of the MIT-Silicon Valley axis also has political implications. As already noted, the majority of maker education is centered around STEM, especially programming, which is the bread and butter of the technology industry in Silicon Valley. Because there will be a lack of programmers able to position the jobs that will be created in the future, companies like Amazon and Google have a huge interest in bringing programming into formal education—without a large enough workforce to fill their need of workers, their profits and business could drop and fail. My intention with this critique is not to dismiss the educational potentialities of maker settings. However, since education is heavily politicized, it is important to keep these criticisms in mind. Without such discussions, education plays to the market and cultural hype, and thus solidifies technology corporations' positions within wider sociotechnical systems, giving them power and agency to co-determinate what society should deem to be educationally valuable, as has happened with software monopolies found in K–12 and society at large. A more general critique of the maker movement and design education, both of which promote the promise of "creativity and innovation," is that the discourse of creativity often points toward performance and productivity (Stephensen 2010). Stephensen claims that the top-down goal of creating creative citizens is to create economic value for society, not to become artists who make art for the sake of making art. This is what Stephensen describes as “the capitalistic spirit and the creative ethic” (ibid.).

Having introduced the discourse of making in education, I will now attend to literature on the topic of new literacies studies with a particular interest in digital technology and innovative and creative work. This is followed by a review of design education theory and the competencies this literature argues to be important to learn to think and act like a designer. Hereafter, I review literature that argues for the importance of taking a critical stance towards sociotechnical developments and how design and making can serve as venues for critical engagement with sociotechnical issues. This review will serve as the basis for the synthesis of my findings into a framework as I conceptualize design literacy and digital literacies as an interrelation whole and make articulations on what they might entail based on my discussions throughout this dissertations and insights from the included papers. The framework is by no means exhaustive, but it provides a vocabulary and conceptual broadening of digital design literacy.

2.2 NEW DIGITAL LITERACIES IN K–12 EDUCATION

In this chapter, I review and discuss the concept of new literacies and what it means for the future of K–12 education. I use this theory to frame my later articulations on digital design literacy, which form the basis upon which my PhD project activities are informed and legitimized within curriculum-based K–12 education. New literacy studies are relevant as they frame digital design in a larger literacy tradition that currently is underexposed in the field of making in education. Furthermore, reviewing contemporary literature on literacy helps me to legitimize, refine, and explore my research questions, as it puts into question why digital design should be taught in K–12. Finally, I want to clear up any conceptual confusion, particularly regarding the notions of “competencies,” “skills,” “literacy capabilities,” “abilities,” “mastery” and so forth, to make my position clear. Terms that describe the ability to do something well, successfully, or efficiently, usually as a result of experience and training, such as ICT skills, technology skills, IT skills, 21st-century skills, information literacy, digital literacy, and digital competence are often used as synonyms (Ilomäki, Kantosalo, and Lakkala 2011).

Literacy embodies a multitude of educational theories (Kaestle 1985; Coiro et al. 2014). Literacy is, in itself, a loaded word and it remains contested in both education and design literature (Bawden in Lankshear and Knobel 2008, 15–33; Coiro et al. 2014, 1–21). *Merriam-Webster’s Collegiate Dictionary* defines literacy as “*the quality or state of being literate; knowledge that relates to a specified subject; especially: ability to read and write*.” The *Oxford English Dictionary* has a similar definition, “*(1) The ability to read and write, (1.1) Competence or knowledge in a specified area.*” Both define literacy as being capable of reading and writing texts and having domain-specific knowledge. Even though literacy is connected to reading and writing, literacy has historically been an ambiguous concept as it includes a range of reading and writing capabilities (Kaestle 1985), for example, phonology, orthography, and semantics. From this understanding, literacy is not just about being able to spell out words but also to have the capability to construct meaningful sentences that can be conveyed to others (ibid.). Colin and Michele (2011, 4) discuss how literacy only recently has become associated with formal education. Prior to the 1970s, literacy was seldom found within formal education but was understood as the basic precondition of "real" schooling. In contrast, illiteracy was associated with unemployment, drug abuse, or criminality (ibid.). Today, literacy is a common concept used in formal education, and its definitions have changed from simply being a precondition for "real schooling" to a process of life-long learning (ibid.). As Western societies moved to a post-industrial era, the needs of the labor market and employment changed as fewer people were required in the assembly line (Colin and Michele 2011). As society developed a need for people to read and write texts, literacy emerged as a topic of discussion. In line with this, Lankshear and Knobel have defined literacy as "s*ocially recognized ways in which people generate, communicate and negotiate meanings as members of Discourses, through the medium of encoded texts* (Colin and Michele 2011, 33). While this definition is not bound by digital technologies, it proposes that literacies are always negotiated in society through policies, teaching practices, academic thought, and other stakeholders such as industry job demands. As digital technology is becoming ever more ubiquitous, a digital-literate population is becoming directly coupled with economic growth and social well-being (ibid.). However, new literacies often referred to forms of literacies that emerge with new digital technologies and the increase in adoption of digital technologies that become ubiquitous in the world, for example, personal lives and educational systems (Lankshear and Knobel 2008; Colin and Michele 2011; Coiro et al. 2014; Buckingham 2015; D'Amelio 2018). Consequently, new literacies are emerging, one of which is digital literacy, or as I argue in this dissertation; digital design literacy.

During the 1980s and 1990s, literacy was extended with the idea of *educational accountability* (Biesta 2008, 2010). To manage accountability, educational systems increasingly relied on standardized national and international tests (Biesta 2008, 2010; Colin and Michele 2011). New (inter)national-level curricula and curriculum standards and learning goals are increasingly relied upon to evaluate students' literacy. Colin and Michele denote this move as the standards-testing-accountability-performance model of education, the existence of which has been justified with arguments of transparency, improved student performance, accountability for schools to heighten literacy, and for educational quality assurance (Colin and Michele 2011, 9). In extension, Biesta argues that education has entered an age of measurement (2008, 2010). In this age, what is valued in educational systems is in large part determined by what is currently measurable, and thus educational outcomes are valued by institutions' and students' capacities to perform on quantitative assessments. The content of assessment tools used to perform these standardized measurements is often legitimated through the principle of performativity, to optimize the cost/benefit of the educational systems and measure the quality of education (Lyotard 1993; Biesta 2010). What is valued as literacy is influenced by the degree to which comparative quantitative assessments are possible. One can agree or disagree with this development, but people, organizations, and institutions who have an interest in making an impact on the future of education must work with this tactic to further their agenda.

Literacy is interrelated with social, ideological, and cultural ideas and can be fully understood only from these contexts (Colin and Michele 2011, 12–14). Being bound up with social practice and politics, individuals need to learn not only how to read and write texts, but also how we can talk about texts in certain ways, hold beliefs and values about them, and socially and culturally interact with them. Lived, talked, enacted, value-and-belief-laden practices in specific places and times, literacy is always linked to social identities and discourses. The idea of literacy being a precondition for schooling is rejected, instead arguing that literacy is embedded within larger social practices and discourse (Gee 2015, 20). This perspective has manifested itself in the educational language internationally (OECD and DeSeCo 2005; The Partnership for 21st Century Skills 2015; Fraillon et al. 2014). Organizations such the Organization for Economic Co-operation and Development (OECD) have described a set of skills and competencies that the group argue to be essential for students to acquire for the 21st century and have created international literacy evaluation initiatives, for example, the International Student Assessment (PISA) program.[24] These skills and competencies are often related to what is demanded by industry and thus what the job market dictates, legitimized by the constant need for economic growth and, in light of this, optimize the cost/benefit of the education. These evaluation initiatives are quantitative and strengthen the educational discourse described as the age of measurement. In this dissertation, I am particularly interested in how the complex sociotechnical changes driven by new technological designs change the concepts of literacy and what it entails from a design, digital, and critical perspective.

Literacy has been applied to an increasing variety of subjects, and today, almost any subject that is deemed educationally valuable is conceived as being a literacy (Colin and Michele 2011). Since the 1980s, notions such as ITC literacy, digital literacy, or media literacy have become increasingly visible in K–12. Sometimes, literacy is used as a metaphor for competence, proficiency, or capability (Barnett 1994;

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[24] https://www.oecd.org/pisa/ (accessed 19/4/2018).

Colin and Michele 2011, 21; Hinrichsen and Coombs 2014; Pangrazio 2016). Rather than being a metaphor, I view literacy as a broader form of education that goes beyond narrow forms of functional and instrumental skills, for example, how to crop an image or upload a video file to the Internet. Instead, literacy suggests a more rounded, humanistic conception that implies a wider-form education about digitality that is not restricted to instrumental skills (Søby 2003; Buckingham 2015). However, these skills should not be abandoned but taught in parallel with humanistic perspectives (but is not a precondition—one can critique digital technologies without being able to operate them). As with traditional reading, one must be able to operate something with understanding of a certain type of functionality which can be operated in a certain way and thus requires knowledge of a certain domain (interpretation the WIMP, "windows, icons, menus, pointer," interface) and skills (moving the mouse pointer). Similar to the fears of having populations being illiterate, in the traditional sense of the word, educational policy makers now fear that its population might be left behind and become part of the digital divide between those who are digital-literate and those who are not. The increase in what can be considered a literacy has spawned a turn toward the idea of there being an endless array of new literacies—in plural (Colin and Michele 2011, 3–32). The New London Group described the movement from a single literacy, that of reading and writing, to an age of multiple literacies (The New London Group 1996; New London Group 2000). In 1996, the group presented the idea of multiliteracies to move beyond typographic literacy and spurred a new interdisciplinary field of study, often referred to as new literacy studies (Gee 2015). From this position, the field of making in education needs a better understanding of literacy "*in its full range of cognitive, social, interactional, cultural, political, institutional, economic, moral and historical contexts*" (ibid.). New literacy studies take a sociocultural perspective to understand and formulate new literacies, rather than a linguistic perspective, meaning that the study of literacies is a constantly transforming and emerging social and cultural phenomenon (Colin and Michele 2011, 27–33; Gee 2015). Furthermore, it diverges from traditional literacy through a strong focus on critical aspects of decoding and encoding texts, for example, not decoding for truth but for perspectives and understanding how texts are constructed and embodies ideological interests and functions within a sociocultural system. Thus, literacy is no longer exclusively taught in order for individuals to make ends in their day-to-day life but enable them to figure out what truth there might exist about a situation, phenomenon, problem, discussion, or controversy for which there is no definitive answer. A literate individual can reflect on self and his wider relation to the world he inhabits and act upon this world to change it. New literacies are typically addressed with attention to participatory, collaborative, and distributed forms of literacy when compared to traditional literacy[25] and place emphasis on being a producer rather than consuming or banking domain knowledge. I define domain knowledge as knowledge that is particular to specialized disciplines, subjects, or professions, which is acquired through experience with the theoretical or practical understanding of a domain, as opposed to being independent and general knowledge. In this dissertation, this knowledge applies to the digital domain, including the social, cultural, and economic phenomena enabled by digital technologies.

New literacies studies' emphasis on the integrated development of the individual from a holistic perspective have spawned a renewed interested in the German Bildung tradition and how it may inform, and be informed, by the Anglo-Saxon literacy tradition (Tække and Paulsen 2017). Bildung holds the idea that learning should be directed toward emancipation, empowerment, and critical citizenship (Klafki 2011; Hjorth and Iversen 2014). Critical citizens can relate themselves to the world and society that they take part in and show mature responsibility, as an empowered individual, acting within the collective for the collective. Bildung is a lifelong learning process in which the individual, through reflection and action, critically considers his conception of self and the world, in the case of my project, how digital technology shapes the world—also named digital Bildung (Katterfeldt, Dittert, and Schelhowe 2015). An important concept in the Bildung tradition is epochal key problems (Klafki 2011). Klafki argues that students should work with epochal key problems throughout their education and develop a historically disseminated understanding of central issues in the present and the foreseeable future; they should have the insight that everyone shares the responsibility and a willingness to contribute to the solving of these problems. In P5, I successfully rely on the epochal key problems of online data tracking to frame the topic of my workshop and promote critical thinking with the intention to critically empower students. Epochal key problems can also help teachers make design briefs that work within K–12 curricula. However, understanding epochal key problems is not enough; one must also contribute solutions to these problems. One way of solving epochal key problems is through design, as suggested by Hjorth and Iversen who articulate design Bildung as "*the process in which students develop their design repertoire and ability and mindset to act designerly to manipulate and create new technological solutions to solve complex societal or personal problems*" (2014). I argue, that since K–12 are constrained in terms of involving clients from outside the school to make design contracts, epochal key problems are good starting grounds for determining what problems students could work with in design processes. Assessing need is very

[25] Note that traditional literacy can be said to rely on writing as a technology in itself and its evolution; the movement from script to printed texts enabled by the advent of the printing press allowed for innovations in cultural activities such as standardization of language and more rigorous systems of cataloguing (however, there are debates on the consequences, impact and importance of the invention of the printing press (Kaestle 1985)).

different from creating need. Needs-based is founded on the erroneous assumption that a need is easily discerned. From a design perspective, needs are not clearly understood at all. Rather, designers try to form an empathy for a client's desiderata instead of creating new needs (Nelson and Stolterman 2012).

Having introduced the notion of new literacies and related it to digital design and the Bildung tradition, I now turn to the specifics of digital literacy.

2.2.1 Framing Digital Literacy

In this section, I conceptually frame design literacy combined with digital literacy; I will be drawing on digital literacy studies as inspiration for the Digital Design Literacy Framework design. Particularly, I discuss research on new literacies that pertain to digital technology (Lankshear and Knobel 2008; Coiro et al. 2014) that reference national and international education policy texts and seminal educational literacy researchers. The included literature is all positioned at the intersection of literacy and technology and draws on the potential of each while carving out important new territory to be investigated. I primarily draw on literacy theory from the reputed books by Lankshear, Knobel, and Martins (2008), Colin and Michele (2011) as well as Corio et al. (2014), particularly texts that discuss literacy frameworks that help ground my conception of digital design literacy and frame it within a new literacies discourse. The literature brings together a group of international authors in the field of digital literacy. Their work explores a diverse range of the concepts, policies, and practices of digital literacy and discusses how digital literacy is related to similar ideas: information literacy, computer literacy, digital competence, and so on. New literacy also studies conceptual clarity regarding the notions of “competencies,” “skills,” “literacy” “capabilities,” “abilities,” “mastery,” and so forth, to make my working definitions clear. I employ competence as the overarching term that describes the ability to do something well, successfully, or efficiently, usually as a result of experience and training, such as ICT skills, technology skills, IT skills, 21st-century skills, information literacy, digital literacy, and digital competence, are often used as synonyms, for example, digital competence and digital literacy (Ilomäki, Kantosalo, and Lakkala 2011). The underlying assumption in the following is that digital technology should be used not only as a support but as a material (Bergström et al. 2010; Fernaeus and Sundström 2012; Jung and Stolterman 2012) that students have confidence in using when engaged in design processes. In doing so, I point toward the idea that students need to use technologies not only to solve practical problems but also to uncover problems and design solutions to these problems. It additionally places my work inside the domain of educational research, which I argue to be important if the ideals and interests of making in education are to be recognized in domains outside making in education.

As with traditional read/write literacy, digital literacy began with the idea of being capable in operating a computer system as a precondition for other tasks, such as opening a text file, editing the text, and printing it to paper. Since then, the idea has evolved into specifics such as how to utilize different software and services for different tasks, for example, what different word processors do for writing digital texts or what Internet search engines best suit the goal one tries to accomplish. More recently, capabilities such as creating, reflectivity, and critical thinking have been placed as important competencies to develop a digital literacy (Lankshear and Knobel 2008; Colin and Michele 2011; Pangrazio 2016; D'Amelio 2018). The multiplicity of new literacies makes it so that its definition remains broad and open in scope, as there exist various conceptualizations of new literacies used within different discourses (Coiro et al., 2014, pp. 12–13). Digital literacies can be considered a framework that integrates various competences and skills, but according to Martin et al. (Martin A. Martin and Madigan 2006, 3–25), it would not be sensible to reduce literacies to a finite number of competences or skills nor to suggest an all-encompassing model that covers all contexts and situations—"*digital literacy is a condition, not a threshold*" (ibid.). As with traditional literacies, one does not "complete" a literacy, draining the discipline for all its skills, knowledge, and so on. It is for this reason that I claim the Digital Design Literacy Framework to be tentative of what could constitute central competencies of digital design literacy for K–12.

To ground the Digital Design Literacy Framework, I adopt Martin's framework (2008, 151–76) of three levels of digital literacy (as an alternating condition, not as a threshold—fig. 8). Martin's work is useful in that he makes concrete schematic representations of digital literacy scaffolded by written text. Martin base his framework on Gilster's definition of digital literacy, which identifies construction of artifacts and critical thinking as being at the core of digital literacy, rather than technical competencies. Gilster emphasizes that digital literacy is more than a collection of skills and competencies to use in school and the labor market; digital literacy should also be of value in people's everyday lives (Gilster 1998). Martin's digital literacy framework is, to my knowledge, the only and most comprehensive framework within the field of new literacy studies that is schematically illustrated. Martin clears up conceptual confusion and articulates the relationship between literacy, competencies, skills, abilities, and so on. As further perspectives, Martin references the Canadian SchoolNet National Advisory Board, Digital Horizon of the New Zealand Ministry of Education and the European Commission, and the Norwegian Ministry of Research and Education that draws on the concept of digital Bildung. Martin summaries these texts into a list of five key elements of digital literacy:

1. The ability to carry out successful digital actions embedded within work, learning, leisure, and other aspects of life.
2. Will vary according to each individuals' particular situation and is a process of lifelong learning.

3. Digital literacy is broader than ICT literacy and includes elements drawn from several related digital literacies.
4. Acquiring and using knowledge, techniques, attitudes, and the ability to plan, execute, and evaluate digital actions in the solution of tasks.
5. Be self-aware of own interactions with digital technology and to reflect on one's own digital literacy development.

On the basis of these key elements, Martin defines digital literacy as "*the awareness, attitude and ability of individuals to appropriately use digital tools and facilities to identify, access, manage, integrate, evaluate, analyze and synthesize digital resources, construct new knowledge, create media expressions, and communicate with others, in the context of specific life situations, in order to enable constructive social action; and to reflect upon this process.*" (2008, 166–67).

Based on this definition, Martin presents his framework of three levels of digital literacy (fig. 8).

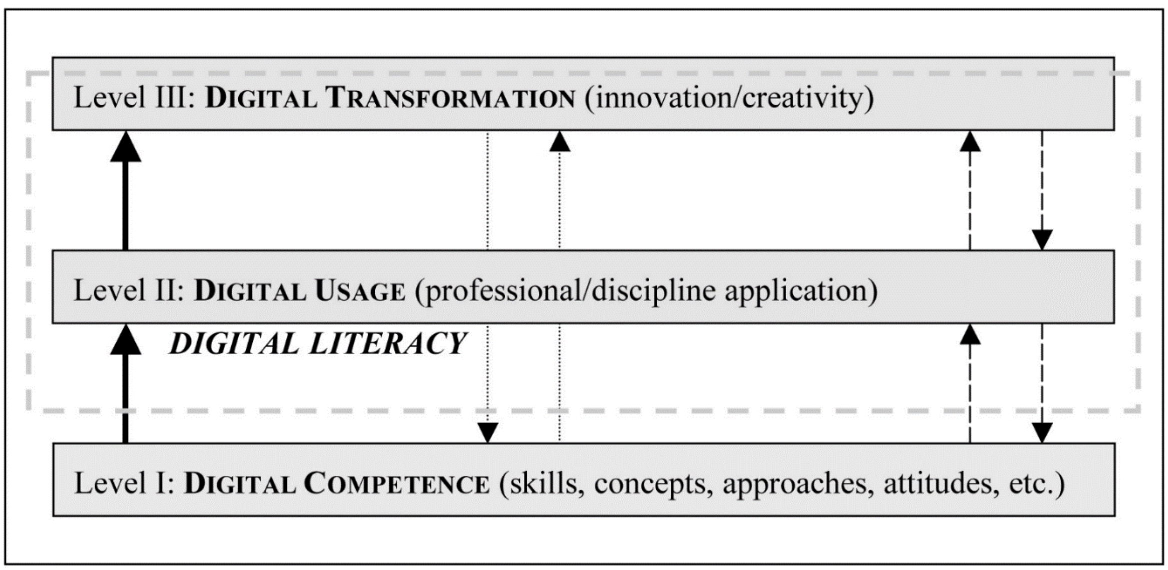

Figure 8—Martins three levels of digital literacy (2008, 167) .

Level 1 consists of digital competences, requirements, and pre-conditions for levels 2 and 3 but cannot be described as a digital literacy in itself. Martin views digital competence as an underpinning element of digital literacy. Moving from competence to literacy, one must consider the importance of "situational embedding," which denotes that digital literacy must involve the successful application of digital competencies within life situations. Martins lists 13 processes that are more-or-less sequentially developed competencies that underpin digital literacy. These involve instantiations of the learning processes in a relevant domain including analysis of digital resources, evaluation of the objectivity and reliability of digital resources, and the creation and communication of new knowledge with technologies (see Martin (2008) for a detailed list). The instantiations of the digital competences will vary depending on the situation the student finds himself in. The central level of Martin's framework is that of "digital usage" (level 2): *"the application of digital competence within specific professional or domain contexts, giving rise to a corpus of digital usages specific to an individual, group or organization."* (ibid. 171).

The requirements of the situation shape digital usage, for example, complete a specified task or suggest a solution to a problem within a particular domain context. One such domain is the school system, which Martins describes as a community of learning. Digital literacy is put into use as an individual is presented with a task or problem that arises out of a specific life context, such as work, study, or leisure time. To complete or solve this task or problem, the individual tacitly identifies a competence requirement, which he has acquired through the learning processes available and that he deems to be an appropriate competence to use. Knowledge of the domain informs the competences used to tackle a task or problem. On this background, digital usage is termed as informed uses of digital competences within different life-situations. The movements between digital competence and digital usage in fig. 8 depict that the outcome of digital usage feeds back into the individuals' digital competencies, and back again. The third level of digital literacy is that of "digital transformation," which happens when digital usage enables innovative and creative work and stimulates significant change within the domain context (Lankshear and Knobel 2008, 166–67). Through this transformative work, students also develop their digital competences and digital usage as they uncover new knowledge and techniques in the process of solving a problem through innovative and creative means. Finally, Martin notes that digital transformation is not a necessary condition for digital literacy and that students do not follow sequential leveling through each stage but are more random and iterative—although some cases require low-level knowledge and skills.

The transformative level shares many characteristics with design thinking. Design thinking has a strong commitment to do innovative and creative work, and the wording of transformative actions also resonates with the objective of designing (Resnick et al. 2005; N. Cross 2007a; Biskjaer, Dalsgaard, and Halskov 2010; Dorst 2011; N. Cross 2011; S. Bardzell, Rosner, and Bardzell 2012; Hanington and Martin 2012). In the words of Jones, design is inherently about proposing "*the initiation of change in [human]-made things*" (Jones 1992, 15), which is inherently transformative. Martin's framings of digital literacies have strong ties to design thinking and making in education; creative and innovative work with wicked problems through design processes that rely on the successful use of digital competencies. The framings provide grounds for legitimizing the potential of introducing in education design thinking that focuses on integrating digital technologies as a means to produce objects. In turn, design work with digital technologies can improve students' digital literacies, as they have to identify the best digital resources to solve a problem, access and evaluate documentation and guidance online, interpret and analyze (or debug) errors that will occur, and synthesize to crate and communicate their design proposals. This is especially true when design processes are unfolded in maker settings. While Martin's framework does touch upon critical thinking, it does not provide a detailed account of what can be considered critical digital literacy. To accommodate this, I will later review literature that gives more detailed accounts of critical digital literacy and uses this knowledge as a component in the Digital Design Literacy Framework I present in chapter 4.

At this point, it will be helpful to differentiate between the concepts of digital "skills," "competencies," "literacies," and so forth. No clearly defined international framework of reference exists for these concepts, but the numerous descriptions and definitions of the concepts have overlapping features in academic and political texts (Lankshear and Knobel 2008, 121–47, 164–67). Rather than discussing these differences in detail (see Gilster 1998; Coiro et al. 2014, 1–22; Bawden; Rantala and Suoranta 2008, 17; 91; Barnett 1994)), I adopt the definitions laid out by Bawden (Lankshear and Knobel 2008, 17) and Martin (Lankshear and Knobel 2008, 151). Competence as a noun can be scoped with an adjective such as "computational" and will function as an overarching term that describes a set of skills, knowledge, attitudes, and so forth deemed to be valuable within a discourse or domain. Competences are the pre-conditions for becoming literate. For example, computational competences include skills such as navigating an operating system's file manager and understanding of basic programming. Design competences include skills such as being able to externalize ideas through craftsmanship or problem setting and framing (as we shall later, disseminating design competence into an array of skills is difficult, as the concepts used to articulate design thinking are abstract and are hard to disintegrate into smaller operations as with computation). There is no threshold of skills that determines when one is competent within a given domain. However, we can point toward features that are more or less desirable, or fundamental, which is one of the contributions of the Digital Design Literacy Framework dissertation (see chapter 4). Development of literacy takes place when the competences are applied in the context of a profession or discipline (e.g., education). Competences only become literacies when students have to engage in solving "real" problems, problems that have relevance outside the school. One can, therefore, be competent but not literate if the competences are never put to use in a real-life situation. Moving from competence to literacy, one must consider the importance of *situational embedding* (Lankshear and Knobel 2008, 151).

In summary, the field of literacy has transformed from one literacy associated with being able to read and write text to that of multiple new literacies, often associated with new digital technologies and their growing role in the world. This growth has paved the way for a post-typographic era that conceptualizes literacy beyond the traditional modes of reading and writing print-based texts. The concept of literacies is broad in scope, but there are indeed many similarities between what educational scholars argue to be important characteristics of new digital literacies. In some instances, the various definitions of skills, competences, and literacies are close to identical, and their slight differences may be difficult to notice and are often developed based on the educational and academic community they serve. Based on my literature review, we can trace three turns. First, a turn toward humanistic virtues in the digital environment, second, a broader focus on creativity and design to innovate and transform the existing with digital technologies, and third, taking a critical stance towards technology's impact and relationship with society, culture, political and economic, ideologies, values, and so forth. Thus, there is a turn from instrumental skills and multimodal text evaluation to critical thinking on sociotechnical development. Furthermore, there is a desire for introducing design-like activities that can enable students to participate in changing the world and serve as a vehicle for teaching other subjects. New literacies studies theoretically frame and legitimize my conceptions of digital design as a literacy.

2.2.2 Design Literacy

Apart from digital literacies, another core component of digital design literacy is *design*. The issue of design literacy and its underlying competencies are central to my work in several ways. Firstly, it is the subject of my research activities as I deal with the conceptualization and articulation of digital design as a literacy. Secondly, exploring the design competencies will provide the basis for my proposition that the challenges facing K–12 are a conceptual understanding of digital design literacy and knowledge of how to integrate design with digital technologies in maker settings and create new pedagogies to facilitate teaching. Thirdly, elements of design theory form the basis for articulating my research approach. Finally, I consider my work a design challenge, as it entailed bringing about intentional change in the world, which I have argued to be preferable for future education. The purpose of this chapter is to review how design scholars articulate different design competencies and discuss the knowledge deficits in the making in education research community with regard to design in K–12 education.

Introducing design as a literacy in general education has been suggested previously (Baynes 1974; Archer 1979; A. Cross 1980, 1984; Davis et al. 1997; Pacione 2010) and that design represents an important area for educational development. Design *literacy* emphasis that K–12 students do not need, or have the desire, to be educated as expert designers. Instead, it is part of individuals' broad formation. While the topic of teaching design in K–12 has only recently surfaced as an explicit issue in making in education, similar discussions have a longer history in various disciplines related to design, for example, industrial design and architecture. However, by applying the idea of literacy, we are not discussing mastery of specialized subjects but, instead, competencies that are within the capabilities of everyone to develop to get by in everyday life (design is fundamental to human beings, e.g., arranging one's home is, in itself, a design activity). Archer (1979) argues that design should be regarded as a fundamental aspect of education (not specialized) on a par with and distinct from science and the humanities. Students should realize that they are designers and they can improve their design competencies just like improving their reading and writing. However, criteria for what makes someone a literate digital designer have not been explored in making in education literature. Furthermore, there is a lack of literature that addresses knowledge facilitation and exchange between design theory and digital design practice in K–12 maker settings, which is central in my work (I return to this conceptual bridging in chapter 4). Thus, these competencies need to be rearticulated to fit with the ideas of a literacy. I unfold what I, based on research from the included papers and the following literature review, contend to be some of the central design competencies of digital design literacy.

To position digital design literacy within the design discipline, I adopt Cross's schema of phases of development in design (fig. 9).

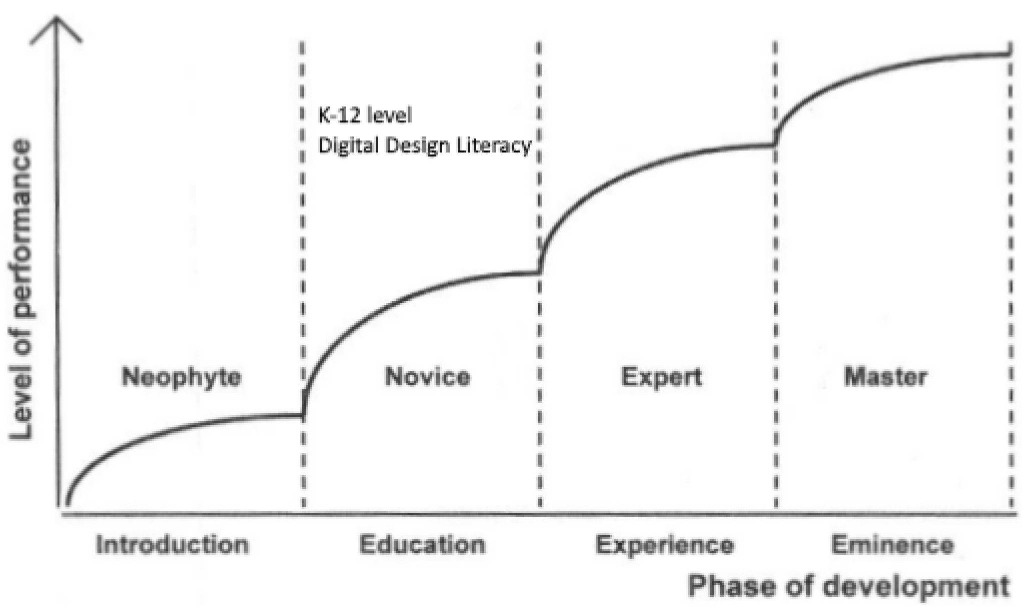

Figure 9—To become digital design literate, one must be a novice. However, one need not be an expert or master of design. Adopted from N. Cross (2011).

My adoption of N. Cross's schema depicts the phase of development at which digital design literacy for K–12 is positioned (fig. 9). In describing his schema, N. Cross writes that "i*n order to develop expertise, it seems that a novice needs lots and lots of practice, guided by skillful teachers. The novice also needs exposure to many good examples of expert work in the domain and needs to learn to perceive and retain these examples, or precedents, in terms of their underlying schema or organising principles*." (2011, 147). This exposure unfolds through the "*process of design*" which he adds "*is not just for designers, but for anyone whose business it is to create or lead something (…) anyone whose job it is to imagine something that does not yet exist and then plot the path from imagination to existence.*" (Pacione 2010, 8).

N. Cross articulates the nature of design competence thus, "*Design [competence] is summarised as comprising resolving ill-defined problems, adopting solution-focused cognitive strategies, employing abductive or appositional thinking and using non-verbal modelling media.*" (1990). In 1984, A. Cross stated that "*Much debate revolves around the superstructure of design education. That is, the ideas, products, the various facets and constraints of art and design culture into which the child is to be introduced.*" I interpret these statements as a call for more research on what competencies can be considered important foundations of design literacy. To incorporate digital design literacy into K–12, the praxis of design needs to be more formally understood and clearly expressed as a literacy, not as a profession. Established concepts of design education mostly relate to specialist training and as preparation of students for a profession. However, these concepts cannot simply be transferred to K–12 because:

(1) no studies explore the students' use or lack of design competencies in a making in K–12 education context;
(2) not all expert design competencies are relevant for K–12;
(3) design theory does not inquire into a formal school and does not consider the challenges of this context (e.g., teachers or the organization of formal schools);
(4) there is a lack of exemplars that showcase students' work with design and digital technologies (their studies are accountable to expert design practice);
(5) design requires a different approach to traditional methods of teaching, and the education of its teachers is needed (i.e., for teachers to teach design, they need a language to articulate what competencies design entails);
(6) theory on design expertise does not relate to the broader discussions and discourses around K–12;
(7) specialist design teachers are firstly designers and secondly teachers, but in K–12, all teachers are firstly teachers and only secondly specialists in other fields.

In design theory, competence has been conflated with capability, ability, and expertise so that there is no clear distinction (see P1 and (N. Cross 2011; Nelson and Stolterman 2012; Gray, Toombs, and Gross 2015)). I apply the notion of competence to denote collectively the different terms used to define the combination of practice, theoretical knowledge, and mindset used to state the quality of being adequately or well qualified, providing a structured guide to assess the behaviors of individual students. Hence, my use of competence will refer to a higher order that encapsulates many lower-order notions such as skills, knowledge, tools, attitudes and so on. (Lankshear and Knobel 2008, chap. 7). Based on the included papers, I draw attention toward what constitutes design competence and its lower orders of skills, knowledge, and so forth to bring about an operational definition of what can be considered some of the central design competencies and how this relates to my conception of the Digital Design Literacy Framework presented in chapter 4. As the concept of digital design literacy emphasizes design, a review of design competencies is required to determine what students should be expected to develop. Thus, this section will bridge central competencies that inform the Digital Design Literacy Framework. This bridging is based on discussions of competencies in design theory related to design expertise and the included papers. I use the notion of design theory broadly, covering research that addresses fundamental issues of what constitutes design competence.

What follows is a review of several seminal design researchers' take on what competencies are essential to expert designers. Informed by design competence theory, I show how the included papers contribute to a better understanding and articulation of digital design literacy for K–12. I will discuss design competence on a general level, without disregarding the design of digital artifacts. This is important since there are particular competencies determined by the specifics of the design domain in question. A longstanding design discipline is architecture, which demands competencies other than those of the digital designer. New challenges presented by new materials, technologies, and knowledge contributions in the field make design competence a moving target. I draw on design theory that discusses:

(1) how designers name, frame, and make inquiries into wicked problems;
(2) what a rich repertoire means for being a competent designer and how it can be developed;
(3) how designers work with design materials and navigate the design processes and how making can scaffold process navigation and relate these to the specific discipline of designing digital artifacts.

I discuss these three because they are the competencies that I have explored and contributed knowledge to in the included papers and because the three are frequently discussed in literature on design expertise. Hence, I introduce the competencies expressed in my papers and reflect upon these based on design theory. Throughout this section, I position the included papers and argue for how they contribute a bridge between theory and practice to gain an understanding of design competencies as part of digital design literacy. Having reviewed the gaps in understandings of digital design literacy in making in the education community, I will now discuss the three competencies that I have found to be relevant to both K–12 (findings from the included papers) and expert designers (literature on design competence),

(1) how designers name, frame and make inquiries into wicked problems

One particular and important difference between maker activities that focus on STEM education rather than design education is the idea of wicked problems and ultimate particulars. While both activities usually start with some brief or problem to be explored, STEM education takes a technical rational stance towards inquiry, that is, students try to discover a truth behind a phenomenon, for example, a law of physics. While the artifacts students make in STEM activities are unique and particular, the problem they try to solve is not wicked or an ultimate particular but has a pre-defined truth, such as understanding Newton's laws of motion. In design, there is no truth to discover. Instead, design is characterized by the wickedness of design problems. Resolving wicked problems requires students to take a designerly stance towards inquiry (see P1 and P4). Whereas STEM education uses the possibilities in maker settings to explore, explain, and understand physics or mathematics, design education uses maker settings as a resource to explore and create solutions to wicked problems that by nature do not have a single correct answer or truth, unlike the laws of physics. The philosophical traditions that underpin the two paradigms are also different, which in broad terms can be described as a scientific perspective and a humanistic perspective. Krippendorff argues that "*Science articulates the constructions that worked so far. Design articulates constructions that might work in the future—but not without human intervention*" (2007, 10), and he elaborates on the basic activities of design, among these that designers (1) consider possible futures that are inherently not predictable from laws of nature, (2) evaluate the desirability of these futures in relation to the people who are to inhabit them, and (3) search the present for variables that create a space of possible action. Elaborating on the distinction between science and design, Nelson and Stolterman (2012) argue that science and design address two different ends of a continuum; science moves from the particular to the general and universal whereas design deals with creating the particular, the non-universal. STEM education focuses on positivist science, whereas design is more qualitative and pragmatic in its approach to dealing with problems. In confronting wicked problems, the designer cannot focus only on that-which-is (description and explanation) but must engage with that-which-ought-to-be (ethics and morality) while considering that-which-is-desired (desiderata) for the given situation. Looking through the design scholars' statements of how designers approach problems, we can deduce some common traits. First, design is exploratory, investigative, and takes a designerly stance towards inquiry into problems (Schön 1984) which is crucial for the designer to develop if he is to engage successfully with wicked problems (Schön 1987; Buchanan 1992; Coyne 2005). A designerly stance entails reflection on the first intentions that set the designer on a specific path of inquiry toward action. However, schools tend to direct students to adopt a stance of technical rationality and thus develop routine expertise. Routine experts see wicked problems as tame and focus on answers that are readily at hand, easily accessible, or drawn on a set of finalized solutions. Taking a technical rational stance when confronted with wicked problems can end in forms of process paralysis, as the wicked problem does not lend itself to rational resolution. Taking a rational stance when engaging with wicked problems can lead to a narrowed focus on that-which-is versus that-which-ought-to-be without consideration for that-which-is-desired. Designers work iteratively rather than linearly, making judgments on design decisions, and revisiting and reflecting on these judgments to determine the needs of others (c.f. 2.1.3 and 2.2.2).

Designers select features of the situation to which they choose to attend (naming) and identify areas of the solution space in which they choose to explore (framing) to formulate a design problem to be resolved; they set boundaries, select particular things and relations for attention, and impose on the situation a coherence that initiates a subsequent process (Schön 1984). Successful design is not based on extensive problem analysis, but on adequate problem scoping and a focused or directed approach to gathering problem information and prioritizing criteria. However, no research exists on K–12 students' stance towards inquiry and there are no assessment tools for evaluating students' stance towards inquiry in "the age of measurement"—a deficit that I fill in P1 and P4 (see chapter 5).

(2) design repertoire and ability to critique and retrospectively reflect on digital designs

Closely related to the designer's stance towards inquiry is the idea of repertoire (Schön 1987; Löwgren and Stolterman 2004, 47, 166): "*Designers benefit from a rich repertoire of examples, exemplary models of related design ideas that are sometimes called formats. Many theories of design and design methods describe the early ideational work as a matching process between the designer's repertoire and the situation at hand. Design processes are shown in empirical studies to be driven by initial exemplars structuring and shaping the work*" (Löwgren and Stolterman 2004, 46). Knowledge, perspectives, exemplars, and experience from different design domains and processes are important parts of designers' repertoire. Initial comprehension of a situation is based on our experience through which we have formed knowledge, perspectives, and habits. It is against this backdrop—the repertoire—that situations may appear more or less problematic and familiar when our habitual response does not lead to expected outcome. The transformative relationship of digital design is directed toward understanding and acting in response to problematic situations, and though we draw upon experience and knowledge, this repertoire is challenged through inquiry and evolves in the process. Exposure to design exemplars, the activity of working through design processes, and development of a design language are essential in developing a rich repertoire. The designer sees the situation as something already present in his repertoire, but not to subsume the situation under a finite category, technical rational solution or rule (Schön 1984, 138–41; Löwgren and Stolterman 2004, 47, 166). A rich repertoire helps the designer to bring experience to bear on a new ultimate particular. It is, however, not enough to have a rich repertoire of examples that are exemplary in some sense. It also requires an articulation language and understandings suited for describing and analyzing qualities of artifacts and their impact in the world (a language of maker technologies did not exist at the time of this writing). Exemplars must be analyzed with rigor at which point a design language and domain knowledge become necessary. While the outcome might lose its direct and immediate relevance in the next problematic situation, it does add to designer's repertoire and prepare them for action. A repertoire of exemplars and an articulation language must be capable of handling specific details as well as the whole of the design in question, through the interplay between the visible details and the less visible whole. Hence, students are expected to work exemplarily in understanding and analyzing common issue and suggest solutions, for example, from reconstructing thoughts and ideas that may have led to a specific design.

When the designer makes sense of a situation he perceives to be unique, he sees it as something already present in his repertoire. Ideally, this will lead to reflections on how artifacts affect our lives, by inviting students to critique and reflect on particular designs that preferably represent a school of design, for example, Apple or Kono belong to a school that focuses on form and material qualities, whereas Reddit or Twitter focus on qualities related to web design, such as interface heuristics. Design schools never stand on their own but are entangled with values, politics, economics, fashion, and so on. Activities involving design criticism may, therefore, foster a dialogue in which Schön argues that reflections on examples of design build up a personal repertoire of subjective insights, understandings, and knowledge about particular design situations. In the case of my studies, this repertoire pertains to the digital realm. Thus, one key trait of expert designers is the accumulation of design experience and exposure to large numbers of design exemplars. If we accept Klafki's proposition that students should work with epochal key problems throughout their education, it becomes essential for them to develop a historically disseminated understanding of central issues in the present and the foreseeable future. This also requires students to gain the insight that everyone shares the responsibility and a willingness to contribute to the solving of these problems. Epochal key problems resonate well with the designer creating preferred futures. If students are to design potential solutions to these problems, they need to be thinking critically about the issue, which again, requires the students to expand their repertoire with domain knowledge of these epochal key problems. Fig. 10 shows how this relationship can be illustrated. Digital designers work within the digital domain which requires the digital design student to accumulate a rich repertoire, which I argue can benefit from drawing on epochal key problems that relate specifically to challenges that occur when designing digital artifacts. I claim that epochal key problems can be considered that-which-ought-to-be and that-which-is-desired as they concern a large portion of humans today on a global scale. I propose that epochal key problem makes for good design briefs when planning design activities for K–12 students.

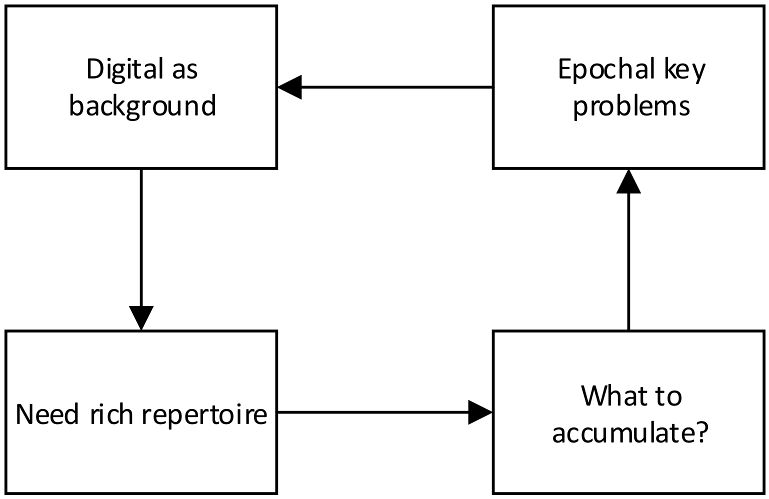

Figure 10—Relationship between student repertoire development based on epochal key problems that pertain to the digital domain.

While there is a lack of knowledge of how to build a repertoire, Löwgren and Stolterman suggest approaching the issue by providing students with examples of digital artifacts and engage them in collaborative critique sessions (Löwgren and Stolterman 2004, 47, 59). Designers should also do critique as reflection, evaluation, reuse of knowledge, accountability, and so forth. In continuation, J. Bardzell claims that the critical interpretive interrogations of the relationships between "*(a) the interface, including its material and perceptual qualities as well as its broader situatedness in visual languages and culture and (b) the user experience, including the meanings, behaviors, perceptions, affects, insights, and social sensibilities that arise in the context of interaction and its outcomes*" (J. Bardzell 2011) can be considered a "knowledge practice." Criticism as a knowledge practice enables designers to engage in a back-and-forth moving process with material particulars of artifacts and interpretative wholes (ibid.). Criticism can help designers cultivate a richer repertoire, sensitivity, and critical reactions to the wholes of designs. Such engagement can inform design processes, critiquing and innovating on design values, ethics, processes, methods, and so on and expose the long-term and holistic consequences of designs. While the designer's repertoire is not a specific competence, it is still an essential trait of competent designs to have a rich repertoire. With a rich repertoire, the designer can better tolerate uncertainty and work with incomplete information (N. Cross 1990). Thus I argue that building a repertoire among K–12 students is an essential part of becoming digital design literate and that design critique and retrospective reflections can help students in building their repertoire.

Based on the idea of repertoire, it follows that design competence is not about finding the correct ways of doing things, a definitive method, a subsuming rule, or the perfect tool for the job. Rather, design is always about acting in unique situations, making it impossible to formulate generally applicable rules that will always resolve the problem at hand. Design competence is in itself the result of a design process and has to be treated as such—as it resides in the process, the artifacts, and in people (N. Cross 1999). Both Krippendorff's (2006) and Nelson & Stolterman's (2003) conception of design fundamentals deal with the concept of what is desired to be put into existence by those who are served by design and suggest that design intention should build on such a conception. Based on the work of Schön, the design practitioner has to reflect on her actions by separating herself from the actions and by judging the outcomes of the actions through reflection-in-action and reflection-on-action (Schön 1984).

Based on the above, I claim that a rich repertoire is an important aspect of what it means to be a competent designer. However, this is a lifelong process of building up exemplars and so forth. This is problematic for the situation that K–12 students and teachers find themselves in, because of the constraints mentioned above set by the current educational system in Denmark. I suggest that students should develop their repertoire of knowledge, perspectives, exemplars, experience, and so on in different subjects, not just design in making. Ideally, students will apply their critical thinking to reflect on their everyday use of digital technology. Thus, building up a rich repertoire will and should happen as much in everyday life as in school. When setting up and facilitating such activities, it is important to keep in mind that building a rich repertoire is not the same as banking knowledge. Repertoire building activities related to the digital domain should be grounded in students' personal life and experiences rather than traditional school lecturing. Students and teachers should be partners in exploring new domains and engage discussions about their findings, concerns, understandings and so forth of the topic in question.

(3) design materials and design process navigation

According to N. Cross, it is essential for designers to be able to communicate design proposals through drawings, list of parts, mock-ups, and other modeling material as a means of problem-solving—externalizations of ideas. Design praxis is comprised of four overlapping qualities (Wolf et al. 2006). Designers work through non-linear but iterative process of intent and discovery, where the particular activities and judgments lead to sudden designs that are not deterministic. Creating artifacts is integral when going through a design process to make interpretations, judgments, and discoveries. The making of artifacts positions the designer as an agent of investigation and discovery whose production creates a suggestive state and perpetuating alternatives, suggesting different ways of looking at something and attempting to clarify a situation. Designers must also be able to communicate and articulate their design ideas through design language, verbal and non-verbal, from which others might draw insight or build upon. It enables people to engage in discourse about the usefulness or applicability of a concept or set of design decisions. Design artifacts can aid process navigation and design judgments—artifacts must be valued as the diversity of prototype-like artifacts that scaffold the design process, rather than just the end product. Designerly use of materials for externalizing ideas is as a process of trying out design moves and discovering their consequences and not only as a means for presentation (Schön 1987). Reflecting on my findings in P2, it would seem that the teacher's inability to navigate a design process properly might also have to do with their lack of competence in managing diverse materials to scaffold the design process. A central concern of design is the conception and realization of new things through appreciation of the material culture and the application of the arts of planning, inventing, making, and doing (Nelson and Stolterman 2012, chap. 10). At its core is the language of the designer "modeling;" it is possible to develop students' aptitudes in this language through maker activities.

Archer attempted to define a holistic concept of formal design education; "*[by] design education I mean making all children aware of the ideas and values and problems of the material world around them and helping them to achieve some competence in doing and making, judging and choosing, inventing and implementing. [This process is] a fundamental capacity of mind equal in importance to the language capacity, that is exploited by designers but is part of everyday life.*" (1979). What can be deduced from this quote is that making and implementing artifacts as part of a design process are fundamental to design praxis. From the perspective of digital design literacy, materials are central to the process of making and externalization of ideas and visions into artifacts. However, there is an important difference between the notion of making understood from the perspective of the maker movement and making understood from the perspective of design. Whereas the maker movement focuses on the design of personally meaningful objects, design is about bringing something artificial into the world with a specific purpose, for a specific situation, for a specific client and user, with specific functions and characteristics and done within a limited time and with limited resources. Artifacts become material for reflection on- and communication of ideas and aid process navigation. The toolsets and skills are similar, but the context and purpose of making are aimed toward different goals. In continuation, Nelson and Stolterman (2012, chap. 10) argue that design concepts must be made as concretized or materialized things that have an appearance and can be experienced in the world. This requires that a varity of hands-on activities are brought to bear on making a design concept real to communicate it to others. The final production of a design should not be separated from its conceptual design. When this happens, the design does not mature in consonance with the formative ideas underlying it. Nelson and Stolterman focus on two aspects: design materials and the crafting/making process. Materials are what a designer brings together using structural connections or compositional relationships. Materials are what designers use to bring a design concept into its existence, to make it appear and be experienced in the real world. Competent designers devote time and attention to developing a deep understanding of materials and crafting skills, but this cannot be undertaken in isolation from other aspects of designing (thus expanding the designer's repertoire). The materials chosen redefine the design's potential as well as its limitation and influence what design ultimately can be made. Schön (1983) found that designers use materials in the design process as a partner; material "speaks back"—*situational backtalk*. When materials speak back, they do so by showing the designer its limitations and restrictions, as well as possibilities, revealing qualities of the design that would be impossible to imagine without having them materialized. To produce a new artifact—abstract or concrete, social or physical—necessarily means that the material to be used for the design must be appropriately chosen. One way for the designer to choose materials is to have a language that can articulate their properties and qualities, both in terms of materials that go into the artifacts and the best tools for the job.

When a design concept has been materialized, there is no longer a distinction between that-which-is and that-which-does-not-yet-exist, which makes for valid judgment of the overall design. Nelson and Stolterman use the notion of *connoisseurship* to describe how designers craft with materials. Familiar examples of connoisseurship include film, music, and literary critics or a qualified beer brewer's judgment of the qualities and nuances of beer. In each of these cases, the connoisseur cultivates a domain-specific capacity for judgment through an on-going devotion of time and attention with relevant design and art examples, theories, expert perspectives, and critique. This sort of "material critique" contributes to one's design repertoire. The designer's repertoire and ability to understand and judge material qualities is essential and requires direct and intimate contact with the material involved. It requires experience, a sense of limits and possibilities, a language of materials, and a feeling for material realities (e.g., textures, colors, modes of interaction). It is also a strong argument for the potentials of teaching digital design literacy in K–12 maker settings, as students, ideally, would come in contact with a wide range of materials, for example, maker technologies, cardboard, digital drawing or electronics. This is not something that can be taught in a three-day crash course, which makes it somewhat problematic in terms of current pedagogical practices where teachers are first teachers rather than design partners. Accordingly, teachers did not develop unique design materials for framing and feedback of the students' process or have knowledge or experience in moving between diverse phases, using analog, and digital materials, during ideation and fabrication.

In the next section, I will return to my claim that a critical understanding of epochal key problems related to the digital domain is essential to develop among students in terms of building a repertoire directed toward the digital, understanding the materiality of digital artifacts and helping them to become critically empowered.

2.2.3 Critical Digital Literacy

"There is clearly a need for continuing to challenge and test what we mean by critical digital literacy in the complex, contemporary digital landscape." (Pangrazio 2016, 165)

Critical literacy is required at all levels of education, from K–12 to university (Dewey 1916; Freire 1973; Lankshear and Knobel 2008, chap. 1; Colin and Michele 2011, 22–26). At the start of my PhD project, the idea of a critical digital literacy had started to gain a footing in design education literature related to the digital domain (Hinrichsen and Coombs 2014; Frechette 2014; Pangrazio 2016). These scholars discuss what critical digital literacy entails, how it might be defined, and how the malleability of the concept inadvertently is ideologically defined by various groups with interest in the future of education. While technology can solve problems, it also has the potential to increase the existing divisions of cultural capital, power, and wealth, thus creating more problems than it solves. The purpose of this section is to discuss critical digital literacy to expand upon the work presented in P5 to provide a wider and accessible range of conceptual handles that researchers and teachers can leverage in their work when discussing digital design literacy. I discuss how a critical perspective on digital technology can help prepare students for shaping and living in a digitized world and how having a critical consciousness can foster empowerment and democratic citizenship. I argue that a critical perspective on the design of digital artifacts and their place in society presents an opportunity to educate students in being critically reflective when designing and interacting with digital technologies and enrich students' design repertoire. The following discussions on critical digital literacy ultimately lead to my discussion on how and why a critical dimension is important for digital design literacy.

Critical theory has offered criticism from capitalist, colonialist, poststructuralist, feminist, psychoanalytical, and privacy perspectives. What is true for all of these is the relationship between the oppressed and the oppressors. A prime example of critical theory is The Frankfurt School, embodied in the works of scholars such as Horkheimer, Noeri, and Adorno (Horkheimer, Adorno, and Noeri 2002), who argued that products of mass media and consumer culture were politically regressive, often relying on notions of ideology and alienation as understood from a Marxist tradition. One common trait among these traditions is skepticism of the sociotechnical and that reality is not what it seems but rather that something is hidden from the oppressed, for example, capitalist domination or unpaid labor on social media sites (Fuchs 2014). Critique can help expose these hidden forces that determine much of our lives. This means that the critical digital-literate can take a skeptical position and make valid criticisms. Such views are reflected in Freire's critical pedagogy (1970). Freire asserts that students can go from the "consciousness of the real" (a naive consciousness) to the "consciousness of the possible" (or critical consciousness; *conscientização*). A naive consciousness of that-which-already-exists sees causality as static facts of the real and is thus deceived in its perception. A critical consciousness understands that things and facts as they exist empirically, in their causal and circumstantial correlations, will and can be changed. To apprehend a problem also means to apprehend its causal links. The more accurately people can grasp true causality, the more critical their understanding of the world will become. To do this, one must perceive oneself as an active agent of change and perceive the world as a mutable entity. Intentional change is fundamental because it is the process of changing reality. Freire argues that we all acquire social myths which have a dominant tendency, and thus learning is a critical process which depends upon uncovering real problems and actual needs. A naive consciousness of that-which-already-exists sees causality as static facts of the real and is thus deceived in its perception. Critical consciousness is a process of developing a critical awareness of one's social reality through reflection and action. This is similar to how designers approach the world; one must perceive oneself as an active agent of change and perceive the world as a mutable entity through acting. Critical consciousness is also an essential part of Bildung, where learning should be directed toward goals of emancipation, empowerment, and critical citizenship (Klafki 2011). When I refer to empowerment, I am referring to the critical and democratic view of empowerment (Hardy and Leiba-O'Sullivan 1998; Kinnula et al. 2017) as being the main objective of critical digital literacy. In line with Freire's concept of critical consciousness, I suggest that unlike traditional models of critique, development of critical digital literacy should start from a personal position, so that an individual's beliefs and emotions can guide the analysis. This calls for new pedagogical practices to be developed.

Besides having an empowering potential, a developed critical digital literacy can also be beneficial for design education, as it creates competencies for the analysis of other designs through retrospective reflection. In literary terms, the argument is that it is just as important to learn to write texts as it is to read them critically. One example could be to reflect critically upon the manufacturing process involved in designing cellphones. The demands for new and faster digital products create a work environment that has led to several suicides in Chinese factories that supply Apple's products[26] or on the material-mineral construction of these devices—for example, tantalum extraction, coltan, and the wars in Congo,[27] digital rubbish and broader environmental destruction. Such praxis allows students to assess the benefactors and the subjugated within the digital age from the perspective of the designers who made the product and its use in the world. Activities involving design criticism may, therefore, foster a dialogue, where Schön,

[26] https://www.telegraph.co.uk/news/worldnews/asia/china/9006988/Mass-suicide-protest-at-Apple-manufacturer-Foxconn-factory.html, https://en.wikipedia.org/wiki/Foxconn_suicides (accessed 9/4/2018).
[27] https://www.theatlantic.com/international/archive/2011/07/is-your-cell-phone-fueling-civil-war-in-congo/241663/ (accessed 10/9/2018).

among others, argues that reflections on existent examples of design build up a personal repertoire of critical subjective insights, understandings, and knowledge pertaining to particular situations.

There is no shortage of valid arguments for how making in education can benefit student development through its project-based, hands-on DIY approach. However, the pedagogy that is dominating the making in education is functionalist, rather than pursuing tactics from the arts' and humanities' tradition of critical and aesthetic theory (Ratto 2011; G. D. Hertz 2014; Iivari et al. 2017; Papavlasopoulou, Giannakos, and Jaccheri 2017). Maker settings are inhabited by functionalistic technologies accompanied by advertisements that claim they catalyze creative processes (ibid.). However, leaving the critical and aesthetic dimension behind hinders students in developing a critical consciousness toward the sociotechnical and expand their critical understandings of digital designs, which is why competence in critical thinking is an important part of digital design literacy (Löwgren and Stolterman 2004, 60; Wolf et al. 2006; Poggenpohl 2008; Pacione 2010; Nelson and Stolterman 2012, 139–58). Critique is in itself a creative praxis that creates and acknowledges the various modalities in which critique can work across different digital design perspectives.

While design is often understood as a process of making or shaping futures, design critique is oriented backward and toward superior power (Kress 2009, 6), as a practice of unpacking and critical examination. As suggested by Pangrazio (2016), development of critical digital literacy requires practices that should aim to explore and expand on the human, interpretative process associated with digital technology, revealing the general design of digital technologies such as the Internet, that manifests and maintains systems of power and privilege (Fuchs 2014). Making and design practice also provide a scaffolding structure for individuals to engage with the complexity of discourse, ideology, and power related to the digital domain. According to Pangrazio, critical digital literacy is largely positioned as an either/or dichotomy in terms of thinking versus design action. Pangrazio suggests "critical digital design" where digital design praxis functions as a mode of critique that aims to develop a more comprehensive and nuanced understanding of sociotechnical issues. Design activities can scaffold critical engagement and help to reconcile the either/or dichotomy. This line of argument resembles the emerging field of critical making (G. D. Hertz 2014), a praxis that combines critical thought and making to create an artifact that explores and embodies critical reflections.

From a design perspective, Papanek argues than an uncritical position to design can lead to problems such as self-destructive behavior or addiction.[28] Papanek links "the evil design disciplines" to the aggressive and manipulative character of advertisement, reiterating Nelson and Statesman's point that design should not try to create new needs. However, designers have generally been successful in shaping markets for products that people did not desire, but which they have been coerced into adapting. Papanek warns against superficial solutions and of "evil design cultures," for example, the so-called Kleenex culture: "*When people are persuaded, advertised, propagandized, and victimized into throwing away their cars long before they wear out, their clothes with the latest demands of fashion, their high-fidelity sets whenever a new electronic gimmick comes along, and so forth, then we may begin to consider everything obsolete (…). That which we throw away, we fail to value. When we design and plan things to be discarded, we exercise insufficient care in design, in considering safety factors, or thinking about worker/user alienation from ephemeral trivia"* (Papanek 2005, 87). The Kleenex culture is still present today and can in many regards be considered the default mode of operation for many digital design companies today (Pope 2017). Designers should take a morally responsible and holistic approach to design, as they are in a position to change the world through design praxis. Thus, responsible designers adapt technology to the individual's needs and desires when resolving "real problems" (Papanek's descriptions of real problems are close to Klafki's epochal key problems) instead of creating needs. If we accept Papanek's arguments, designers should take a critical perspective toward their practice and that of other designers.

From a critical perspective, students should gain an understanding of how digital designs affect all domains in Western societies while showing the moral responsibility for what they wish to bring into the world (Hinrichsen and Coombs 2014; Pangrazio 2016; Song 2016). Hence, the digital design literate should be competent in analyzing existing designs and contextualize them within broader perspectives. It is not a feasible position to view technological developments as independent from society or as a driving force in societal development. The situation is one of mutual influence; we shape technology and technology shapes us. Thus, it follows that digital designers cannot passively accept current conditions but must critique the reciprocal relationship between technology and humans. Critique moves between distance and involvement. Distance means detaching oneself to critique from the outside while trying to avoid critical stagnation. To avoid this stagnation, one must become involved in changing the situation—

[28] I consider Facebook's psychological experiments on users without their knowledge as a good example of how design of digital services can lead to self-destructive behavior. The test, which was intentionally designed by Facebook—not a mistake, experimented with exposing one's friends' positive emotional content, resulting in fewer positive posts of their own. Another test reduced exposure to negative emotional content and the opposite happened (Kramer, Guillory, and Hancock 2014).

involvement that can benefit from design. Thus, I claim that the most promising modes of critique are those that lead to social change while taking social and moral reasonability for one's actions. As pointed out by Löwgren and Stolterman (2004), "*The role of the critic is an important one (…) her task is to analyze existing designs and contextualize them in broader perspectives of history, society and culture (…); a language of use qualities says nothing about how to design an artifact or how to address its totality, but it may support the designer in her ongoing work of developing a repertoire, an articulation language, and a sense of quality, it may help the designer be prepared for new design situations, but it can never be a prescription for action in any specific situation*" (ibid. 96, 140). An essential trait of the design critic is retrospective reflection, which I discussed in section 2.2.2. In addition to reflecting on one's own actions and thoughts, a designer can benefit from reflecting upon other designers' actions and thoughts. However, this is not easy to achieve in practice, since the matter for reflection is contained in the designer's mind. It is very difficult to "peek" into another designer's mind to see the assumptions, intentionality, and sense of quality that guide her process. What we can access is the tangible outcomes from designers' actions and thoughts. As I report in R1, Danish K–12 students encounter many digital artifacts every day; each of these can be examined and analyzed concerning the original designer's own ideals and ideas. Questions such as "What ideals and what values might have guided the designer to create a product with these qualities?" or "What emotions did the designer intend its users to experience?" are examples of retrospective reflection. Retrospective reflection can never reveal the ideas and ideals behind a specific product with certainty, but it will force the designer to come up with arguments and ideas that could explain a specific design. Retrospective reflection does not lead to a recipe for how to approach design tasks, but it can help students in developing their design repertoire with a critical dimension.

My experiments presented in P5 took the assumption that one of today's oppressors are companies whose business is based on tracking and surveilling users' online activities and that the oppressed are those who use their services. I assume that the existing status quo serves those in power, that is "big tech," and that there are oppressed groups and conditions in the world. In the experiment, I encouraged students to scrutinize critically the status quo and critically reflect on the oppressing conditions of the status quo of online data tracking. I must admit that students did not engage in making or design activities, nor did the students get to set up technical countermeasures. However, the students did develop a new awareness and understanding of how online data tracking works and its uniqueness on the Internet—awareness and understanding that the majority of students did not have before engaging with critical thinking on online data tracking. To scaffold critical digital literacy teaching, Pangrazio proposes the use of visualization tools *"to develop a more practical and in-depth understanding of digital networks, while at the same time* *questioning the conceptual tools that shape our engagement."* (Pangrazio 2016, 171). However, there are only a few studies on K–12 in-class activities that adopt visualization techniques (Pangrazio 2016) with which the digital context might be conceived and approached. There is a lack of exemplars addressing how students and educators can approach and experience critical empowerment. In P5, I explore critical thinking combined with digital tools that enable student to reflectively explore critical issues of socio-technical development by utilizing the potentials of adversarial design (DiSalvo 2012). I return to how my work in P5 has filled this knowledge gap in chapter 5.

To summarize, critical digital literacy is an essential trait of digital design literacy. Firstly, from a Bildung and critical pedagogical perspective, critical digital literacy can help students to become critically empowered and be democratic citizens. Secondly, a critical digital literate can scaffold critical empowerment, going beyond what the fields of IDC and making in education have been primarily focused on in their research. Thirdly, critical and retrospective reflections can prompt students to develop a holistic understanding of the interplay between the design of digital technologies and society, politics, economy, culture, and so forth that can expand their design repertoire and give them new insights into their interactions with digital technologies. I argue that students' ability to critique digital artifacts will be crucial to any long-term plan to empower students critically, not only as digital designers but also as users of digital technology. Learning instrumental computer skills and learning to think critically are not at odds with one another but should be taught in parallel. Digital technology use in the classroom should support students and teachers in gaining knowledge and awareness of how digital technologies such as the web are designed. I consider digital literacy to encompass critical digital literacy. This means that whenever I refer to digital literacy, I am also talking about critical digital literacy.

2.2.4 A Genealogy of Literacy

In this section, I establish a genealogy to encompass the context of the debate that my research participates in by outlining a genealogy that aligns and traces the discourses to which my research is related (Brandt and Binder 2007). Genealogy refers to how the presented research connects and positions itself to threads of discussions and practices of peers within the particular field of study and everyday discourse in topical society: "*To extend the questions of on what and for whom knowledge production is directed to also encompass which context of debate and dialogue the research is participating in*" (ibid., 13). Throughout this chapter, I have presented the fields of related work within design through making in education and its relationship with new literacy studies. Fig. 11 depicts my adoption of what Brandt and Binder present as the genealogy of design research. By doing this, I suggest that I have not only partaken in and contributed to the academic field of making in education but also contributed knowledge and practices to support K–12 schools in integrating digital design literacy. Fig. 11 illustrates the genealogy as sequential steps, as features from one literacy tradition feed into the next.

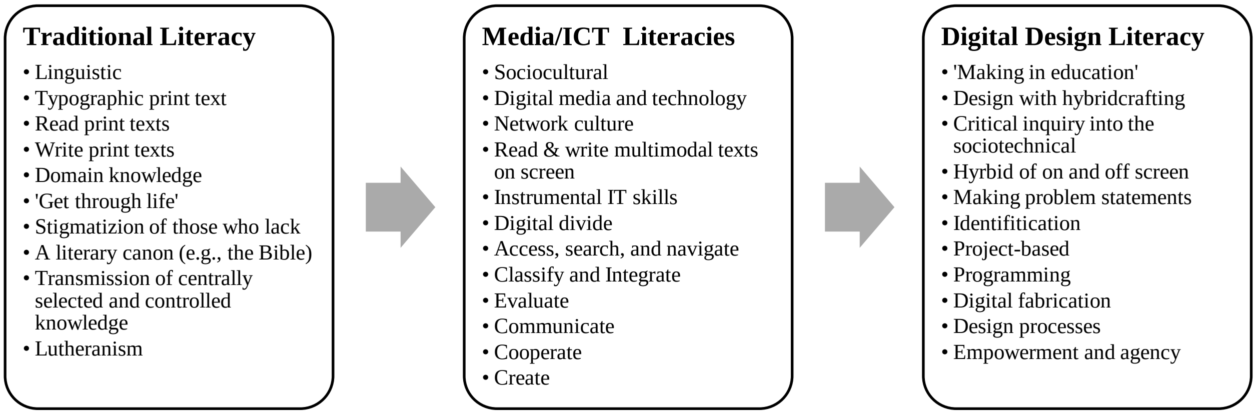

Figure 11—A genealogy framework to position my approach within a larger literacy landscape and its emerging ideas of design- and critical digital literacy.

As in making in education, new literacies studies also emphasize the educational potentials of hands-on design and making activities to scaffold students' educational development. My genealogy relates to literature on literacy that frames making in education within a larger educational discourse. The genealogy goes from an emphasis on traditional literacy such as reading and writing texts from a linguistic perspective to an emphasis on competencies such as accessing, communication, and evaluating digital texts. As I have argued throughout this chapter, we now see a turn toward designerly ways of engaging productively and critically with digital technologies, scaffolded through maker settings and activities. Fig. 11 illustrates the alignment between the different literacy traditions that my research inscribes itself in. The following bullet points summarize some of these alignments, specifically selected in relation to the area of my PhD project:

- Collective and cooperative work.
- Learn to change society for the better.
- Being able to engage in (retrospective) reflective and critical thinking.
- Act with intention and have a voice in the world.
- The idea that unpacking and critically examining digital technologies helps develop a critical consciousness toward their design and impact on the world.
- Competent to express own ideas, values, and beliefs and in this way mobilize personal or affective responses to epochal key problems.
- More than using digital resources effectively; a special mindset or stance towards designing (and the design of) digital technology.

- Challenges the instrumental use of digital technologies as transparent or neutral teaching aids, grasping the means through which communication is created, deployed, used, and shared.
- Includes humanistic virtues from the Bildung and critical pedagogy traditions, developing critical consciousness and empowerment.

2.3 SUMMARY

I have argued how my research is positioned in relation to existing literature concerning the emerging field of making in education. This dissertation and its included papers can be seen as a response to the momentum and development of maker settings in K–12 education that are intertwined in my research:

From traditional literacy toward new digital literacies, in that my interest in exploring the development of the concept of literacy in the 21st century where students are expected to develop personal agency to manage and master digital technologies in a society that is rapidly being digitalized, and more importantly, to be not only competent technology users but also have the skills to shape sociotechnical development as well as to feel empowered to do so.

From classrooms to maker settings, in that my focus is directed at understanding and teaching digital design literacy facilitated and instigated by the introduction of maker technologies, rather than on the settings; furthermore, my work relates specifically to students' design processes and their use of digital maker technologies, and for this reason, I am interested in exploring and articulating what constitutes digital design literacy when taught in K–12 maker settings.

From desktop computing to maker technologies, in that the educational settings I explore employ novel means producing and designing with technologies and materials that go beyond relying on traditional screen-based interfaces; I employ the term maker technologies to denominate these new technologies that encourage people to produce and design digital artifacts rather than nearly consuming them.

From a focus on functional aspects of computing toward designerly-oriented ones, in that I am concerned with the potentials and effects of maker technologies in addition to the instrumental functions they afford; this includes design quality articulations of feedback and form properties when employed in a design process.

From a focus on STEM education to interest in digital design literacy education, in that design is not just for designers but for anyone who wants to imagine something that does not yet exist and then work through the process from imagination to material existence.

From a digital literacy understood as primarily functionalist to interest in critical digital literacy, going beyond mainstream view and functional view of empowerment of students toward critical and democratic empowerment.

In the following chapter, I will present my research design, its method, and how my experiments are related.

3 RESEARCH DESIGN AND APPROACH

In this chapter, I outline my research approach and introduce the experimental work that form the basis of my research contributions made in this dissertation. I argue that my PhD project may be understood within the notion of *design-oriented research* (Fallman 2007) realized as *experiments* and *intervention* contained in *program* by the method of *constructive design research* (Binder and Redström 2006; Brandt and Binder 2007; Koskinen et al. 2011). This approach grounds my experimental and interventionist approach and offers a coherent way for discussing how my research, arguments, and contributions are connected to my design activities and to the societal and academic discourses that I have outlined in the preceding chapters. I start this chapter by discussing academic design research and practice and proceed to position my approach within the methodology. I then describe my research environment and my research experiments and how they are related.

3.1 ACADEMIC DESIGN PRACTICE AND RESEARCH

In a 2004 article, Bayazit characterizes research design as "*the study, research, and investigation of the artificial made by human beings, and the way these activities have been directed either in academic studies or manufacturing organizations.*" (Bayazit 2004). While Bayazit's definition is broad in scope, it provides a good starting point for discussion of the term. Löwgren has a similar abstract definition: "*The essence of research is to produce knowledge, and the essence of design is to produce artifacts.*" (Löwgren 2013). In 1981, Archer proposed the following definition of design research: "*Design research is systematic inquiry whose goal is knowledge of, or in, the embodiment of configuration, composition, structure, purpose, value, and meaning in man-made things and systems.*" (Archer 1981). According to Zimmerman, Forlizzi, and Evenson (2007), the definition of "design research" is inconsistent and confusing within design research communities, and they argue that design research "*implies an inquiry focused on producing a contribution of knowledge*." However, this can be said to be true of all sciences, natural or humanistic—the systematic generation of new knowledge that contributes to a larger pool of knowledge within a given subject, field, or problem, undertaken to better our understandings of the world. However, in the natural sciences, the underlying epistemology is usually one of positivism, using inductive and deductive methods to generate universal principles and laws that can be reproduced independently of the context in which the object or phenomena of the study were investigated. The three definitions of design research imply mainly questions and concerns regarding research methodology in which design researchers are themselves employing design as a mode of academic inquiry. “Design” itself is a debated term. It is both a noun and a verb (Flusser and Cullars 1995), and it is my contention that laypersons’ interpretation of the word design is primarily concerned with “designer brands” or “designer products” which are often expensive luxury products, ranking alongside fashion (making it difficult to explain to laypersons what design thinking is).[29] We can also claim that design research is generally concerned with bringing non-existing things into the world by means of design praxis. These activities task the designer with understanding the relationships between present and non-existing/future technological possibilities and new ways of being in the lifeworld (Ihde 1990).

In his article, “The Nature of Design Practice and Implication for Design Research,” Stolterman (2008) compares the notion of complexity in science and design research. Stolterman claims that natural science does not provide appropriate methods to deal with the complexity and wickedness of design research because design research must be grounded from an understanding of the wicked nature of design practice and its object of study which does-not-yet-exist (ibid.). In scientific fields of study, the focus is on the universal and existing whereas design “*deals with the specific, intentional and non-existing* (…) *the goal is all about creating something non-universal. It is about creating something in the world with a specific purpose, for a specific situation, for a specific client and user, with specific functions and characteristics, and done within a limited time and with limited resources*.” (ibid. 59). Thus, design practice and research rely on the creation of a desired change of reality manifested as an ultimate particular (Nelson and Stolterman 2012). This has also been the case for my design and research practice, which relied on the creation of a desired change of reality by introducing digital design in K–12 manifested as an ultimate particular (Nelson and Stolterman 2012). In continuation, Hallnäs and Redström (2006) argue that design research is neither concerned with being true or false but rather being suggestive and aims toward resolution rather than solution. Based on this, the research contributions presented in this dissertation are not neatly formulated and finalized answers to the question of how to conceptualize digital design as a new literacy—it is suggestive. The research contributions made in this dissertation and the included papers resides in a spectrum between general/abstract knowledge and particular/concrete instances of

[29] Based on my classroom observations. See (Smith, Iversen, and Hjorth 2015, 27) for an example of this; Researcher: ‘‘What did you think design was?” Agnes: ‘‘Clothes, or something’’ Sarah: ‘‘Yes, clothes! That’s what you think of when you hear the word design’’.

human designs, being accountable to both practical exemplars and theoretical development and grounding.

Design entails creating the particular in the form of an artifact for a specific client or group of people, with particular needs in particular situations. A design artifact need not be a physical product but can also be understood more broadly, including systems, programs, frameworks, and services (Löwgren and Stolterman 2004, 7–8). It refers to the artificial, something made by humans, and how it emerges as part of a larger whole that never exists in isolation but rather interacts with ordering and organizing of elements into systemic relationships and connections with, for example, human culture, society, and economy, that have intentionally been brought into the world (Nelson and Stolterman 2012, 93). This means that design is not purely chaotic, subjective, and irrational when related to a larger whole of compositions and assemblies. As argued by Stolterman (2008), design has its own structure, procedures, and components that, when used by a competent designer, are organized as an emergent whole.

At the beginning of my PhD studies, maker settings were only just starting to enter Danish K–12 schools. Maker settings, the environment that I wanted to inquire into, did not exist at the outset of my PhD project. Hence, there were no existing contexts to study my research question. Therefore, I had to design the-not-yet-existing context for teaching and studying digital design literacy through making in K–12 education. As unfolded in chapter 2, research into making in education has primarily emphasized development of STEM competencies rather than development of digital design literacy. Since digital design literacy had yet to be introduced in Danish K–12, it was not possible to study digital design literacy as an existing practice in Danish K–12 schools. This required me to study the not-yet-existing, thus deviating from traditional scientific research (Löwgren and Stolterman 2004, 32; Nelson and Stolterman 2012, 28–40). Thus, to explore my research question in school maker settings, I had to engage in design practice to bring forth the not-yet-existing, an ultimate particular that focuses on the future world that I had an interest in investigating. My design of the-not-yet-existing did not result in prototypes of digital technologies; "*materials is not limited to physical things, it also applies to the abstract material used in the composition of a process. Materials are what a designer brings together using structural connections or compositional relationships.*" (Nelson and Stolterman 2012, 175). Instead, I have relied on design research practice to create the context for my research supported by composing and connecting new educational materials, resources, and services. This includes the design and facilitation of workshop-like classroom activities (e.g., P5 where I propose the use of adversarial design in teaching critical digital literacy), scaffolding teaching materials, new modes of teaching and teacher training programs (P2 demonstrates how a combination of design theory, in-school practice, and peer-to-peer learning created a framework to facilitate and support co-development of new teaching practices). While natural science is concerned with uncovering universal truths, design research wishes to answer questions of "how could the world be?" by inquiring into the real and changing this to some ideal situation. From this perspective, my PhD project has been about changing the existing situation through design into a more preferred situation, which I claim to be the introduction of digital design literacy in K–12. Design researchers and practitioners alike face wicked problems in their work (N. Cross 2007b). As a design researcher, I was confronted with the complexity of making inquiries in K–12 classrooms. This complexity embodies a specific type of problems—"wicked problems" (Rittel and Webber 1973).[30] It is a type of problem that differs from the "tame problems" in the natural sciences. Tame problems erroneously see problems as well-defined and have clear criteria for whether the problems have been solved correctly. Whereas natural sciences try to isolate problems to lower the potential for errors in controlled experiments to contain effects of dependent variables, design researchers and practitioners must realize that no wicked problem ever exists in an isolated vacuum, but that they also interact with other problems, as a kind of system of problems that are interrelated both logically and illogically. Wicked problems distinguish themselves as having neither a clearly defined problem set in stone nor set criteria for whether a problem has been solved (Rittel and Webber 1973), as they are inherently ultimate particulars. As such, the research question in this dissertation cannot be neatly formulated and that answers to the question are suggestive rather than providing a truth. I have to face wicked problems in my work, constantly finding myself in situations in which trade-offs and compromises were unavoidable, and in which the problems were not tame and solvable in the technical sense of the word. From this perspective, the challenges of introducing new subjects and literacies in K–12 can be considered wicked problems. The challenges become wicked as schools are forced to explore their relation to new technologies, pedagogies, open-ended projects, and subjects that do not have any established ways of assessing digital design literacy and how their teaching relates to society at large. Such challenges cannot be resolved using traditional scientific methods, as the challenge is to change a situation by bringing into the world something that did not-yet-exist while also studying this change. However, this does not exclude scientific methods from being used as part of the design process, as it can be useful in activties such as inquirying into a wicked problem or managing materials. In R1, R2, P1, and P4, I combine a designerly and scientific approach by moving from the particular to the general. I do this by applying theory on how expert designers approach wicked problems and use statistical methods for generalizing findings across a larger sample of students. Findings from R1 and R2 are not meant to find a solution to the wicked problem of introducing a yet-to-be subject in K–12

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[30] Closely related are that of social messes that also aim for resolutions rather than solutions of problems (Horn and Weber 2007) and Schön's claim, inspired by Dewey's philosophical tradition of pragmatism (Dewey 2005; Shapiro 2010), that designers work with messy situations (Schön 1984).

but rather to have a baseline to better understand aspects of the wicked problem at hand. If design researchers or practitioners do not confront and stay with the wickedness, they will heighten the risk of achieving poor results within the project, as every resolution is a one-shot operation. As soon as resolution is brought forth, the situation is changed, and because every design situation is an ultimate particular, it is never possible to go back and try a different approach to the exact same problem. The ultimate particular is non-universal (as opposed to universal principles brought forth by traditional scientific inquiry) but specific to the context, purpose, situation, stakeholders, and the available resources in question, which cannot be accomplished using a scientific approach (Nelson and Stolterman 2012; Stolterman 2008).

My research and design activities can be described as *research-oriented design* and *design-oriented research* (Fallman 2007). Fallman makes this distinction to highlight the different modes of inquiry and knowledge production between these two design activities. Designers and researchers work within a continuum of tensions, where research-oriented design is concerned with "the real" and design-oriented research is concerned with "the true." This continuum is also present with Nelson and Stolterman, who claim that "the true" and the "the real" are basic components of inquiring into design (2012, 27–40). In research-oriented design, the artifact or intentional change in the world is the primary outcome and result, whereas production of academic knowledge is less of a concern. Rather, it applies knowledge from design research to inform a design process. As such, I have also been engaged in doing research-oriented design given that my intervention experiments have, in part, been designed and planned without the author's knowledge ed based on design theory. Design-oriented research uses design praxis as a means for generating academic knowledge: "*Design-oriented research argues that this new knowledge, this new description of a state of affairs, is of a kind that cannot be attainable if design—the bringing forth of an artifact such as a research prototype—is not a vital part of the research process*" (ibid., 197). The contributions in this dissertation should be considered design-oriented research, as my inquiries required me to design a research space in which a designerly approach and perspective was employed, meaning that I engaged in the initiation of *change* in several Danish K–12 schools. Besides having engaged in design practice, I have applied design as a theory of inquiry for analyzing my empirical data of teachers and students practicing design in maker settings and to explain my findings. Examples of this can be found in P1 and P4, where I draw on the concept of stance towards inquiry as a way to interpret responses to survey items. In P2, I apply design theory on the importance of materials management to describe teachers' challenges in teaching digital design. In P3 I, use theory on coupling between action, function, and feedback to articulate on form properties and action-function couplings of maker technologies in K–12.

Schools are faced with the task of exploring and making concrete new aspects of their practice based on a vision of how they want their institution to change. From this wickedness, some problems emerged throughout my project. For instance, it was problematic to study the use of maker technologies among students in my first intervention experiment, since their competencies in using these, for example, the Arduino microcontroller, was lacking. This, in turn, affected the material outcomes of the students' design processes (see P3). Numerous issues occurred throughout the students' design processes, which my colleagues and I had no control over; some students would be tired and unmotivated, some students did their homework, others did not, and unmotivated students would sometimes disturb other students, and so forth. This also meant that my role as a researcher, facilitator, and educator changed and became blurred throughout each of my intervention experiments. In studying students' use of maker technologies, I also had to assist them in building what they had planned out from their design idea, while also documenting the process to capture qualitative data for my research. P2 showed that local teachers lacked competencies in using maker technologies and could not, therefore, handle these issues without support from me or my colleagues. The observations and semi-structured interviews that make up the empirical basis for my findings in P5 were difficult to collect because I had to oscillate between being the main teacher of the classroom activities with Lightbeam and the discussions surrounding it while also being a researcher. This complicated my work as a researcher because I would often be called upon to help resolve very basic technical issues, for example, installing a web browser and adding an extension (R1 also suggests a lack of digital literacy among the studied students). The wickedness of my research context drew me away from my initial intentions with the experiments which sometimes resulted in my being unable to study the questions that I initially set out to. However, I do not consider this to be a failure, since design research tolerates *drifting*, meaning that "*design research has a nature of 'drifting' that in other research disciplines would be regarded as watering down the research contribution. Traditionally, in science literature, drifting is regarded as bearing the touch of randomness, the uncontrolled, illogical and inconsistent. However, in design research (…), drifting or pursuing alternative opportunities in the vicinity of one's work is an embedded way of arriving at relevant and high-quality work.*" (Krogh, Markussen, and Bang 2015, 42). The work presented in this dissertation has drifted along the three trajectories presented in section 1.1: conceptual, measurement, and educator (fig. 12).

From the conceptual trajectory, I have drifted across three topics of interest: design, digital technology, and critical thinking (the parabolas along the conceptual trajectory in fig. 12). I do this because I seek to combine the design, digital, and critical domains of literacy to generate an understanding of what digital design literacy could be. Each literacy informs and broadens one another with competencies that can be beneficial across all three literacy domains. This conceptual trajectory, which has been my main interest, has been drifted back and forth between studying students' usage of maker technologies, their critical perspective on online data tracking, and their ability to take a designerly stance towards inquiry, each highlighting distinct and overlapping competencies of digital design literacy. Because teachers are essential actors in scaling and sustaining the teaching of digital design in K–12 (the educator trajectory), it is imperative to gain an understanding of how to work with teachers for them to utilize successfully design processes supported by the maker settings and technologies available to address wicked problems with their students and what challenges teachers encounter in doing so. Identification of areas where teachers are challenged has informed the Digital Design Literacy Framework by articulating as-yet uncovered digital design competencies. While my work can inform teachers and their in-school practices, it is not the primary focus of this dissertation. In the notion of design-oriented research I employ, there is an interdependency between understanding digital design competencies and teaching challenges; teaching digital design is inherently about what is ultimately particular, and in doing design research that is suggestive. Thus, I have engaged with what is particular so that my claims can be substantiated. The measurement trajectory has contributed to my conception of digital design literacy by drawing a rough picture of students' literacies across the threads from the conceptual trajectory.

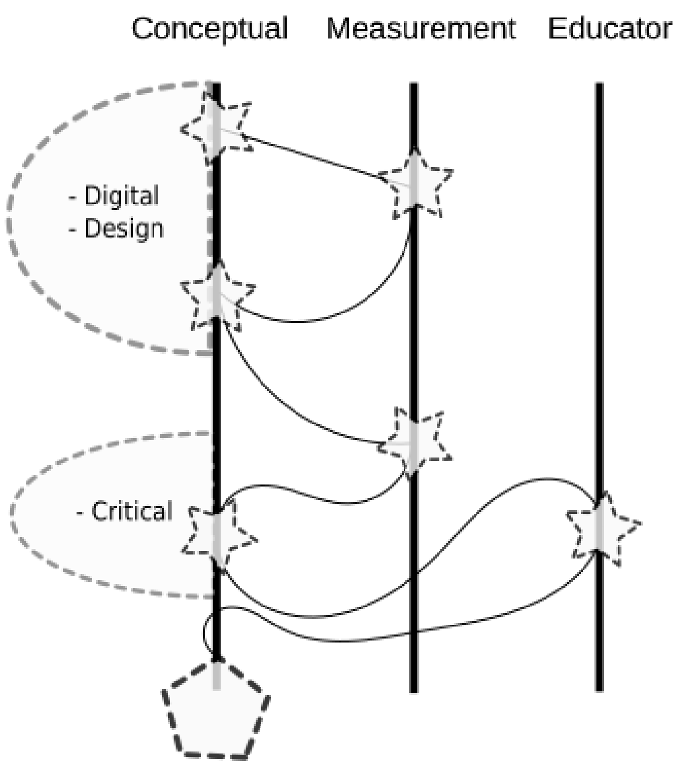

Figure 12—Drifting between the three trajectories.

Fig. 13 illustrates how the drifting between the three trajectories has partly been shaped by analyzing my empirical data (circle in the bottom half), and finally an analysis across the studies (larger loop). These studies have been influenced by several theoretical domains throughout my project, specifically those that I introduced in chapter 2. The red line going across the central thread of my research endeavors—conceptualizing digital design literacy—represents how the different theories have informed my individual studies and vice-versa. For example, in creating the two surveys reported in R1 and R2, I had a vague idea of how designers' approach wicked problems, only to later realize that the notion of stance towards inquiry as articulated by Schön suited my analysis of student responses from the two surveys to create a design literacy assessment tool (P1).

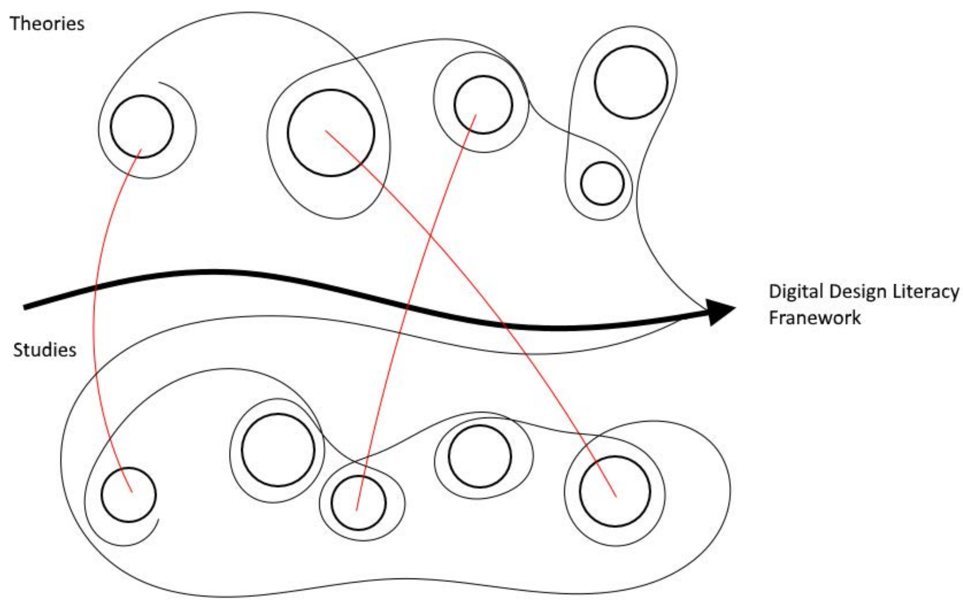

Figure 13—My research shed light on digital design through making in education from different but interrelated perspectives. While my project was ordered in temporal succession in terms of time, my research activities and how they were undertaken were less rigid and drifted.

Drifting has not been a problem in my research, but more of a complication, as my aim has been to expand the concept of digital design literacy through the experiments presented in my papers, including the planning, facilitation, and design of educational settings and scaffolding materials. Thus, my work has continuously explored new aspects and approaches for teaching and understanding digital design literacy as an acknowledged new literacy. In totality, the drifting across the three trajectories helped describe a novel conception of digital design as a literacy and add a theoretical distinction from digital design expertise. All my experiments are framed based on their predecessor. I will return to this method of serial or procedural experimental research by applying the mixed-methods to illustrate and warrant my choice of combining quantitative and qualitative work.

To clarify further how I have reached my research contributions, I adopted the typology of Krogh et al. (2015) to account for my research activities and how they, in combination, have contributed to my knowledge generation: "*Typology describes five distinct methods of knowledge production through design experimentation: Accumulative, Comparative, Serial, Expansive, and Probing*." Applying this typology allow me to articulate how my experiments have been carried out and how they have gradually generated knowledge. The five typologies can be combined and are not mutually exclusive. Of the five typologies, *serial* and *expansive* are the most appropriate for describing my work. It is expansive because I have explored digital design literacy from various perspectives and contexts, each adding to an expanded understanding of the concept. Since digital design literacy for K–12 has yet to be studied, I argue that the included papers all help extend what digital design could be as a literacy within making in education to address educational ideals for K–12. Thus, my intention with this dissertation is to uncover new aspects, approaches, articulations, and techniques for understanding and teaching digital design literacy. Hence, I expand the idea of what "digital design" as a literacy might mean for teaching through making in education. My work can also be considered as being serial as it has unfolded through an opportunistic and pragmatic approach, for example, the scheduling of classes, what subjects and topics students were currently studying, and the individual teachers' interests. A concrete example of this can be found in P5. Through a participatory design process with two local teachers, I produced a lesson that touched upon the epochal key problem of online data tracking and privacy. The objective was to engage students in making inquiries into the theme of "Hacking Global Communication." This theme was chosen by the local teachers to have students reflect on their relationship with digital technology when enmeshed with ethical, ecological, social issues, and so forth. My colleagues and I had already collaborated with the teachers. We had been visiting the participating school multiple times in, talking with teachers and students who knew us by name and vice versa. One of the teachers knew that I had an interest in studying critical thinking related to digital technologies in K–12. She, therefore, invited me to work with her on designing sevreral lessons. This allowed me to design a three-hour in-class lesson which would serve as my research context. Without this invitation or general talks with the teachers, I would not have had the opportunity to study critical aspects of digital literacy. In section 3.3.2, I will illustrate in detail how my work is serial by introducing *mixed-methods* as a generalized approach.

In the following section, I will detail the research environment that I engaged with and how I designed the context for my research.

3.2 Research Environment and Context

To generate credibility and highlight potential biases in my research, it is necessary to discuss the research environment and context (Koskinen et al. 2011). Such discussions open my work for scrutiny by making my research process transparent and account for how my research programs have been in dialog with society and the making in education community.

As I briefly mentioned in the introductory chapter, the research activities that have led to this dissertation derive from my involvement in the research and development project FabLab@school.dk, conducted between 2013 and 2018 by a small interdisciplinary research team in the Child Computer Interaction Group at Aarhus University, Denmark.[31] The project's objective was to study design education and the use of digital technology in K–12 maker settings.[32] The organization of the FabLab@school.dk project was unique in terms of its participatory research foundation and the partnership between municipalities and academia, which allowed for the creation and maintenance of new maker settings involving diverse stakeholders of students, politicians, designers, and international researchers. The FabLab@school.dk project was launched and initially formed in conjunction with a new political agenda of introducing a cross-curricular focus on innovation, entrepreneurship, and digital technology in the Danish public-school system in 2014.[33] The target group was K–12 students aged 11-15 years old. The students for my studies came from urban areas of Aarhus (pop. ~300,000) and Vejle (pop. ~55,000). Students were all from relatively similar, middle- to upper-middle-class families and socioeconomic backgrounds (in a Danish context). In the participating schools, teachers and principals were committed to exploring and integrating the possibilities of making in an educational context and had invested in the construction of maker settings. My research was carried out as part of the subject called "Design and Crafts," which at the time was the primary site for digital design education through making. However, this turned out to be problematic as teachers had little or no experience in facilitating learning and design processes involving maker technologies. As a consequence, teachers and municipalities in the project quickly started to raise concerns about having the right knowledge and practical training to implement maker technologies such as Arduino, LittleBits, Makey, 3D printers, laser cutters, and other electronic kits into existing subjects, and about the physical and material requirements for creating maker settings in the schools, and so forth. Although solving these issues was relevant to the development of the project, it was important to define our role as researches continuously, rather than consultants, who were co-investigating an emerging field together with the stakeholders to establish a sustainable educational initiative. I have, in a sense, designed the context and settings, allowing me to inquire into my research questions within the overall environment in which my project was situated. Furthermore, my design and research practice relied on the creation of a desired change of reality, manifested as an ultimate particular (Nelson and Stolterman 2012). Based on this, the research contributions presented in this dissertation are not neatly formulated and finalized true or false answers—they are suggestive rather than a set of requirements.

[31] Part of the Center for Participatory Information Technology at Aarhus University.
[32] Maker settings were referred to as FabLabs in the project.
[33] https://www.industriensfond.dk/fablabschool (accessed 10/10/2018).

While making in education was novel in a Danish context, for both research and educational practice (Smith, Iversen, and Hjorth 2015), the setup created a common direction and offered flexibility to develop my research interest as it evolved throughout the project. It is the nature of design and design research to cross the boundaries of disciplines. Hence, my research has not taken place in a vacuum as all the experimental activities that I have been involved in have influenced by perspectives and ideas from internal research colleagues and external stakeholders. This collaborative work has served two interrelated purposes for my PhD project: (1) to generate empirical data for analysis and (2) to address the real-life challenges that are experienced in schools when introducing digital design literacy.

My various design and research endeavors required me to balance different roles: a researcher, designer, facilitator, and teacher. I have operated the role of being a design practitioner and a design researcher not as an outside observer but as part of a proactive design-oriented research group (Fallman 2007). My colleagues and I were the main facilitators and teachers of the classes, while the local teachers were in the background. This created some problems as my colleagues and I are trained as digital design teachers at the university level and researchers without much experience in educating K–12 students. It was nonetheless the position I had to take in order to gain empirical data for later analysis. Had I not moved between these roles, teachers without experience with digital design would be left to their own devices, and hence, it would be difficult for me to carry out my studies (as seen in P3, teachers are challenged when teaching digital design). Although my studies were carried out in authentic classroom settings as part of students' everyday school schedule, the settings were somewhat artificial since the available resources would not normally be present in the participating schools. For example, I would normally not be present to assist students with using maker technologies in the classroom; it was a one-shot operation but with the intention of having teachers and the school sustain these settings and teachings. My involvement in these activities exposed me to a complex and wicked process of communicating and negotiating with stakeholders (municipalities, schools, teachers, stockholders etc.), working under strict planning and changing research contexts (my research had to align with the year plan made for the individual schools and classes), teaching K–12 students without much prior experience, and so forth, as well as exploring new terrain within making in education. My role was not that of an objective researcher doing controlled observations; rather, I was actively engaged in shaping the research by bringing my own values, background, interests, and competencies to the different research and facilitation activities in the classrooms. This all relates back to how my research has drifted not just between abstract theory and concrete studies but also in the roles I have had to take (fig. 14).

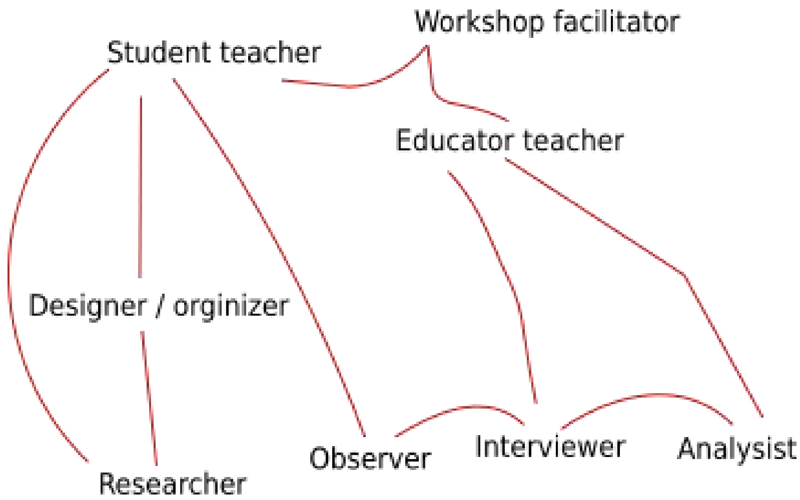

Figure 14—I have been in constant flux between different roles through my project.

Focusing on digital design as a literacy implies that it has to target formal educational settings to establish knowledge of *relevance* and *extensibility* (Zimmerman, Forlizzi, and Evenson 2007). I argue that I have contributed knowledge of relevance by framing my research within the current state of affairs in terms of challenges that emerge from the introduction of digital design through making in education and by articulating the preferred state that my project attempts to achieve and arguments for why this state is preferred, thus positioning my research in a contemporary societal discourse. Based on my literature review and genealogy of literacy, I claim that my work has relevance for the future of K–12 education. All work throughout my PhD project has been done in close collaboration with local school teachers, which allowed me to study authentic school settings and gave teachers new understandings of how digital design literacy education might be introduced in their schools. Studies with students in settings such as public maker settings or after-school clubs do provide opportunities to study digital design literacy, which can to some degree be transferred to formal K–12. However, the available resources, the number of students per teacher, the experience and competence of the teacher, and other factors differ between informal and formal education. Thus, to generate knowledge, which has relevance to formal K–12 education, I have done all my qualitative studies "in the wild"—the K–12 classrooms. Such contextualization has its challenges with regard to capturing and generating knowledge. Using Schön's metaphor of the swampy lowlands, I encountered the dilemma of academic rigor and relevance: *"imagine a cliff overlooking a swamp. Researchers may choose to s[t]ay on the high, hard ground where they can conduct research of a kind the academy considers rigorous, though on problems whose importance they have come increasingly to doubt. Or they may go down to the swamp where they can devote themselves to the social problems, they consider truly important, but in ways that are not rigorous in any way they know how to describe. They must choose whether to be rigorous on the high ground or relevant in the* *swamp (…) Nowhere are these dilemmas more apparent than in the field of education."* (Schön 1992, 120). Schön's swamp metaphor points toward the issue of my studies; I conducted my research in the swamp.

Contributions made in this dissertation are relevant for integrating digital design and making in education by being extensible, scalable, and sustainable. By its being extensible, I claim that research and educational communities can leverage the knowledge that I have generated. This is exemplified in P2 which led to a framework for teacher training, and P5 which contributes new methods for introducing critical digital literacy. Similarly, my contribution of the DeL tool in P1 provides the educational system with a tool to assess students' stances toward inquiry. Hence, a central ambition behind my work has been to provide knowledge, which is relevant to the "swampy" context in which I conducted my studies. The main characteristics of my research contributions are that they are suggestive, interventionist, and provide resolutions rather than solutions. My research can be considered to be suggestive in that it attempts to find proper methods, techniques, tools, or concepts for reflection that will further design practice and research, to varying degrees. It is interventionist as it engages with designerly activity in a reality outside the laboratory.

There is, however, more to design research than how the field conceptualizes research contexts with its complexity and problems. The methods used to generate knowledge and the type of knowledge created using methods to deal with wicked problems comprise one distinct feature of design research. To warrant knowledge contribution in design-related research communities, is it necessary to explicate how to generate rigorous design-oriented research knowledge.

In the following sections, I will detail my research approach and methodology. I review and discuss Brandt and Binder's (2007) *constructive design research* approach to demonstrate how design research can be framed and done. This includes an account of how the research becomes communicable and defensible among peers and thus finds relevance among researchers and practitioners. The basic proposal by Brandt and Binder is that constructive design research process can be understood as being exemplary and interventionist research anchored in *questions, programs,* and *experiments* combined with the notion of *genealogy*. I combine literature on constructive design research with mixed-methods (Creswell 2014) to schematically explicate my work in terms that are generalized beyond methods related to digital design. Mixed-methods provide schema to categorize and elaborate on my research and the relationship between my experiments and included papers. It also provides a theoretical foundation for combining quantitative and qualitative methods that I have employed. Because of the fluidity of the approach proposed by Brandt and Binder, and the limited descriptions of what Krogh et al. suggest as being a serial approach (2015), mixed-methods helps me to frame my research more rigidly and temporally.

3.3 Constructive Design Research

In this chapter, I introduce the methods that have led to my experimental work that forms the basis for answering my overarching research question. I argue that my work can be understood as *design-oriented research* realized through *constructive design research*[34] driven by my overarching research question and explored through *programs* and *experiments* (Binder and Redström 2006; Brandt and Binder 2007; Koskinen et al. 2011). This approach underscores the experimental and interventionist character of my work and provides a frame for discussing how my arguments are connected to the field of making in education. I also introduce mixed-methods and describe how I have applied mixed-methods as a generalized methodology that works across many different fields and draw on both quantitative and qualitative methods. Mixed-methods provide a language to communicate the temporal relationship between my experiments and the included papers. My work has been motivated by a question of how to conceptualize digital design literacy. This question is, fundamentally, broad and has been pursued through three programs, which I regularly discuss and relate to my research approach throughout this section. First, I will discuss issues on generating valid knowledge in design-oriented research.

Methodologies used to generate knowledge in design research have received criticism from Koskinen et al. (2011). They particularly critique research-on/in/through-design (henceforth *RoitD*) (Dalsgaard 2010; Gaver 2012; Basballe and Halskov 2012; J. Bardzell, Bardzell, and Hansen 2015) as being too narrow and lacking in richness compared to constructive design research. Furthermore, Koskinen et al. argue that the richness of design research is "*lost in definitions of research through design that tend to place too much weight on design at the expense of other important activities that make constructive research possible.*" (2011, 7). Koskinen et al. prefer to talk about constructive design research which they articulate as "*design research in which construction—be it product, system, space or media [often in combination]—take center place and becomes the key means in constructing knowledge*" (2011, 5). This short definition is based on an empiricist and pragmatist philosophy, which is a common trait among design scholars understanding of design research and practice (Waks 2001; Dalsgaard 2009, 2014). Constructive design research emphasizes that scholarly inquiry is made possible through design practice.

[34] Note that constructive design research has developed from the notions of research-through-design, exemplary design research, and experimental design research (Koskinen et al. 2011)

While constructive design research is the approach that I have adopted for my PhD project, it is clear, despite Koskinen et al.'s critique, that there is a strong connection between RoitD and constructive design research. The differences are nuanced. Both approaches probe into a non-existing world imagines by the designer and researcher and the knowledge outcome seems to be the same as is generated with RoitD. Furthermore, both approaches produce ways to understand how people, processes, and products interact, and show how to appropriate the knowledge in design practice, which in turn can inform design-oriented research strategies. The two approaches to design research have, in many ways, the same goals and through very similar methods, if not identical. Despite this critique, I have chosen constructive design research as my main research approach. When researching and designing potential futures with teachers and students in K–12, this approach is rigorous in its notion of how to generate knowledge from multiple positions. This rigor stems from explicating formulations of design programs that frame design experiments, that in turn answer questions put forward by the program (Brandt and Binder 2007). The combination of program and experiments address the overarching research question of the research project. By using constructive design research as my main methodology, I have been able to frame and argue for how I would investigate that which did not-yet-exist. Besides the theoretical reasons, I opted for the constructive design research approach for three pragmatic reasons. The FabLab@school.dk project was imagined to be a constructive design research program from the start. I was committed to designing the non-existing, which would later "come into existence" and serve as my empirical basis. Constructive design research has provided me with handles to deal with the complexity and wickedness design research as my research has relied on the creation of a desired change of reality, manifested as an ultimate particular. It helps me illustrate the drifting nature of my PhD project and its sometimes illogical relationships when viewed from traditional scientific methods.

In the following section, I discuss the specifics of constructive research design and how it has been applied to my research. I then turn to mixed-methods and argue why and how it provides me a frame for understanding the serial relationship between my experiments.

3.3.1 Question, Program, and Experiments

Constructive design research refers to research in which construction and design—not only material products but also systems, spaces, frameworks, or media, and so on—are the main means of generating knowledge (Koskinen et al. 2011). Constructive design research deals with bringing about the not-yet-existing into the world by probing an imagined future. Binder and Redström (2006) and Brandt and Binder (2007) argue that constructive design research is based on the formulation of an overarching question (can be a larger societal issue or academic questions) studied in research programs and explored through concrete experiments (interventions). *Questions* refers to the research question that guides the initial and overarching academic inquiry. *Research programs* frame and contextualize the research question by proposing a possible, preferable change in the world that one has an interest in studying. Programs are areas of exploration and set the goals for the design and research work. Binder and Redström (2006, 3) differentiate between a research program and a design program: "*Where ordinary design work proves its relevance through what the program can accomplish in terms of finished design, design research has to show the strength of the program beyond the individual experiments.*" Programs ensure that what is studied can be transformed into viable applicable knowledge within a particular context and be conditioned by accounting for the particular context in which it was conducted (see section 3.1). *Experiments* are the means of exploring programs through concrete measures: "*Experiment[s] in design research [are] on the one hand the results of a truly designerly engagement with possible form that can be appreciated and evaluated as design and on the other hand as a deliberate attempt to question what we expect from such design.*" (ibid. 3). Thus, all empirical material is collected through experiments.

Nelson and Stolterman's theory of design as creating the not-yet-existing resonates with Brand and Binder's focus on designerly engagement with imagined futures. Thus, my research does not rest on the assumption that programs and experiments precede each other, but that the two interact in a complex relationship. Redström rejects the "theory-precedes-experiment" argument and point out that it just as often goes "experiment-precedes-theory:" "*It does not matter so much which of them emerges first; they still depend on each other to the extent that they fully play their parts only when both of them have become present*" (2017, 107). This argument holds for my work. R1 and P1 highlight this distinction. In R1, I relied on literature on design and digital education to design questions for the baseline survey (what competencies were the most relevant to investigate as a baseline for future work), and thus theory preceded the experiment. This was reversed in P1, where the survey experiment preceded theory (Schön's theory on stance towards inquiry).

The development of programs can be traced along three steps: "*(1) formulating a design [/research] program; (2) realizing the program by designing, implementing, and evaluating design examples; (3) reflection and formulation of results.*" (Redström 2017, 85). A program is characterized by both intent and unfolding, an intertwining or projection and process. It depends on a certain worldview, a basic set of beliefs and assumptions, to be effective. A program includes a set of beliefs, ideals, assumptions, intentions, and worldviews (Brandt and Binder 2007). Each program I have engaged with has taken the assumption that there are aspects of competencies with regard to design, digital technologies, and critical thinking, which every student could benefit from developing. An additional assumption that underpins my programs is that making can support development of digital literacy and design literacy. My experiments express these assumptions through concrete measure, sometimes tacitly, sometimes not. Experiments aim to strengthen, challenge, and express the programs (ibid.). Experiments are suggestive of the program’s basic assumptions by showing what is possible within the program and generating new insights that are substantiated in the relationship between program and experiment. This means “that whereas the experiments answer to the questions/suggestions put forward by the program, it is the combination of program and experiments that addresses the underlying research questions.” (Binder and Redström 2006, 4). Fig. 15 summarizes Brandt and Binder’s description of the relations between question, program, and experiment (2007). The relationship is fluid, since changes in one area may cause transformation in another and the overarching question can emerge from an intervention and present new potential research agendas. Using constructive design research has benefited my work by allowing me to have a broad overarching research question—how can digital design be introduced, sustained, and articulated as a new literacy through making in formal K–12 education—and explore it from different positions framed by programs and experiments. This approach is also well-suited for positioning the included papers to shed light on my overarching research question from my three research trajectories.

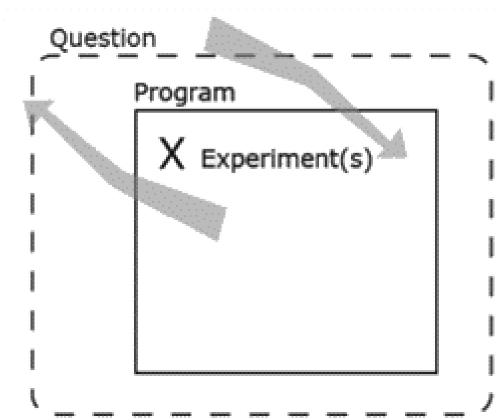

Figure 15—How a question is framed in a particular context set up around a program in which the design researcher conducts experiments. These relations go back and forth, e.g. an experiment might transform the research question; thus, the progression is typically not fixed but dynamic and iterative. Taken from (Brandt and Binder 2007).

Dalsgaard elaborates that, if external stakeholders and researchers are to collaborate in design projects, there has to be some overlap between them (Dalsgaard 2009). My research was carried out in collaboration with stakeholders outside of academia, who had specific goals and wishes that were not driven by an overarching research question. Instead, the funding partners had explicated assignments that required my colleagues and I to develop new lesson plans and curriculum, establish school maker settings, administrate and analyze baseline and follow-up survey, create an international network with local communities, and develop and teach a master course for teachers. My obligations to external stakeholders across the programs illustrate how my work has drifted between practicing design and research. For example, in designing the two survey experiments (fig. 17), I had to fulfill both my academic desires and those of the external stakeholders. Some survey items were not of interest in my studies but were important to include for reasons such as international collaboration and comparison with a similar survey done by Blikstein et al. at Stanford University, Palo Alto, Calif., USA (Blikstein et al. 2017). I find it appropriate to account for this aspect to showcase how my work has been communicating with people outside academia.

In fig. 16, I adopt Brandt and Binders "question, program, and experiment" framework combined with Dalsgaards additions to map and clarify my research activities. Fig. 16 has not been guiding my PhD project from the outset but has been constructed in retrospect to provide structure for this dissertation and as a tool for reflection. Fig. 16 depicts how each program (the squares) overlaps and relates. The stars denote the experiments (the stars) which I carried out to explore the programs in which they were nested. The top-left eye represents my initial observational field studies in three Danish schools.

Since little was known about teaching digital design through making in K–12, it was necessary to gain a preliminary understanding of what might be an interesting phenomenon to study and to align my research with students' use of, experience with, understanding of and competencies with digital technologies and design. It was necessary because I would otherwise risk that my qualitative intervention experiments would put too high demands on teachers" and students' competencies with digital design, which might have paralyzed their process. To accommodate this, my colleagues and I did a few preliminary in-school observations of students working with digital technologies, which provided me with initial ideas of what to study and a sense of the reality that students and teachers found themselves in[35]. The preliminary observations also helped me to identify relevant issues and would serve as the underpinning for the survey with a larger sample of students (see R1), which I would later explore in more detail through qualitative intervention experiments. My research design was structured so that the collection and analysis of quantitative data were followed by the collection and analysis of qualitative data (see section 3.3.2).

For the sake of presentation, I have numerically denoted each experiment as quan. (*n*) and qual. (*n*). Quan. (*n*) refers to my quantitative survey experiments; qual. (*n*) refers to my qualitative intervention experiments (see fig. 17).

[35] These observations did not result in any academic publication, nor was it the intention.

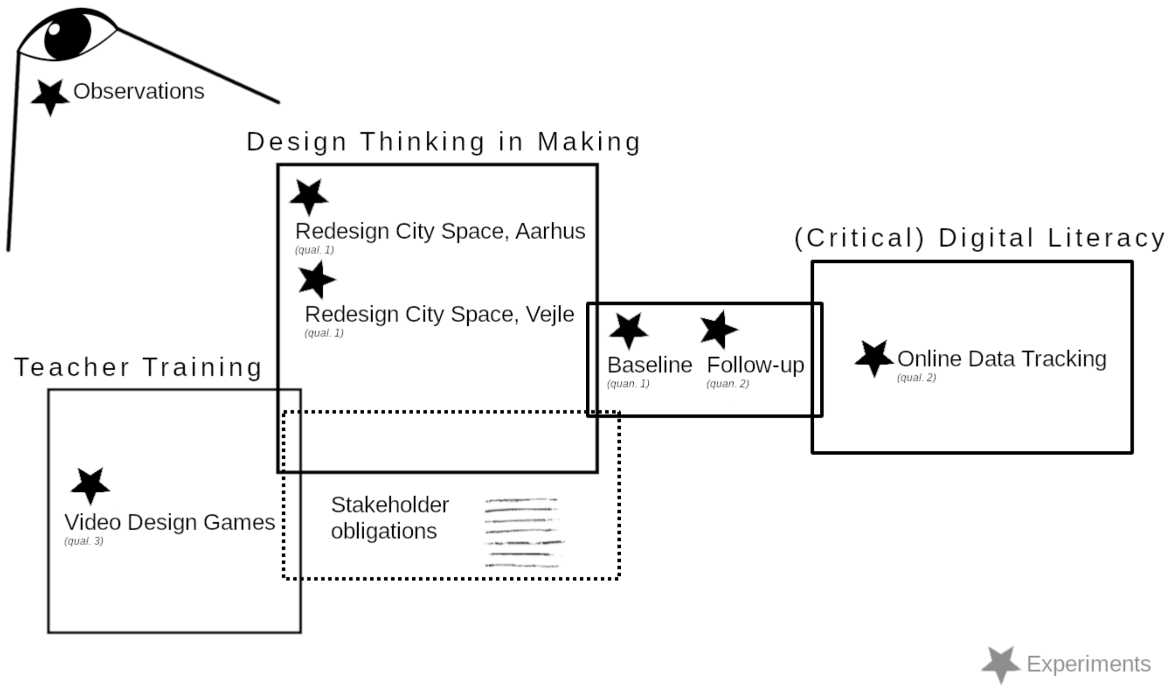

Figure 16—Activity model of question, program, and experiments that I have conducted in my PhD project.

I have pursued my research question within three programs that can be formulated as taking a teacher, design, and (critical) digital perspective (fig.16). The three programs work both as suggestions for inquiry and as a contextualization of my research question. They are suggestive in the sense that they propose that digital design literacy might provide a useful framework for K–12 and for researchers working with digital design through making in education. Even though the programs have not been carried out in the same context, they all touch upon my overarching research question and share a concern for the topic of digital design literacy through making. The strength and potential of my programs have been explored through a range of quantitative and qualitative experiments involving various stakeholders. A consequence of this diversity was that each program produced several lines of inquiry that evolved in parallel. An example of this is my work analyzing my baseline survey data while planning the “Design Thinking in Making” program and experiments. Results from the baseline survey trickled in while I was planning the experiments found in the “Design Thinking in Making” program. The survey results helped me get a better understanding of what to expect from students and teachers with regard to digital and design competencies, which in turn influenced how I planned and designed the experiments within the program.

Having illustrated how my research can be framed as constructive design research, I will provide a detailed overview of my experiments and how they are aligned. These experimental activities serve as my primary sources of empirical material for my research and highlights how the knowledge and practices that I have generated have been successfully transferred and applied to policy and educational practice.

Study	Object of Study	Method	Participants	Duration
2014: Observational field studies Qual. 0	Making in education processes created and facilitated by local school teachers.	Qualitative research: - In-class audio & video observation recordings - Field notes - Interviews with 6 teachers and students	5 classes of 5^{th} – 9^{th}-grade students 5 teachers 3 schools	4 weeks
2014: Baseline survey Quan. 1	Students’ use of, experience with and competences, with digital technology, hacking, privacy concerns and design.	Quantitative research: - Survey data - Observations	1,150 students 50 schools	4 weeks of survey data collection, approx. 6 weeks of analysis
2014: Design Thinking in Making: Redesign City Space Qual. 1	Students competencies with maker technologies and design processes developed and facilitated by researcher in FabLab school.	Qualitative research: - Video observation recordings - Field notes - Interviews, 12 students	4 classes of 7^{th}-grade students 2 teachers 2 schools	8 weeks, 2-3 hour in-class lessons
2015: Critical Digital Literacy: Hacking Global Communication Qual. 2	Students’ experiences and concerns with online data tracking and surveillance, hardware hacking, and remixing of digital content.	Qualitative research: - Video observation recordings - Field notes	1 class of 7^{th}-grade students 1 school 3 teachers	3 weeks, 3-4 hour in-class workshops

		- Semi-structured interviews with teachers and students		
2016: Teacher Training Master Course Qual. 3	Teachers' competences in design processes with maker technologies facilitated by researchers and co-developed with teachers. "how to educate teachers to teach digital design."	Mixed methods: - Video observation recordings - Exam portfolio - Interviews with teachers	45 teachers 6 FabLab leaders 7 external consultants	14 weeks x 2
2017: Follow-up survey Quan. 2	Follow-up on students' use of, experience with, and competences with digital technology, hacking, privacy concerns, and design.	Mixed methods: - Survey data - Interviews with 22 students	449 students 17 schools	4 weeks of survey data collection, approx. 6 weeks of analysis

Figure 17—Overview of my main research activities for the FabLab@School.dk project (2013-2018).

What follows are detailed descriptions of my research experiments.

Experiment quan. 1 and 2—Baseline and follow-up survey on digital technology and design processes

Scale	Domain/ Setting	Number of participants	Activity duration	Approach	Educational content
Large	Public schools classrooms	1.150 students 50 schools 3 municipalities	60 min. pr. classroom	Quantitative assessment	None
Medium-Large	Public schools / classrooms	449 students 17 schools	60 min. pr. classroom	Quantitative assessment	None

Figure 18—Top row is the baseline survey; bottom row is the follow-up survey.

My two quantitative survey studies took the form of online questionnaires (quan. 1 and quan. 5). The large number of respondents allowed me to generalize my results and include a wide range of students with different ethnic, socio-economic, and educational backgrounds.

In the first quantitative survey experiment (quan. 1), I quantitatively investigated the use and understanding of digital technologies and design among students aged 11-15 years in Danish schools. This created a baseline from which my subsequent research experiments were inspired and informed, that is, it was important to get an initial understanding of students' competencies with maker technologies before designing intervention experiments that would rely on students' abilities to use these technologies in their design activities. Questions probed their use and knowledge of digital technologies, both in and out of school, their knowledge of design, and their perspectives on the issues of hacking, open data, and privacy. The survey was conducted as an online questionnaire with 227 questions spread across six related themes: (1) Personal information (2) School and leisure time, (3) Everyday use of media and technology, (4) Technology education in school, (5) Design literacies, and (6) Hacking and repair of technology.

The baseline was accompanied by a follow-up survey which allowed me to measure the effects of the FabLab@School.dk educational program from 2014 to late 2016. I had multiple intentions with the baseline survey. First, I wanted to get insights into the state-of-the-actual in terms of students use of digital technology in and outside of school. Second, I wanted to gain insight into their understandings and knowledge of design thinking. Third, I wanted to know what thoughts students had on sociotechnical issues such as online privacy and whether students had engaged in hacking and repairing activities. Fourth, I wanted to have an initial idea of what I could expect in terms of competence level when I would later do qualitative studies. Finally, I wanted to do a follow-up to survey study for statistical comparison. I had the hypothesis that students who participated in the FabLab@school.dk would improve their competencies significantly through digital design. In extension, I had the hypothesis that students who had not participated in the FabLab@School.dk project would not have developed these competencies to the same extent as students who had worked with design and maker technologies.

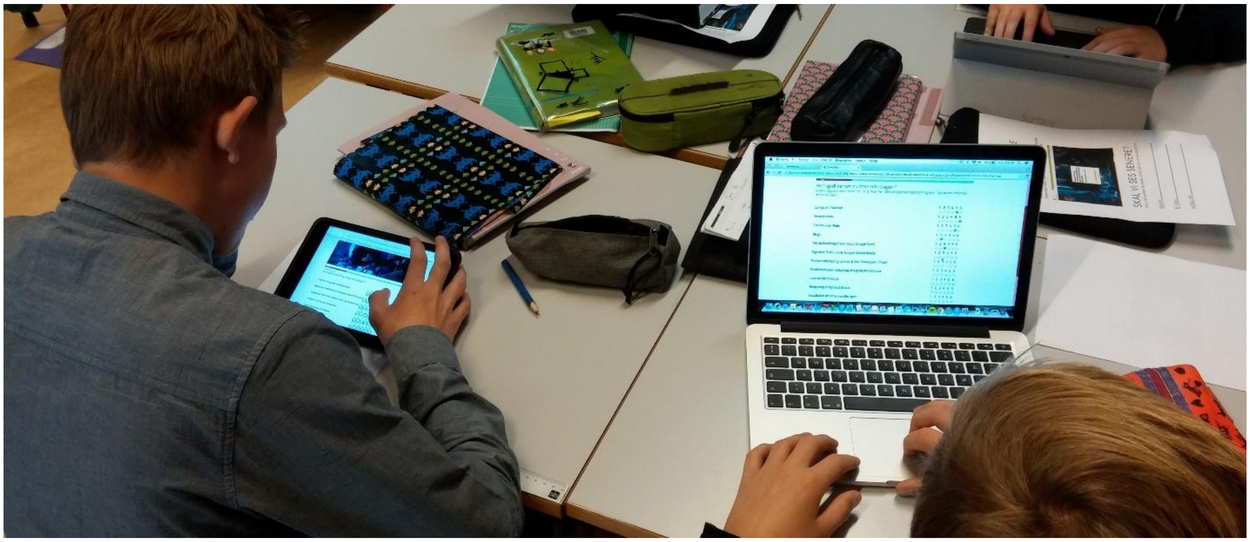

Figure 19—Students answering the baseline survey.

To test this hypothesis, my colleagues and I designed and administered a follow-up survey. The follow-up survey was conducted to compare the extent to which students who had participated in digital design education would score higher than students who had not. The number of questions in the survey was reduced from 227 to 111. It was not possible to study the same students throughout the project period since some of the students who participated in the baseline survey had left school before the follow-up survey was administrated. To accommodate this, I had to rely on a group of students from schools that were formally part of the FabLab@school.dk project and had received digital design education (to varying degrees) and one group of students from schools not within the project (had not received training in digital design). While the follow-up survey did not include as many respondents as the baseline survey, it did provide evidence to make some initial suggestions as to how digital design education in maker settings has improved some of the students' competencies. The sample of students in the follow-up survey was not randomly selected, meaning that results found in R2 are not representative of the whole population of Danish K–12 students. In this quantitative experiment, however, only a convenience sample was possible because I had to use naturally formed groups (the students from different schools and classrooms), of which the control group were volunteers. Thus, the methodological procedure used in this survey can be defined as a quasi-experiment. With these constraints in mind, conducting a quasi-experiment can be advantageous as true randomization was impractical and unfeasible. A quasi-experimental approach was more feasible for my context since the lack of randomized assignment in research design posed challenges in terms of internal validity. Consequently, my studies reported in R1 and R2 cannot rule out alternative explanations for its findings, that is, alternative reasons for why the measured effect on students who had received training in digital design had become more digital design literate when compared to students who had not (Cook, Campbell, and Shadish 2002).

Finally, findings from the two surveys (quan. 1 and 2) informed my qualitative experiments on students' experiences and concerns with online data tracking (qual. 2) and on teachers' challenges with teaching digital design literacy (qual. 3).

Experiment qual. 1—Redesign City Space (Aarhus and Vejle)

Scale	Domain / Setting	Number of participants	Activity duration	Approach	Educational content
Medium	School maker settings	4 classes of 7^{th-}grade students 2 teachers 2 schools	Two-three hours pr. classroom	Qualitative research	Design thinking in maker settings

In this experiment, I introduced digital design and making through a series of six-week introductory classes in two school maker settings and used this as my context of inquiry. The experiment was an exploration of the potential of introducing digital design to K–12 students and teachers who had no previous knowledge or experience working through design processes. The experiment was developed in close collaboration with the external stakeholders, who required us to help schools establish FabLabs and, develop content, methods, and techniques for future lesson plans that would involve design. Three researchers and one teacher were present throughout each intervention. Each researcher took on different roles throughout: (1) support students with materials and technologies, (2) support teacher and student to navigate the design process, and (3) ethnographic-inspired field work to collect empirical data for later analysis. My interest lay in exploring student's interaction and engagement with materials and digital technologies present in this context, which resulted in the contributions made in P3. Two schools from Aarhus and Vejle were selected for my study, as they had recently established maker settings. Students had middle- to upper-middle-class socio-economic backgrounds. Both schools were committed to exploring the educational possibilities of making and digital design and had invested in 3D printers, LittleBits, Arduino, Makey, and various craft materials such as cardboard, paint, and hot glue. Teachers and students were unfamiliar with maker technologies. In total, 45 hours of course activity were documented, transcribed, and analyzed.

Figure 20—The students' documentation and materials based on their field studies and presentation of their final mock-up.

Experiment qual. 2—Critical Digital Literacy: Hacking Global Communication

Scale	Domain/ Setting	Number of participants	Activity duration	Approach	Educational content
Small	One school/ classroom	40	Three hours	Qualitative research	Critical thinking and reflection on sociotechnical

In this experiment, I qualitatively explored students' critical digital literacies through three interventions as in-class lessons that all focused on epochal sociotechnical problems; issues of copy-left/right and FLOSS/proprietary licensing; issues of online data tracking and mass surveillance; e-waste, repairing and planed obsoletion. The intervention was split into three tracks, or sub-experiments, under the header of "Hacking Global Communication." The three tracks were; (1) "Online Data Tracking and Surveillance," (2) "Remixing the Web," and (3) Hardware Hackathon: Repairing and Planned Obsoletion. I will be focusing on only the first track in this dissertation, which I have written about in P5. This study aimed to have students reflect on their relationship with digital technology when enmeshed with ethical, ecological, and social issues, and so forth. These lessons were run as pilots, as critical literacy was not present in the current school curriculum, and the participating teachers had not previously taught students to be critical toward sociotechnical developments. Furthermore, this program initiated a discussion on critical digital literacy and conceptual development.

Experiment qual. 3—Teacher Training Master Course

Scale	Domain/ Setting	Number of participants	Activity duration	Approach	Educational content
Medium	University/ municipality FabLabs	45 teachers 6 FabLab leaders 7 external consultants	14 weeks x 2	Qualitative research	Teaching teachers to teach design thinking in FabLab

In this experiment, I made inquiries into the challenges of training K–12 teachers to teach their students design in making. Its interventions focused on educating teachers to teach design in K–12, driven by the need for new teacher training strategies and empirically based knowledge under the umbrella of *educating design educators*. As part of the teacher training course, I developed and employed the Video Design Game. The Video Design Game helped teachers enrich their understanding of the role of externalizations in communication and assessment of ideas. The course was developed within the FabLab@School.dk and run as a pilot course. Participants were either practicing teachers or educational leaders of central FabLabs with the responsibility of servicing teachers in different municipalities. It was crucial for our project to advance an understanding of what capabilities teachers need and how they might create new practices to support the development of students' design literacy. The experiment was designed to get a first understanding of what competences teachers need to teach design literacy to K–12 students. Details on the course and its outcome can be found in P2.

Having detailed my experiments, I will now describe how they relate to my question and programs. All my qualitative experiments have been driven by exemplars (Binder and Redström 2006) of what could be done and how, that is, examples that express both the possibilities and the characteristics of each design programs' worldview. However, this approach also presents a double challenge for me as a design researcher. The exemplars have to demonstrate both that what is proposed by the program can be successfully carried out and provide evidence that substantiates that pursuing the suggested line of inquiry will provide opportunities of unprecedented change and novelty, both for one's self and others.

The three programs reflect my research trajectories presented in section 1.1. Each program has contributed knowledge along the three trajectories which in turn has contributed to answering my research question and informed the Digital Design Literacy Framework (see chapter 4). Employing the idea of constructive design research programs allowed me to pursue different lines of inquiry each of which shed light on my research question from different perspectives and frame my work as a coherent and interrelated whole. In the following, I exemplify this approach by referencing how the Digital Design

Literacy Framework builds upon my research efforts. The conceptual trajectory was explored in all three programs, specifically the three perspectives of “design,” “digital technology,” and “critical,” which each highlight features of digital design literacy. As my research approach encourages drifting, the three perspectives are intertwined and have mutually influenced each other. The measurement trajectory was explored through the survey experiments, which cut across the “Design Thinking in Making” and “(Critical) Digital Literacy” programs. The survey experiments unfolded the interests of the two programs but were not concrete instances of interventionist experiments. The unfolding of these programs through survey experiments contributed to the measurement trajectory by providing a quantitative understanding of the state-of-the-actual of students’ digital design literacy and new development tools for quantitative assessment (see P1 and P4). The educator trajectory was explored in the “Teacher Training” program. The “Video Design Game” experiment in combination with the theoretical perspectives on design competence (see section 2.2.2) gave me new understandings of the pedagogical challenges that educators face when teaching digital design literacy to students. Schematically illustrating my work with the constructive design research approach also allowed me to account for how the programs relate to external stakeholders and contracted assignments—that is, stakeholders wanted my colleagues and me to qualify teachers to teach digital design.

Multiple revisions and alternatives of the overarching research question emerged throughout my project. Some interventions opened up my mind to new perspectives or concepts that transformed my initial research question. Furthermore, my research was constrained by the practicalities of designing and transforming an unwanted situation (lack of design education with digital technology in K–12) that would be usable for the participating schools and the involved stakeholders who had their own purposes and ideas for the FabLab@school.dk project. Each experiment also showcases my commitment to generate relevance for both K–12 education and the making in the education research community as each of my intervention experiments have been carried out in direct collaboration with an external stakeholder, for example, the contracted assignments requested by our funding partners. Such drifting makes design research complex and wicked, as design research is indispensably shaped by practical concerns, contracts to fulfill, work under different contexts in the same domain, adapting to changing budgets and timetables, and so on.

Since my collection of empirical material has unfolded as a serial process, I argue that mixed-methods can help me describe my work (Krogh, Markussen, and Bang 2015) with very concrete concepts for how my research has unfolded temporally and as a sequential process. As I have already discussed, it would be an oversimplification to map my experiment as a neatly planned process where one experiment naturally leads to a new hypothesis to be tested. Thus, fig. 21 presents schematic representations of how my work can be mapped from a mixed-methods perspective. This perspective helps illustrate how each experiment is aligned over time, as opposed to fig. 16, which is more fluid in its methodological conceptions. I claim that because of the complexity of design research, it is beneficial to view my research approach from multiple perspectives. A sequential representation of question, program and experiment is not enough to capture all details and peculiarities of how my quantitative and qualitative research are related.

3.3.2 Moving Through Mixed-Methods

In this section. I discuss how my research has relied on mixed-methods. Creswell defines mixed-methods as the *"combining or integration of qualitative and quantitative research and data in a research study. (…) resided in the idea that all methods had bias and weaknesses, and the collection of both quantitative and qualitative data neutralized the weaknesses.*" (Creswell 2014, 563). Mixed-methods aim to accommodate the methodological limitations inherent to quantitative and qualitative methods respectively. The mixed-methods approach allows me to conduct and triangulate my findings that involve quantitative survey questionnaires and qualitative in-school experiments and gain a more holistic understanding of my research question. In my case, a holistic understanding of my research question entailed triangulating generalizable and quantifiable knowledge combined with context qualitative exemplars to create detailed accounts of my survey findings (see 3.3.1). Additionally, mixed-methods help me to elaborate on the connections between my experiments and the included papers from a temporal view and how they come together to form this dissertation (fig. 21).

My mixed-methods design can be characterized as a combination of *explanatory sequential* and *exploratory sequential* (Creswell 2014, 564–71). It is exploratory because my qualitative studies informed both of my quantitative surveys, and it is explanatory because my survey results are explained in more detail through my qualitative experiments (see 3.3.1). The phases are combined using a strategy of connecting, where insights from the one phase contribute with new understandings and questions in the next (Creswell 2014). The phases sometimes overlapped, so while doing qualitative intervention experiments, I was also doing statistical analysis of the survey data (see 3.3.1 for a discussion on this "drifting"). While constructive design research relies on the design of imagined futures to create a context for inquiry, mixed-methods is more generalized and does not directly touch upon the aspects that make design-oriented research distinct from other research approaches.

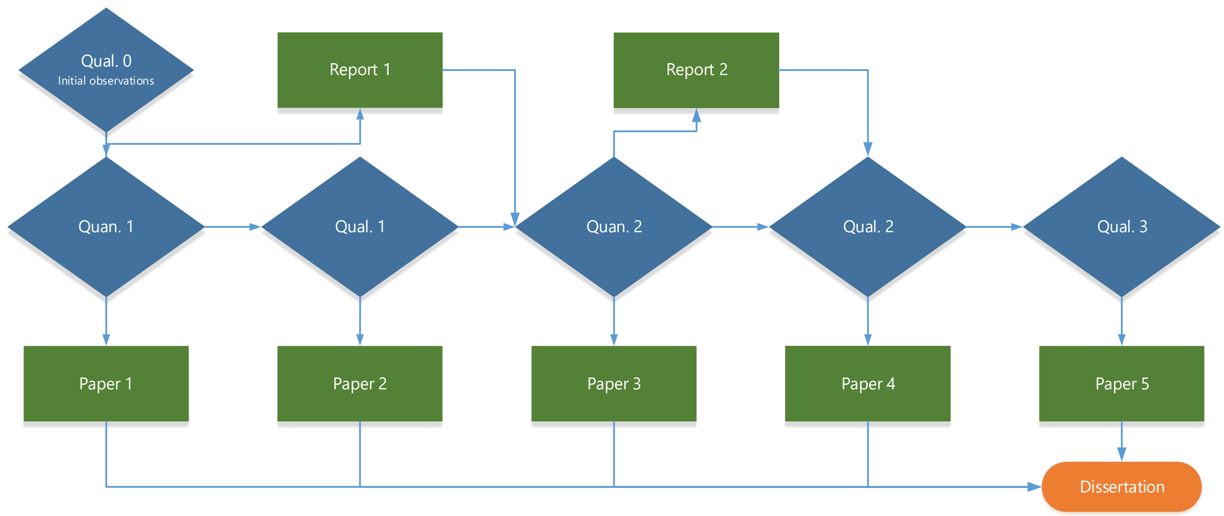

Figure 21—The sequential mixed methods research design as applied in my PhD project.

Fig. 21 illustrates how my research experiments have serially informed one another over time and have created the empirical basis for the included papers, which in turn have laid the basis for this dissertation.

The findings from qual. 0 and qual. 1 became the basis for my research contributions in P3 and to some degree in P2. In qual. 0, I actively observed students working with maker technologies and teachers who were not competent in using maker technologies. As my program took the worldview that digital literacy is an essential component of digital design literacy, I set up an intervention experiment expressing this worldview (qual. 1). To further my understanding of students' work with maker technologies, I took a proactive observation position and I supported students with their technical difficulties. This allowed me to do semi-structured interviews with the students on their use of maker technologies in their design processes. Hence, a main objective of my intervention experiments was to get a better understanding of how to articulate and scaffold the teachers' and students' work with integrating maker technologies into their design process (see P3). At the time I was carrying out qual. 1, teachers had yet to receive training to teach students in digital design. My colleagues and I, therefore, had to create scaffolding design and teaching materials to facilitate the classroom teaching (qual. 1). The teachers helped facilitate the class but would often ask us how to deal with sudden problems that emerged throughout the students' design processes. This insight then initiated a bottom-up teacher training course (qual. 3) from which I would generate a workshop to facilitate the development of new pedagogical practices and understandings of the competencies lacking among teachers.

My initial in-school observations (qual. 0) informed the design of my baseline survey (quan. 1) and contributed to the development of the Digital Design Literacy Framework by providing insights into students' use and knowledge of digital technologies (in and out of school), their understandings of design and creative processes, and their perspectives on hacking, data, and privacy issues (see R1 and R2 for details on questions, administration, data treatment, and results). Since my research question deals with the development of digital design literacy through making in education, I focus on the design perspectives in terms of students' knowledge and use of digital technologies for design activities as well as their critical stance towards sociotechnical problems. Results from R1 and R2 should be considered as tentative measures, which guided further qualitative investigations, but which are not yet established as valid measures of the concerned traits that my surveys inquired into. Results presented in R1 are mainly descriptive in R1's approach to the collected data, and it serves the purpose of presenting these data in a way that lends itself to further exploration. Thus, the results reported in R1 descriptively informed my first qualitative intervention experiment (qual. 1) by giving me the insights that (1) students are consumers rather than producer of digital media and technology, (2) few students have knowledge of maker technologies, particularly digital fabrication, (3) schools focus on teaching basic "office literacy,"[36] (4) most students do not act on their creative ideas, and (5) students lack knowledge of design processes. The combination of knowing that the participating students were generally not digital-literate and findings on students' use of maker technologies in design processes (qual. 1) contributed the empirical basis for my contribution made in P3. This ultimately contributed to my design of the Digital Design Literacy Framework by pointing toward the importance of being competent in using maker technologies and traditional craft as being a central aspect (see chapter 4). As explained in chapter 2, it is central for students to develop a guiding language to articulate material qualities as I provide in P3.

Findings from quan. 1 and qual. 1 led me to revise some of the question items in the baseline survey, as some were deemed to be irrelevant for my research, specifically questions related to STEM. These revisions were carried over to the follow-up survey (quan. 2) to measure the effects of the FabLab@School.dk educational program from 2014 to late 2016. P1 and P5 would later build on data generated and interpreted from the baseline and follow-up survey, which has contributed to the Digital Design Literacy Framework by pointing toward the importance of having a critical consciousness toward technological developments in the world.

In summary, by mixing quantitative and qualitative research, my research gained breadth and depth of understanding, while offsetting the weaknesses inherent in using one approach. Insights gained from my programs and experiments did not provide an exhaustive answer to my overarching research question,

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[36] By "office literacy" I refer to competencies related to the use of office suite software (https://en.wikipedia.org/wiki/Productivity_software#Office_suite accessed 10/10/2016), e.g., Microsoft Office and Google Drive, particularly word processors and presentation programs.

which my project is not intended to do. Rather, the question exists to frame my research inquiries that result in new insights that are suggestive. I claim that my project and, by extension, my research question, can be considered as a wicked problem in itself, which is therefore likely to output wicked answers that do not necessarily "solve" the research question. Thus, my primary intention with the posed research question is to guide my various inquiries that can result in new insights from several perspectives of the project, which is also clear from the drifting between question, program, and interventions present in the included papers.

Having discussed my research methodology and how my individual studies relate, I will now turn to the presentation of the main contribution of this dissertation; the Digital Design Literacy Framework.

4 Toward a Digital Design Literacy

In this chapter, I unfold the aspects of the Digital Design Literacy Framework, which I have found to be essential in the included papers as well as my review and discussion of literature in chapter 2. Digital design as a third area of education has not been developed to the same extent as science and the humanities. There is a lack of a genuine conceptual framework for understanding the subject of digital design in K–12, particularly regarding articulations on how to conceptualize digital design from a new literacy studies perspective (see chapter 2.2). To accommodate this lack of knowledge, I present the concept of digital design literacy as a framework which encompasses my contributions to the turn toward digital design in making in education. This elaboration ties together notions from design and digital literacy theory, as discussed throughout the three previous chapters, and the contributions made in the included papers.

In chapter 3, I described my research approach as constructive design research driven by question, programs, and experiments, which have guided my theoretical and experimental work. This approach is suggestive as it aims at producing framings, articulations, and concepts for reflection that further an understanding of digital design as a literacy within making in education in more or less direct ways. I claim that such a framework is crucial in allowing the field of making in education to evolve as a field that seeks to introduce and sustain digital design in K–12 education. Hence, the Digital Design Literacy Framework is not intended to be a complete dictionary with finite definitions of all digital design competencies. Instead of contributing an exhaustive notion of digital design literacy, the Digital Design Literacy Framework provides a basis from which to build better arguments for the value of digital design literacy and contributes a wider range of conceptual handles on what constitutes digital design literacy than previously discussed in the making in education literature. The framework is suggestive and expansive rather than being finite and all-encompassing, and there are certainly other competencies and ways to articulate digital design literacy than suggested in this dissertation. Hence, the framework is provisional and aspirational for future work. It is provisional as I have arranged the framework for the present situation in K–12, which will change as new technologies, subjects, and pedagogical issues emerge.

In the remainder of this chapter, I outline the Digital Design Literacy Framework and present arguments for how the framework provides new knowledge of how to understand, frame, and articulate digital design as a new literacy when taught and developed through making in K–12. The framework is valuable to researchers, teachers, students, and policymakers as it provides a missing language needed to articulate aspects of what digital design entails from a new literacy perspective. The framework will be presented as a collection of schemas, rather than relying on a single visualized framework model, which offers only a singular perspective among multiple perspectives that are too complex to be captured from a single viewpoint. Hence, the Digital Design Literacy framework is a combination of text and visualizations.

4.1 THE DIGITAL DESIGN LITERACY FRAMEWORK

To articulate digital design literacy schematically, I adopt Martin's framework of digital literacy. While there have been many attempts at capturing the characteristics of literacy when related to concepts such as competence, skills, abilities, and so on (see section 2.2.1), I use Martin's (2008) model of digital literacy as a starting point to help me schematically articulate key concepts and some basic relations between what I view as usage of competencies, literacy, and empowerment. I do this based on the assumption, which also is a small contribution of this dissertation, that competence can be seen as a concept that encompasses various skills, abilities, attitudes, and so forth, and that people develop literacy by using their competencies in a larger project within a certain discipline. Rather than transferring and translating scholarly descriptions of professional design competence that already exist, I have come to understand what I claim to be some essential digital design competencies by bridging the gap between theory and practice, exemplified in the included papers with which I have made reflections on understanding and teaching digital design literacy (Dalsgaard and Dindler 2014).

The Digital Design Literacy Framework is arranged as three levels: *competencies*, *usage*, and *empowerment.*[37] Of these levels, literacy is first reached when the underlying competencies are put into

[37] Note that Martin's original framework uses the notion of "transformation" rather than "empowerment". I have chosen to use "empowerment" at the third level rather than "transformation" because design by definition is transformative. That is, design seeks to transform existing situations into prefered ones. This transformation through design can empower students in differents ways, e.g. democratically or critically (Kinnula et al. 2017).

usage in a larger project (fig. 22). As discussed in section 2.2, I use the concept of competence as the overarching term that describes the ability to do something well.

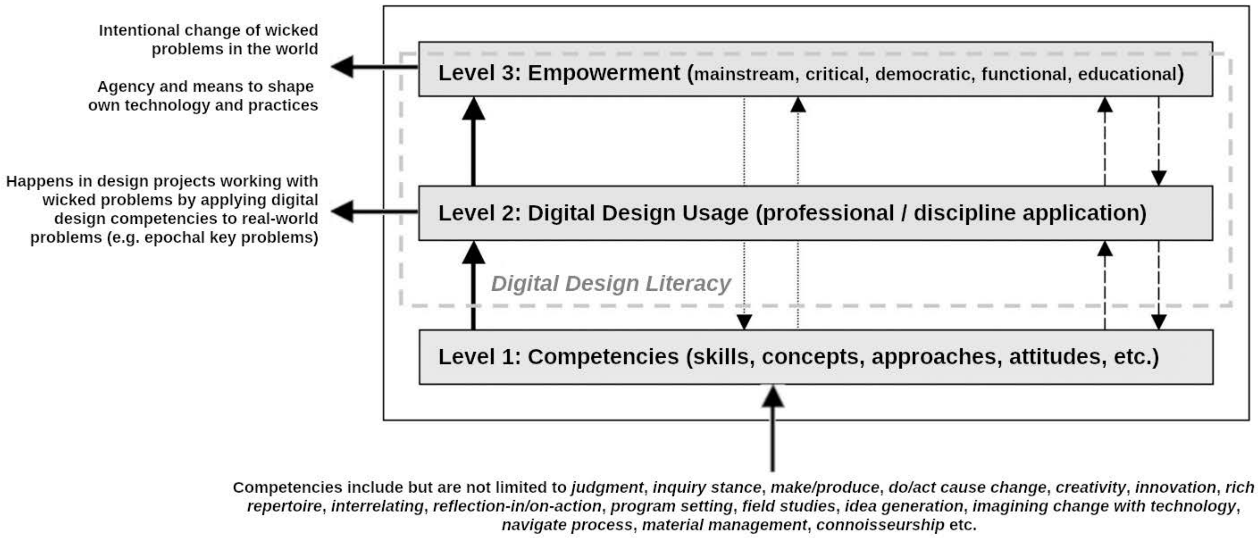


Figure 22—Competencies, usage, literacy, and empowerment as related in the Digital Design Literacy Framework.

The first level, *Competencies*, contain a wide range of concepts, skills, abilities, domain knowledge, attitudes, and so on. Hence, I use the notion of competence as a container to clean up conceptual confusion. From this view, notions of skills, abilities, and so on represent lower-ordered sets of abstract and concrete actions that students take in their design processes. This perspective encourages students to engage in situational embedding, meaning that students must thoughtfully use their digital design competencies within work, learning, leisure, and other aspects of everyday life and education. This includes, but is not limited to, the contextually-appropriate usage of maker technologies, design materials, taking a designerly stance towards inquiry, and reflecting on the transformative social impact of their design concepts and digital artifacts. By contextually-appropriate competence usage, I am referring to how the requirements of a situation shape how and what competencies might be appropriate to use when students are to identify and resolve wicked problems. Design digital usages are, therefore, fully embedded within the activity of working through a design process. Situational embedding of competencies is a precursor of digital design literacy, but competencies cannot themselves be articulated as literacies. Hence, digital design literacy denotes the appropriate and informed usage of digital design competencies. Fig. 22 illustrates where these aspects are positioned as understood from a literacy perspective. An example of a competence that can be considered a skill would be that of material management that I have investigated in P2 and discussed in section 2.2.2. Stance towards inquiry is also a competence, but more of an attitude and approach to understanding wicked problems than a skill. I return to this differentiation after describing levels 2 and level 3.

At the second level, *Digital Design Usage*, students can develop literacy in the usage of digital design competencies in working with wicked problems, giving rise to a corpus of digital design usages specific to the student. The usage is shaped by the requirements of the situation. Thus, to become digital design literate, digital design competencies must be put into action as the student is presented with a task or problem that arises out of a specific life context, be it professional, educational, or leisure time. The arrows between design digital competence and design digital usage in fig. 22 depict the reciprocal relationship between design digital usage and the students' design digital competencies. The usage of a competence moves the student closer to developing literacy, and the experience gained from having used these competencies feeds back into the individual's development of competencies. The student identifies a competence requirement and draws on something already present in her repertoire (consciously or tacitly). The student may then develop the needed competence through the learning process that is made accessible and possible in maker settings, supported by their teachers and group. The student would then, ideally, make a reflected use of the developed competence in her design process. For example, it is not enough to internalize knowledge; the student must also proactively apply this knowledge in situations that are not simply recounting banked knowledge of standardized evaluation tests. Rather, it is about the usage of developed competencies in carrying out a complete design process. Hence, to reach the level of digital design literacy, students should become the main agents in driving the design process and thereby further develop their competencies to design as well as to discuss technology and its impact on the world; the student becomes the protagonist (Iversen, Smith, and Dindler 2017). This requires hands-on and project-based activities, for which constructionism and maker settings are auspicious.

At the third level, *Empowerment*, students can reach different forms of empowerment, be it management/mainstream, critical, democratic, functional, and educational/competence (Kinnula et al. 2017). These five views are not exclusive, but overlap and can be combined to accommodate the strengths and weaknesses of each. Empowering students can make them take a protagonist position, which "*positions the children at the center of the design process as they engage with real-world design problems. The objective is to support their own development of skills in terms of designing and reflecting on technology.*" (Iversen, Smith, and Dindler 2017, 35). I suggest that the third level of empowerment directly relates to students' ability to make intentional change to wicked problems and take agency as a protagonist who can shape technology and be reflective toward their and others' interactions with technology. Because digital design is fundamentally a praxis of transformation (see section 2.2.2), I argue that using the notion of empowerment at the third level is appropriate. Note that empowerment is not a condition for digital design literacy, but should be considered a part of being digital design literate. Rather, literacy denotes the usage of competencies, which can lead to different forms of empowerment, for example, educational empowerment. Improving competencies by using them in real-world situations can empower students in different ways, which ultimately leads them to become literate. Empowered students have improved possibilities to shape their life and society in general. Hence, I align myself with the claims made by Iversen et al. (2017) and Iivari and Kinnula (2018): Students who are to become the makers and shapers of future society need to feel empowered and not accept the current situation of the world and not merely fit into existing society. Kinnula et al. (2017) go so far as to argue that empowering students can lead to richer intellectual life, better academic competencies, better jobs, better socio-economic status, and improved quality of life.[38] My research contributes to the discussion on student empowerment through digital design in maker settings by framing it in a literacy discourse. This framing has gained only a little attention within the making in education research community, which I maintain as being important when working within educational discourse. Empowerment happens when the transformation through competence usage gains a concrete foothold in the real world. However, it is not clear how researchers and teachers should assess whether students had become empowered in some sense. While many digital design literate students may achieve the empowering level, empowerment is not necessary as a condition of digital design literacy. Activity at the level of appropriate and informed usage would be sufficient to be articulated as being digital design literate.

Design digital literacy resides at levels two and three (fig. 22). Without situationally embedded usage of digital design competencies (level one) in some larger project with wicked problems, literacy is never reached. Note that students do not follow sequential leveling through each stage but are more random and iterative, as students' usage of their competencies differs in accordance with the situation at hand. In this process, students might experience challenges relating to a lack of competence, for example, in managing maker technologies as design materials. To overcome this challenge, students must take a step back to reflect on what competencies are needed to resolve the situation. This is not only to be excepted by the students but also their teachers, who should identify what competencies students might need to develop to resolve problems in their particular situation. Thus, the instantiations of the digital design competencies will depend on the design situations which students encounter in their design process. As a consequence, the degree to which various competencies students develop depends on the situation in which the competencies are used. For example, a student might be knowledgeable about programming an Arduino, but this knowledge is expanded by enriching the student's repertoire when experiencing the usage of this

[38] However, it is not entirely clear what is meant by improvements in quality of life—or what quality of life referers to.

knowledge to resolve a problem. Thus, the competencies that the student develops are shaped in accordance with his personal experiences that might not be a pre-defined learning goal.

To frame and nuance my suggestions of central digital design competencies further, I apply Nelson and Stolterman‘s descriptions of design fundamentals acquired through activities that sustain and nourish design inquiry and action (2012, chap. III). While one can understand design through theories, one will never learn them abstractly. It requires constructivist learning similar to that of designing in maker settings. Nelson and Stolterman provide two schemas, one representing four domains in which design learning can be addressed: (1) *design character,* (2) *design thinking,* (3) *design knowing,* and (4) *design action*. They connect these domains to four design competence sets of (1) *mindset,* (2) *knowledge set,* (3) *skill set,* and (4) *toolset*. Nelson and Stolterman use these domains and sets to explain design learning and position competencies which should be developed in the process of becoming a designer (fig. 23).

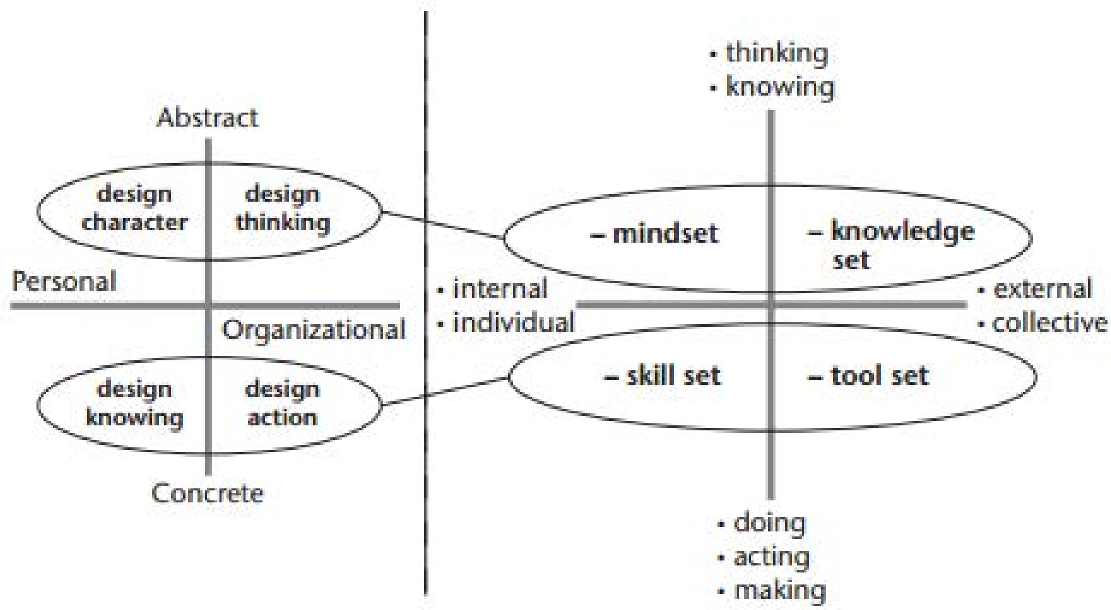


Figure 23—Schema showing the interconnections of domain- and competence sets essential to design (Nelson and Stolterman 2012, 231).

The coordinate axes depict where the competencies reside. By internal/individual, Nelson and Stolterman (2012) refer to the traits that are inseparable from the designer and are particular to him and his situation. In contrast, external/collective points toward generalized knowledge and tools that are separable from the designer. Examples of an external toolset could be maker technologies, which have specific and universal qualities, whereas the skills set to operate and manage maker technologies is tied to the individual. Schools might have the latest and greatest 3D printer on the market, but without the proper skills, this tool does not yield much of an outcome. Furthermore, each set is broken down into concrete and abstract competencies. Abstract competencies include thinking and knowing, whereas concrete competencies refer to making and taking action in the material world. It is necessary to be able to mediate among the sets so that the competencies are put into a holistic whole: "*The mediated sets are distributed between design knowledge, which is separable from the knower, and design knowing, which is inseparable from the knower. Separable knowledge is inclusive of the knowledge set and toolset. Inseparable knowledge involves access to the skill set and mindset.*" (Nelson and Stolterman 2012, 230).

Frameworks are good for visualizing relationships and reducing complexity. Hence, the Digital Design Literacy Framework has been designed based on a combination of the frameworks by Martin (fig 22) and Nelson and Stolterman (fig 23) to present what I have argued to be some of the central competencies of digital design literacy (fig. 24). I have determined these seven competencies to be important based on insights from the included papers and revisits of my research to further nuance and develop the notion of digital design literacy. The Digital Design Literacy Framework as illustrated in fig. 24 provides an expanded understanding of what constitutes some of the competencies that are important to become digital design literate through work in maker settings. The schematic representation in fig. 24 aids in mapping the seven competencies that my research suggests to be essential, as well as their relationship with literacy and empowerment. Furthermore, the Digital Design Literacy Framework contributes an understanding of specific digital design competencies, which researchers and teachers can use to make rigorous and relevant articulations when the educational goal is to develop digital design literacy among students. The framework also provides an account of how my research is arranged and articulated within a holistic framework.

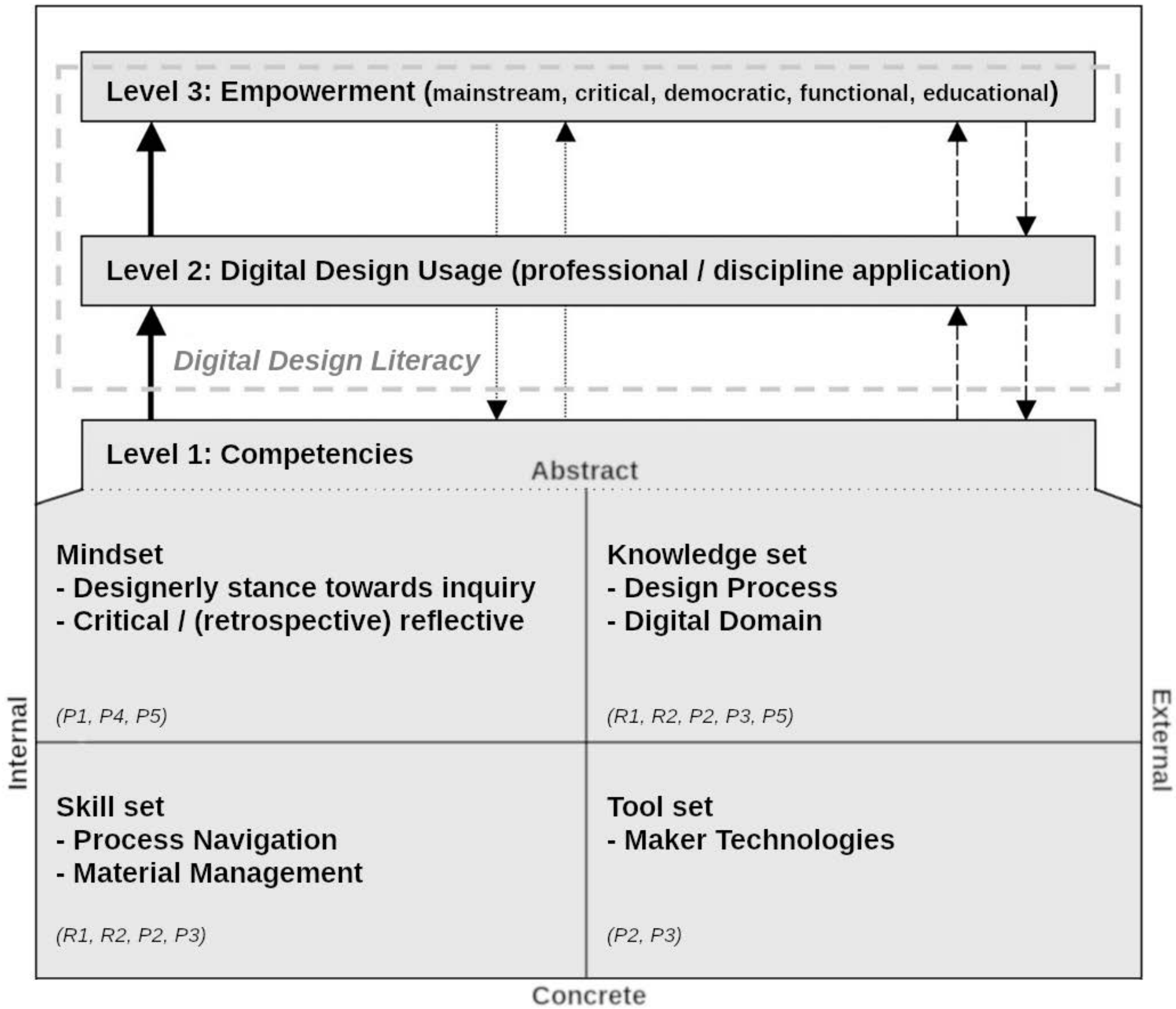


Figure 24—The Digital Design Literacy Framework. The schema represents a more nuanced articulation of the individual competencies throughout the notion of sets. Emphasis is put on connecting design and praxis with digital technology. The relationships to the included papers are put in parentheses.

Having schematically illustrated the Digital Design Literacy Framework, I will now define digital design literacy. Based on the insights from the included papers and the discussions made throughout this dissertation, I propose the following definition: Digital design literacy is the individual's ability to appropriately use design and digital competencies to act as a creator of preferred futures by bringing about that-which-does-not-yet-exist with a specific purpose, for a specific situation, for specific people, and with specific functions and qualities. This implies having a reflective and generative mindset, a rich repertoire and the capacity to use materials and digital technologies confidently to design artifacts with consideration for that-which-is-desired by other people by taking a designerly stance towards inquiry. The competence to make artifacts positions the student as an agent of investigation, discovery, and change. It requires the competence to engage both in critical thinking to critique the digital environment, culture, and society at large and to be reflective and critical toward one's design processes and interactions with digital technology. Development of digital design literacy happens when competencies are used in open-end and authentic design projects that are based on wicked problems. Ultimately, digital design literacy can lead students to become empowered individuals who can create and shape their and others' use and interactions with digital technologies in society. Digital design literacy is developed when competencies are employed in resolving real-world wicked problems.

This definition focuses on students' competence to identify and state (name and frame) the problem to be solved and the actions to take in the design process. Accession, interpretation, and evaluation of the design brief must be done in a rigorous and reflective manner. It requires students to organize, integrate, and set out the materials and resources in a way that will enable them to investigate an authentic wicked problem and create a space for iteratively working with the wickedness. This implies being able to examine and navigate the design situation using concepts, knowledge, approaches, attitudes, and materials—what I have articulated as competencies. Students should be able to combine their knowledge, resources, and materials in reflective and hands-on activities to create new artifacts which qualities they can communicate to other people. This includes being able to present and make grounded arguments, resolutions, and other outcomes relevant to the design brief students are working with. Finally, students must consider the success of the design process and reflect upon their development as a digital designer.

My definition of digital design literacy resembles Buchanan's definition of design as a new liberal art of technological culture (1992) and Löwgren and Stolterman's definition of interaction design as the process in which existing resource constraints to create, shape, and decide all use-oriented qualities of a digital artifact for one or many clients (2004). Emphasis is on digital materiality, technology, sociotechnical issues, taking a holistic approach to the problem at hand, and an ability to appreciate and compose artifacts in their totality. Fig. 25 illustrates several other potentially relevant digital design competencies. It also illustrates that there is constant mediation between competencies. Fig. 25 is also a call for other researchers to inquire into other digital design competencies and relate these to the Digital Design Literacy Framework. It provides framing of digital design literacy that enables a view on the relationships between the various competence sets—which might change over time. For example, the underlying competencies of design thinking may be relatively permanent, but new digital technologies are constantly changing and create new questions. Likewise, issues related to the emergence of new digital technologies change over time.

In the following sections, I discuss the individual competence sets, how they can be articulated, how they relate and can be operationalized. I base this discussion on findings from the included papers, the arguments presented throughout chapter 2, and by revisitation of the research contributions in the included papers. I argue that the seven highlighted competencies can be considered as both means and educational goals of design processes in maker settings in K–12 education. This is a preliminary taxonomy with descriptions of the seven competencies that my research has found to be important for students to develop. There is strong mediation among the sets (spiral in fig. 25), meaning that one might have knowledge of tools but that such knowledge is "wasted" if not put into concrete action using the skills one has developed. On the other hand, it is difficult to acquire the competencies to manage materials and tools such as maker technologies, if one does not have the required knowledge of the digital domain. As I show in P5, students do have the skills to navigate and consume digital content but lack knowledge of the digital domain that relates to the critical aspects of living in a digitized society, hindering them in developing a critical consciousness.

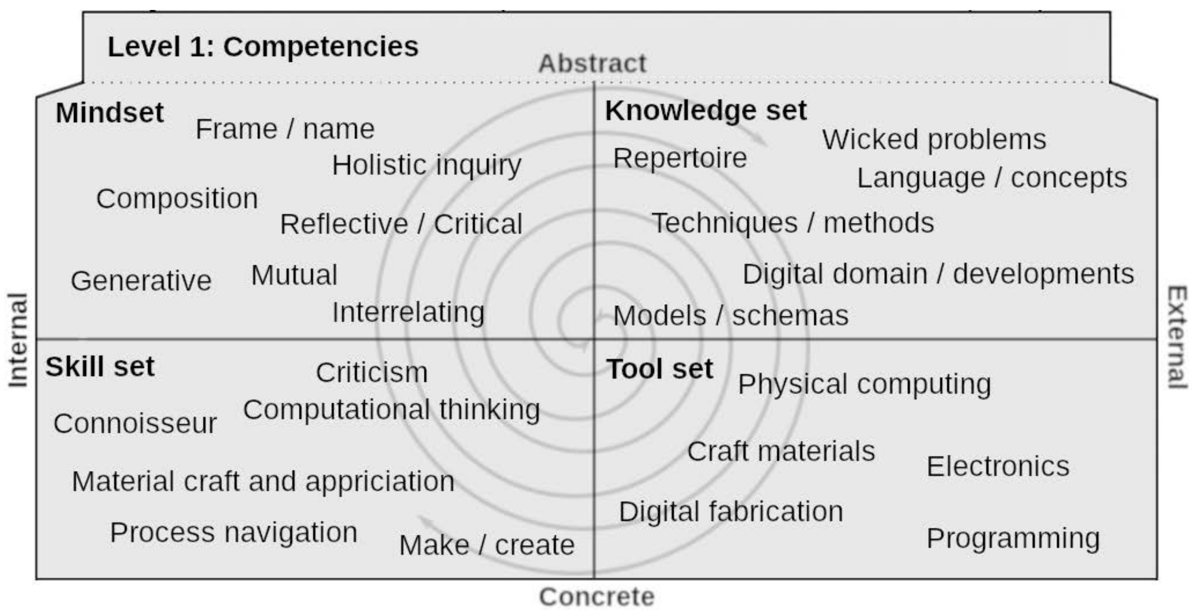
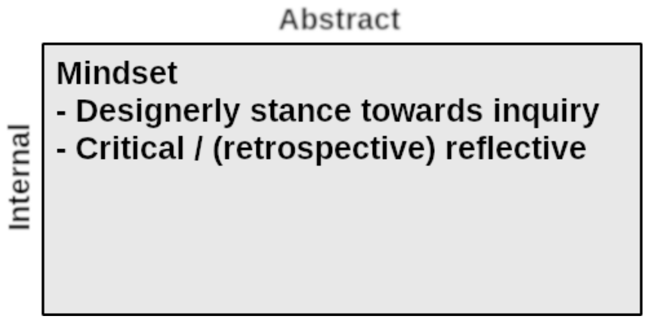


Figure 25—Backgrounded spiral illustrates the mediation of other potential competencies of digital design literacy than those explored in this dissertation.

I start with describing the abstract competence sets that emphasize thinking and knowing, and then move on to the concrete competence sets that emphasize doing, acting, and making.

4.1.1 MINDSET AND KNOWLEDGE SET

In the following sections, I will describe the competencies that reside as at the top-left quadrant and top-right quadrant of the Digital Design Literacy Framework (fig. 24). First, I describe mindset, followed by a description of knowledge set.



4.1.1.1 Designerly stance towards inquiry

Much of my work has focused on the early parts of the design process, where design inquiry leads to establishing an initial understanding of the wicked problem at hand and evolving the design situation. I have emphasized the importance of research, investigation, and field studies in the beginning of the design process with a focus on exploring wicked problems for certain "other people." The competence to take a designerly stance towards inquiry entails personal reflection on the first intentions that set the designer on a specific path of inquiry toward action by taking a top-down and breadth-first approach to understanding the wicked situation. This requires being empathic to learning to gain a holistic understanding of the situation in the early stages of a design process to discern the problem's preconditions for future design. This implies naming features of the situation and frame areas of the solution space to explore and formulate coherently an adequate problem scoping and directed approach to gathering problem information and prioritizing criteria. This includes setting boundaries, selecting particular things and relations for attention, observe, intervene, describe, and understand the context to initiate an iterative design process.

As argued in P1, it is crucial for the digital design student to develop a mindset that entails personal reflection on the first intentions toward a specific path of inquiry and action; stance towards inquiry. A designerly stance towards inquiry helps designers identify and resolve wicked problems, as it requires making inquiries into how different views of a problem and potential solutions are contradictory (see P1 and section 2.2.2). It is a crucial competence for aspiring digital designers to develop if they are to engage with wicked problems successfully (Schön 1987; Buchanan 1992; Coyne 2005).

A designerly stance towards inquiry is closely related to critical and (retrospective) reflective thinking. From a design perspective, stance towards inquiry and critical digital literacy are connected based on the argument that K–12 must not only train students to inhabit a pre-determined future but empower them to shape an undetermined future. Students of digital design should develop a designerly stance towards inquiry while also being able to examine existing digital technologies and their sociotechnical impact critically to change an existing situation into a preferable one through digital design. As argued by

Papanek (see section 2.2.2), an uncritical position to design of digital technologies can lead to the creation of more problems than they resolve, and result in unfortunate outcomes. From a digital literacy perspective, critical thinking becomes essential if students are to move from a naïve “consciousness of the real” to a critical “consciousness of the possible” (see section 2.2.3). A critical mindset also has an empowering potential, as a developed critical digital literacy can work as a tool for combating oppressors or individuals’ competence to participate in democratic processes. Concrete examples of how students can employ critical thinking on digital technology to combat oppressors can be found in P5, where students gain new insights into how their private data is tracked online. Such activities can lead to practical measures such as using software that blocks data tracking scripts on websites, thus empowering individuals to participate in shaping their digital lives and environment.

Opposite of designerly stance towards inquiry stands routine expertise and technical rationality. Taking a technical rational stance towards inquiry leads to seeing wicked problems as tame and drawing on solutions that are readily at hand, easily accessible, or simply finalized solutions. Taking a rational stance when confronted with wicked problems can end in forms of process paralysis, as wicked problems cannot be resolved rationally.

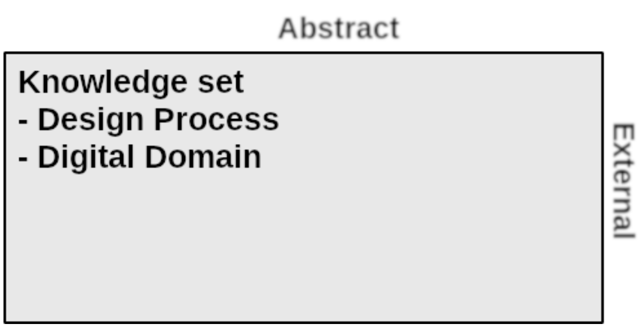
4.1.1.2 Critical thinking/(retrospective) reflection

Critical and (retrospective) reflective thinking requires the digital design student to know not only that he should be thinking critically but also that this requires external domain knowledge (top-right quadrant), for example, how the Internet is designed or how a design process might unfold. This requires not only thinking but also practice, “going into the wild” to explore and acquire domain knowledge to reflect upon and come up with alternative solutions. In explicating abstract knowledge sets, I draw on the results from R1, R2, and contributions made in P5. Knowledge is considered external as it resides in the world, in books, magazines, websites and so on, but it becomes internal when transferred to the individual’s repertoire. Acquisition of this knowledge scaffolds students in improving their skill set and toolset. A critical reception of digital artifacts can also help aspiring designers to generate knowledge and expand their view of digital technologies that are more critical than functionalist in nature. In my conception of digital design literacy, it is important for students both to critique the digital environment, culture, and society at large and be reflective and critical toward their processes and products. Leaving the critical dimension behind hinders students in developing new understandings of the digital domain, which is why competence in design criticism is important to digital design literacy. The critical dimension need not be of the same nature as in P5 but must also account for other kinds of open-ended cultural and sociotechnical commentaries that help examine the role of design when new digital technologies are brought into the world.

The position taken in this dissertation is that technological development cannot be viewed as being independent of society. Rather, I understand this relationship as being one of mutual influence: We design technologies, which shape us, which change how we shape design technologies, and so forth.

When related to digital design, critical thinking and retrospective reflection denote students' ability to critique digitally designed artifacts and critically empower students, not only as a digital designer but also as users of digital technology. Critical digital literacy can help students to become critically empowered and be democratic citizens. The competence to form critical and retrospective reflections can prompt students to develop a holistic understanding of the interplay between the design of digital technologies and society, politics, economy, culture, and so on, which in turn expands their design repertoire and gives them new insights into their personal interactions with digital technologies, for example, social media or online multiplayer games. This includes seeing both sides of an issue, being open to new evidence that disconfirms one's beliefs.

While design is a process of bringing forth the not-yet-existing, critique is oriented backward and toward superior power, as a process of critical examination and reflection. Making and design practice provide a scaffolding structure for students to engage with the complexity of discourse, ideology, and power related to digital domain. I suggest that digital design praxis can function as a mode of critique that aims to develop a more comprehensive and nuanced understanding of sociotechnical issues. Digital design can scaffold students to engage in a praxis that combines critical thought and design to create an artifact that explores and embodies critical reflections.



4.1.1.3 Design process

Drawing on literature on design expertise, I claim that, while having a designerly mindset is key to navigating design processes successfully, one also needs to develop knowledge of the complexities of the design process and gain a repertoire of past design processes and artifacts. Knowledge, perspectives, exemplars, and experience from different design processes are important parts of designers' knowledge set. Knowledge of design processes as understood in this dissertation rest on academic concepts of design thinking voiced by design researchers such as Nelson and Stolterman (2012), Löwgren and Stolterman

(2004), and N. Cross (2011). A cornerstone in my conceptualization of the design process was a generic design process model (fig. 26) that my colleagues and I developed and refined through previous research interventions (Smith, Iversen, and Hjorth 2015). The process model was used for scaffolding and helping teachers navigate design processes. The model illustrates an iterative and explorative process spread along six phases: design brief, field studies, ideation, fabrication, argumentation, and reflection. The model conceives the design process as starting with a design brief containing a problem that in turn gives birth to the initial ideas concerning a possible preferable future. The process then goes on to doing field studies (this is also where taking a designerly stance towards inquiry becomes especially important).

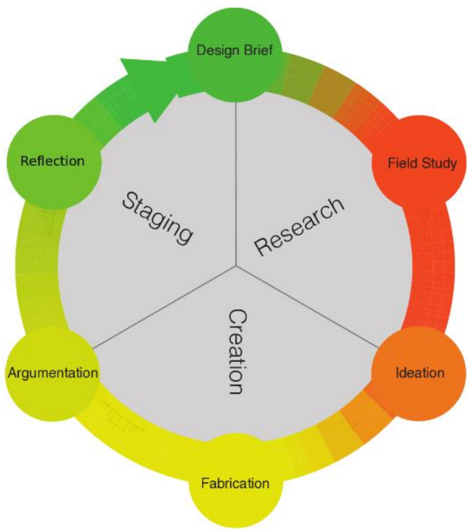


Figure 26—FabLab@school.dk design process model used to scaffold teacher training (see P2).

There are many models and methodologies that try to capture the design process, all of which are valuable and useful in their own right. However, from the perspective of design complexity taken in this dissertation, these models are never comprehensive. It would, therefore, be a mistake to think that knowledge of the design process is to internalize a "correct" model and blindly follow the model without reflecting upon its inherent limitations and advantages. Hence, it is important to gain an understanding of the design process as being the ultimate particulars. This includes an understanding of how designers constantly and repeatedly move between abstract design ideas and the concrete challenges to be resolved in the design situation. It is therefore important to know that, while the design process can be analytically separated into certain phases, in reality, it is much more complex, messy, context-dependent, and open to interpretation than a mere prescription of how to do successful design or do it "correctly." In this sense, it would be a misunderstanding to view a proposed design solution as being complete and satisfactory simply by having moved through each of the phases prescribed by a particular process model. That is not to say that models and methodologies for working through design processes are useless. Knowledge of such models can help the digital design student to plan, organize, navigate, reflect, and evaluate his work. Hence, while the process model proposed in fig. 26 illustrates a linear, step-by-step process, it is pivotal that teachers and students approach these models reflectively and critically, and appropriate aspects of the process model rather than adopting it completely without reflection (P2 suggests that the participating teachers generally had difficulty understanding its complexity and iterative nature). Developing a repertoire of knowledge and reflective understandings of the design process can increase confidence and competence to successfully navigate and iterate across different parts of the design process (see P2). Thus, developing knowledge of the design process as a recurrent leaping between the details and the whole, or the concrete and abstract, is essential. Another important insight is to understand that digital designers create problems and solutions in parallel, and thus coevolve. One design move might resolve one problem, which in turn gives birth to a new problem space, and so on.

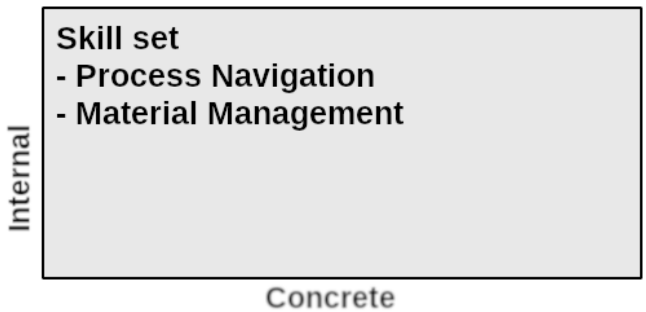
Ultimately, a well-developed repertoire on design processes, including knowledge of models and actual experiences with moving through multiple design processes, will lead the individual to a point of being able to design the design process itself.

4.1.1.4 Digital domain

Digital literacy is a requisite for digital design literacy, as it requires students to understand and work productively with digital technologies. Digital domain knowledge is closely related to material management and critical thinking/(retrospective) reflection. It relates to material management by pointing toward the need for more advanced usage of digital technologies in K–12 that goes beyond “office literacy.” This requires students to acquire knowledge of the digital domain in which they live and for which they are to design. These are basic ITC skills similar to those discussed by the new digital literacies research community; they include knowledge of the relationship between social, cultural, and economic phenomena enabled by digital technologies. Digital literacy entails having knowledge of the potentials and limitations of digital technologies, which supports the deployment of digital tools appropriately and effectively for the task at hand. Students need to be able to solve practical problems dynamically and flexibility as they arise and have a rich repertoire from which to draw. This entails using a range of methods, materials, and technologies both individually and as part of communities. Students and teachers should deploy digital technologies to work with their ideas rather than solely following a set of instructions. This includes both technical skills, “know-how,” and more abstract conceptual understandings of how the digital domain is designed and works. It is essential for developing digital design literacy (and digital literacy in general) to know that all things digital are numerical representations that can be described mathematically and be subjected to algorithmic manipulation, automation used to create digital artifacts, that no digital artifact is fixed but exists in many different versions, and the conceptual model of the Internet as a global network infrastructure.

4.1.2 Skill set and toolset

In the following sections, I will describe the competencies that reside at the bottom-left and bottom-right quadrants of the Digital Design Literacy Framework (fig. 24), which depicts the concrete skill sets and toolsets. First, I describe the skill set, followed by a description of the toolset.



4.1.2.1 Process navigation

Process navigation refers to having an understanding of design processes and the competence necessary to scaffold and navigate a complex design process through a reflective conversation with the design situation, that emerges through iterative dialogues with design materials. Design process navigation is internal as is it a competence bound to the designer and the richness of his repertoire. Design processes are complex and wicked and involve many dilemmas in which the digital designer must make judgments on how to proceed in leaping between details (concrete) and the whole (abstract). This also means that besides designing an artifact, students must learn to design the design process. Predefined methods or models for navigating the design process can be useful knowledge for reflection but should not be completely adopted. Instead, these methods may support students in developing a repertoire, an articulation language, and a sense of quality, thus preparing students for new design situations, but never as prescriptions for action. It is important not to confuse the design process with rigid process models of innovation and entrepreneurship. Through an iterative and explorative process, students must be able to generate reflections and knowledge to address real-life situations. It is about moving from a complex and open situation to a more focused and operational one—from vision to specification. In the process, students are to identify problems and solutions in parallel and have them coevolve in the process through the new insights that students generate in their exploration of the situation. This demands conceptual clarity from students and a nuanced understanding of the relevance and relationships between technology, people, and the wider societal context. This requires a well-defined language to talk about the process and knowledge of the characteristics of design processes, how they might unfold and be navigated.

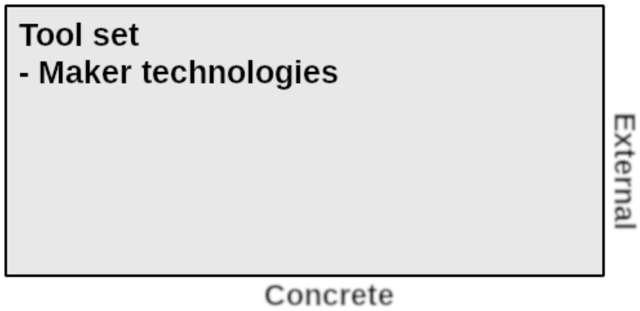
The goal of understanding how to navigate a design process is not the making of functional prototypes by the use of maker technologies but to have students engage in an explorative and open-ended process of reflective conversation with the design situation and its materials. Thus, the competence to navigate a design process is closely connected to managing materials as flexible tools for navigation rather than final products. To cope with complexity, it is important to externalize the abstract thinking that goes on throughout a design process, be it sketches, mock-ups, or prototypes.

4.1.2.2 Material management

A central component of working through a design process is for the digital designer to appreciate and manage different materials. Material management depends on the individual's craftsmanship and material appreciation, and because of its reliance on the designer's repertoire, I consider this to be an internal competence (also discussed in section 2.2.2). To exemplify, it is central for students to develop their own crafting skills while also learning about the qualities of maker technologies by, for example, having a guiding language as I provide in P3.

The digital designer navigates a reflective conversation with the design situation that emerges through iterative dialogues with design materials that result in the creation of artifacts such as prototypes. This means employing material making as a design partner in a flexible process rather than focusing solely on the creation of a final product, Hence, making artifacts is integral to design interpretation, judgment, and discovery. The making of artifacts positions the designer as an agent of investigation whose production creates a suggestive state and perpetuating alternatives, suggesting different ways of looking and attempting to clarify a situation. Designers must be able to communicate and articulate their design ideas through design language from which others might draw insight or build upon. Students should learn to use materials not only as that from which to create final products but to aid their process navigation and design judgments. Hence, materials must be valued as a design partner that speaks back to the designer's action, and thus scaffolds the design process. When teaching digital design in maker settings, this requires craftsmanship, a developed language of maker technology, and connoisseurship. The use of design materials to externalize abstract ideas and thinking has three basic purposes. The first is to iterate and form ideas, the second is to communicate with oneself as a reflective practitioner (Schön 1984), and the third is to communicate with other people.

One of the central design materials to manage in maker settings are maker technologies, which I will describe as a concrete and external set of tools that are essential for digital design literacy.



4.1.2.3 Maker technologies

Digital and craft materials are central to maker settings that enable the creation, design, and production of artifacts. In the wake of the maker, hacker, and DIY movements, a new genre of technologies has emerged; maker technologies (see section 2.1). Maker technologies are the backbone of all activities that happen in maker settings. From the perspective of digital design, maker technologies have made the production process more precise and faster in the creation of custom artifacts. Thus, it becomes essential for students to develop competencies in using these tools; what I have denoted as material management. Material management is essential to digital design literacy, and thus, being competent in using maker technologies becomes an important competence to develop. Maker technologies become the design partner students "speak with" as they navigate their design process. Managing materials requires a design language to articulate and communicate the qualities of the tools used. There are many ways to articulate material qualities of digital technologies. In my work, I have contributed a language of form and feedback qualities to support students in developing a material appreciation of maker technologies, specifically, their potentials and limitations concerning feedback and form properties. Hence, maker technologies are external and concrete artifacts, positioned as a part of the digital designer's toolset, which provide the means for students to externalize their design ideas.

On a practical level, it is important for students to able to state the "material problem" to be solved and the actions likely to be required. Students should be able to locate and obtain digital resources (e.g., open-source code or circuit schematics) and evaluate whether this information has relevance for solving their problem. In the hands-on process with maker technologies, students should have a developed language to communicate introspectively with their group and other relevant people. The language I provide in P3 can be used to think about the above, for example, to identify a technology that enables rapid prototyping such as LittleBits. Such a language can scaffold students in understanding the impact of maker technologies on their design process. Thus, students should also come to an understanding of maker technologies, and design materials in general, as being design partners with which they engage in a material dialogue. Knowing that the process of externalization functions as situational backtalk can help students reveal aspects of the design situation that would be unimaginable had they not been materialized. To produce a new artifact—abstract or concrete, social or physical—necessarily means that the material to be used for the design must be appropriately chosen.

When design processes are unfolded in maker settings, students come in contact with a wide range of maker technologies. While one can be taught the basics of an Arduino through a crash course, a designerly appreciation of maker technologies as a material cannot be developed if not managed and used as part of a design process. Finally, students should be able to reflect on the success and limits of using a particular maker technology, or what we might call "material critique." To reach the highest rate of success when using maker technologies, students need to understand and judge material qualities. This requires direct and intimate contact with the maker technologies involved and the craft materials with which they are integrated. It requires experience, a sense of limits and possibilities, a language of materials, and connoisseurship.

4.2 SUMMARY

The Digital Design Literacy Framework consists of the presented schema (figs. 24 and 25) and the accompanying text and is the main contribution of this dissertation. The framework provides the field of making in education with conceptual handles that researchers, policy makers, and teachers can leverage in their work. These contributions are needed as there does not yet exist any framework that conceptualizes digital design as a literacy and how it relates to specific competencies that insights from the included papers and discussion made throughout this dissertation have shown to be essential traits of being a digital designer understood from the notion of "design is for everyone."

With inspiration from Martin's digital literacy framework (2008) and Nelson and Stolterman's design learning schema (2012), I have described digital design from the perspectives of design education combined with the new literacy studies, thus anchoring my work within a larger educational discourse that exist outside the context of professional design education (see section 2.2.4). The topics that I have studied during the experiments reported in the included papers reflect how my work sheds light on the turn toward design in making in education from different domains of competence. Based on a general discussion of the notion of literacy, I have pursued the idea of how to conceptualize and combine digital literacy with design literacy as a holistic literacy. I have developed and discussed the concept of digital design literacy as a general perspective for understanding the design experiments and contributions made in the included papers and this dissertation. Motivated primarily by my work with K–12 students and teachers, I have developed the Digital Design Literacy Framework as a response to the turn toward design with digital materials in K–12 maker settings as an emerging field within IDC and CCI. The Digital Design Literacy Framework is not a guide that prescribes how digital design literacy should be done. It is a tool for the articulation and reflection on digital design as a new literacy that can benefit from the new constructivist possibilities provided by maker settings. While the included papers are completed works in themselves, not all contributions from my papers directly inform my conceptualization of digital design literacy. For example, I do not consider teachers' challenges in balancing different modes of teaching as being a digital design competence. Similarly, the framework to describe and analyze form properties and interaction couplings of action and function of maker technologies presented in P3 does not discuss competence. However, both are responses to students' and teachers' challenges in managing digital technologies and materials design processes. As I discussed in section 2.2.2, a competent designer should develop a rich repertoire of experience, a sense of limits and possibilities, a language of materials, and a feeling for materials. Hence, the framework I present in P3 aims to support reflection on decision-making—support by being prepared-for-action, not guided-in-action.

Throughout this dissertation, I have revisited the included papers to nuance the theoretical notions that I have used and developed. Moreover, the included papers present examples that nuance the theoretical concept of digital design literacy by showing how the Digital Design Literacy Framework is accountable to both practical exemplars and theoretical grounding. Thus, the Digital Design Literacy Framework can be considered a bridging concept, as it is based on findings that reside between theory and practice (Dalsgaard and Dindler 2014). I argue that the Digital Design Literacy Framework lives up to the principle of accountability to both theory and practice because (1) it is rooted in theory, specifically new literacy studies related to digital technology, design, and making in education; (2) it is illustrated by a range of exemplars found in the included papers; (3) it is developed as a framework through the means of schemas, which in turn resulted in 4) a series of considerations that have led to the conceptualization of digital design literacy to aid in understanding and teaching digital design in K–12. Viewing the Digital Design Literacy Framework as a bridging concept address the challenge of facilitating the exchange between theory and practice regarding digital design education in K–12. The theoretical foundation stems from research on design expertise, new digital literacy studies, and the contributions made in the included papers. The aspect of practice stems from the experiments and analysis of the empirical data found in the included papers. Functioning like a bridging concept, the Digital Design Literacy Framework is generative and intended to inform digital design education and teaching practices and provide an understanding of the aspects that give digital design literacy its particular qualities and to prompt educators and researchers to put an effort into considering these aspects when introducing digital design as a new subject in K–12. The Digital Design Literacy Framework aims to inform both theory and practice as a set of articulations and a range of exemplars from the included papers that demonstrate the scope and potential of their application. From this perspective, the Digital Design Literacy Framework consists of a series of articulations that shape different aspects that are important in expressing the qualities of digital design literacy.

Having presented the Digital Design Literacy Framework—I will now move on to discuss how the research outcome of my studies has contributed new and valuable knowledge to the turn toward design in the field of making in education.

5 DISCUSSION

My research has focused on the potential of maker settings for the development of digital design literacy for K–12 students, *putting design back in the hands of everyone*. CCI and IDC research communities, and hence making in education, have moved from working with children as design partners, testers, informants, so forth to a focus on empowering children to be actors of intentional change and creators of future society. Making and design enable students to build, shape, and adapt artifacts that incorporate digital technologies. Similarly, the field of making in education has seen a turn from STEM education to digital design education and have moved from informal contexts to formal educational contexts (see section 2.1.3). In the wake of this emerging interest in digital design through making in K–12 education, I have uncovered a shortage of knowledge of how to introduce, sustain, and articulate digital design literacy in K–12 education. In this chapter, I discuss how my research has contributed to the shift from STEM to digital design in formal K–12 education and has filled the knowledge deficits on digital design literacy in K–12 education as outlined in chapter 2. My overarching claim is that the research presented in this dissertation has provided an answer to how digital design can be introduced, sustained, and articulated as a new literacy through making in formal K–12 education (see chapter 1). I specifically discuss how the included papers in combination with the Digital Design Literacy Framework have contributed new knowledge to the field of making in education, provided new topics to debate and challenges to explore concerning the introduction, sustainment, and articulation of digital design literacy in K–12 education. First, I discuss how my research has contributed to the field of making in education, and the scope of these contributions. Second, I discuss the relevance of addressing digital design as a literacy taught by teachers and practiced by K–12 students in maker settings with maker technologies and materials. Third, I discuss what I consider the value of the contributions presented in this dissertation.

As outlined in chapter 2, contributions made to the field of making in education have been concerned mostly with STEM education. Although these contributions address constructionism, physical interaction toolkits, and K–12 maker settings, there still is a lack of conceptual and practical understanding of digital design education. This dissertation adds a new perspective to the making in education discourse by drawing on literature on new literacy studies, making in K–12 education, digital literacy, critical literacy, and design expertise to address the theoretical articulation and practical operationalization of digital design literacy. The articulations of digital design that I have established throughout this dissertation is an understanding of digital design as a new school subject and distinct literacy that shares the pedagogical ideas of constructionism with project-based learning to scaffold successfully student development and engagement. I fully acknowledge the importance of the work done on STEM education through making. However, what my work suggests is that introducing, articulating, and sustaining digital design as a new literacy raises awareness of the educational potentials offered by the turn toward digital design in making in K–12 education. Additionally, it positions my research contributions within the field of literacy studies, which I argue to be important if the ideals and interests of making in education are to be recognized in domains outside the field of making in education. Hence, the contributions presented in this dissertation should be considered an expansion of how to leverage the ideas of making in education to introduce new subjects that are relevant in a world that is increasingly relying on digital technologies.

The contributions presented in this dissertation concern both practical and theoretical questions. It can, therefore, be beneficial to understand these as exchanges between theory and practice in that I point toward competencies that are accountable to findings from my experiments and existing literature on design expertise. Hence, the contributions discussed will be composed of three constituents: a theoretical grounding, a series of articulations, and exemplars that embody aspects of the digital design literacy, reflecting the span between theory and practice. For example, in P1, I present the DeL tool, which is based on a combination of design inquiry theory and experimental findings (quan.1, see section 3.3.1). The DeL tool is not strictly based on a theory-precedes-experiment argument nor an experiment-precedes-theory approach (Redström 2017). I am unable to describe what emerged first as it was an iterative process of statistical analysis of quantitative data (the survey studies) and theoretical reflection (Schön's theory on stance towards inquiry). P3 is another example of this. In P3, I first observed students employing maker technologies as part of their design process without a priori knowledge about students' competencies in managing design materials, and only later theoretically reflected on what form properties and feedback meant for students' material management. Hence, the included papers present exemplars as a means to articulate aspects of digital design literacy as they are concrete instantiations of student practice rather than referring solely to competencies deemed valuable among expert designers and researchers. I must state that my articulations of digital design literacy are not intended to be exhaustive. This stems from the fact that it encompasses the interplay between many concepts that are, in themselves, complex and interrelated to such a degree that analytical categorization becomes difficult, sometimes even undesirable.

This chapter is structured so that the discussed contributions are aligned with the three research trajectories that run through this dissertation: (1) conceptual, (2) measurement and assessment, and (3) educator (see section 1.1). Each trajectory sheds light on the turn toward digital design from partially different but interrelated perspectives and illuminates the research presented in the included papers and this dissertation. The individual papers can have contributed knowledge across more than one trajectory. For example, P1 and P4 cut across the (1) conceptual trajectory and the (2) measurement and assessment trajectory, whereas the Digital Design Literacy Framework is primarily concerned with questions along the (1) conceptual trajectory.

The contributions made along the three trajectories are mapped to this dissertation's overarching research question. Contributions made along the (1) conceptual trajectory relate mostly to the articulation of digital design literacy but also touch upon the issues of introducing and sustaining digital design literacy. It would be difficult to introduce a new K–12 subject and sustain it if no language exists to communicate its potentials and challenges, what practice it involves, what students are supposed to develop and gain from digital design education, including competencies, teacher planning, and so forth. Contributions along the (2) measurement and assessment trajectory are concerned with introducing, sustaining, and articulating digital design literacy by identifying stance towards inquiry as a digital design competence that can be quantitatively measured and providing an assessment tool to make large-scale assessment of students' stance inquiry. Contributions along the (3) educator trajectory relate primarily to the introduction and sustainment of digital design as a K–12 subject. Teachers are quintessential for introducing digital design in maker settings, which demands a change in teachers' mindsets, competencies, and approaches to digital design and methods to facilitate and support co-development of new teaching practices (see P2).

In the following, I discuss how my research has bridged the knowledge gaps in the making in education literature when traced along this dissertation's three research trajectories. I start with the (1) conceptual trajectory and move on to discuss the research contributions made along the (2) measurement and assessment trajectory, followed by the (3) educator trajectory. I discuss the value of my contributions for the making in the education community and how it in turn has provided answers to this dissertation's overarching research question.

5.1 (1) Conceptual Trajectory

The contributions made along the conceptual trajectory address the challenge of how to articulate and operationalize digital design literacy, framed as competence usage, literacy, and empowerment from the perspectives of design, digital technology, and critical thinking. To expand the field of making in education toward digital design literacy, it is crucial to develop articulations that contribute a framing and identification of digital design competencies, which can make planning curriculum, making assessments, and teaching digital design more accessible to K–12 teachers. I clear up conceptual confusion that exists in the making in education literature regarding concepts that describe abilities to do something well, successfully, or efficiently as a result of experience and education. This conceptual clean-up also expands the discourse on the turn toward digital design in K–12 within a larger new literacy studies discourse with interest in using digital technology for producing rather than consuming. This clarification is illustrated in the Digital Design Literacy Framework (see chapter 4) which is a contribution in itself. It provides a common frame for understanding and relating the notions of "competencies," "skills," "literacy," "empowerment," "abilities," "mastery," and so on. This framing helps to make my and other researchers' position clear when employing these often confused concepts. I contribute a conceptual understanding of how design and digital literacies mutually benefit one another and can be synthesized and articulated holistically as digital design literacy. These efforts have provided the basis for the Digital Design Literacy Framework which sums up my research and contributes to answering this dissertation's overarching research question. The articulations are beneficial in creating new ways of thinking and talking about digital design in K–12 education, taking the first steps to articulate a language of digital design as a literacy, which is needed for introducing and sustaining digital design literacy to be developed among K–12 students. Before moving on, I will first make a few critiques of the Digital Design Literacy Framework.

A valid critique of the Digital Design Literacy Framework would be that it could have been developed by simply drawing on existing literature related to design expertise. In other words, one could make the case that the Digital Design Literacy Framework is simply a transfer of what design scholars deem to be important competencies. My response to this critique would be that, while I have drawn extensively on the work of design scholars, they do not provide any empirical insights with regard to K–12 education. However, by drawing on my empirical material, I have been able to bridge what the design literature argues to be important competencies with the real-world situations that students and teachers find themselves in. Thus, I have discussed and articulated competencies that are accountable to both theory and the practice I observed in schools. However, I also see this as one of the strengths of the Digital Design Literacy Framework since what I have articulated as essential digital design competencies are described in literature on professional design competence. Thus, it is probable that the findings will apply to a large number of students and classrooms, as I have been able to make the Digital Design Literacy Framework function as a bridging concept, which enables the facilitation of exchange between design theory and the practice performed by students in a formal K–12 classroom with the presence of teachers who experience many challenges when asked to teach digital design.

In the following sections, I present a more nuanced discussion of the contributions made along the conceptual trajectory from three perspectives—(1.1) design, (1.2) digital technology, and (1.3) critical—and how they have contributed to the design of the Digital Design Literacy Framework.

5.1.1 (1.1) Design Perspective

While maker settings provide an advantageous environment for digital design education, there is a lack of literature that discusses design as a new literacy integrated with digital literacy (see chapter 2). Nor are there any criteria for what makes someone a literate digital designer. Furthermore, there is a lack of knowledge of the facilitation and exchange between design theory and digital design practice in K–12 maker settings. To accommodate these shortcomings, I provide the Digital Design Literacy Framework, which articulates four important and challenging competencies that are particular to design and are theoretically grounded in design literature, rather than literature on digital and critical literacy: *stance towards designerly inquiry*, *process navigation, knowledge of the design process*, and *materials management* (see section 4.1). Insights along the conceptual trajectory have contributed to the design of the Digital Design Literacy Framework by bridging practical exemplars of these four competencies studied in the included papers while being accountable to the literature reviewed in chapter 2. What follows is a walkthrough of how the included papers in combination with the Digital Design Literacy Framework have contributed to my articulations on digital design literacy from a design perspective.

P1, P2, and P5 address the challenge of understanding and articulating the underlying competencies of digital design literacy. In P1, I develop and contribute the DeL tool. In developing the DeL tool, I came across Schön's theory of stance towards inquiry. Shown's ideas correspond well to the data outcome of R1. By employing the DeL tool and discussing the empirical outcome, I contribute new knowledge toward understanding stance towards inquiry as an important digital design competence and a prerequisite for successfully engaging with wicked problems. As discussed in section 2.2.2, naming and framing of a design situation to formulate a design problem to be resolved is central to being a competent designer. Good design has an adequate problem scoping and a focused or directed approach to gathering problem information and prioritizing criteria. Hence, teachers need to be aware of whether their students reach for technical rational solutions as opposed to getting to understand the wickedness of design problems. The DeL tool provides teachers with an assessment tool to gain this awareness through quantitative measurements (see the "measurement and assessment trajectory").

In P2 I attend to the notion of connoisseurship (see section 2.2.2), even though I do not explicitly use the concept in the paper—this is a discovery made by revisiting the paper. I address K–12 teachers' management of design materials and suggest that they are just starting to develop design connoisseurship. Based on teachers' reflections on a blog and during interviews as part of their digital design training, I identified three central challenges experienced by the teachers, two of which are of interest to the development of connoisseurship: (1) navigating a complex design process, (2) managing digital technologies and design materials. Teachers who participated in my study and training course presented in P2, worried about not being competent in handling design materials, including maker technologies. I found that they were equally challenged in managing and handling analog design materials and that they did not appreciate the different qualities and affordances of externalizations such as sketches, mock-ups, etc. In retrospect, these challenges indicate that teachers need to further develop their connoisseurship.

As illustrated in the Digital Design Literacy Framework, navigating a complex design process and managing materials are quite distinct from stance towards inquiry. Whereas stance towards inquiry resides internally with the individual and is a mindset, navigating a complex design process and managing materials are skill and knowledge sets that reside externally, which students can obtain by working through design processes that require students to externalize their design concepts. Such articulations are relevant and valuable to teachers and researchers with an interest in introducing digital design to K–12. The Digital Design Literacy Framework can support teachers with clear operational definitions with which to understand and articulate aspects of digital design literacy, which in turn can help them introduce and sustain digital design as a new subject in K–12 making in education. Having a framework like the Digital Design Literacy Framework is valuable when trying to visualize and articulate the relationship between different competencies and can be thought of when understood from a new literacy studies perspective. While the Digital Design Literacy Framework is valuable and necessary for introducing, sustaining, and articulating digital design education, it is not adequate for a full understanding of what goes into developing digital design literacy.

Stance towards designerly inquiry, design process navigation, and material management reside primarily internally with the individual but also require a repertoire of abstracted knowledge and exemplars on how the design process is conceived by professional designers and researchers. P2 provides an example of such an external knowledge set, the *FabLab@School.dk Design Process Model* to help teachers structure and navigate design processes. In the training course, I observed substantial benefits for teachers experimenting with the model in their practice. They gradually increased their confidence in using the process model, which implied an increased competence to navigate and iterate across different parts of the design process.

To manage materials, which in turn help scaffold process navigation, students need knowledge of the digital domain and skill using digital tools, specifically maker technologies. With this in mind, I will now turn to the digital technology perspective on digital design literacy.

5.1.2 (1.2) DIGITAL TECHNOLOGY PERSPECTIVE

From the digital technology perspective, I have investigated students' working through an entire design process involving wicked problems using maker technologies. That is, the contributions presented here are based on investigations of the interactions between students and maker technologies. The evolution of digital interfaces and human-computer interaction is under rapid and constant development. This accentuates the need for continuous reflection on how new materials, interaction styles, and digital technologies, in general, are used in an educational setting. In P3, I contribute such reflection on the material and interactive qualities of maker technologies. The research presented in P3 provides examples of students' usage of maker technologies in design processes and uses these exemplars as the empirical basis for the development of a descriptive framework for articulating qualities of maker technologies on an abstracted level. From a digital perspective, my research contributes a needed language for articulating design qualities of four maker technologies, specifically their *form properties* and the *coupling between user action and functionality feedback*. The articulations presented in P3 focus on the interactions between maker technologies and its users from a materiality perspective as opposed to a language of technical concepts such as input, output, transduce, and analog signal. When related to the Digital Design Literacy Framework, the language presented in P3 should be considered a knowledge set on the digital domain with a focus particularly on maker technologies as a set of tools that students should become competent in using in their design processes.

To manage design materials, teachers and students need to develop a language to communicate material qualities internally and externally (Löwgren and Stolterman 2004). In P3, I argue that the field of making in education needs to expand its design language to fully describe the qualities of maker technologies when used as part of students' design processes. In my studies, maker activities support students in bringing their design abstract concepts into externalizations such as prototypes. This involves hybrid crafting and selection of materials and employing appropriate tools for the job. To fill this in the knowledge deficit, I contribute an expansion of design language as a framework to help researchers, teachers, and students articulate themselves on material qualities, scaffold development of connoisseurship, and material management. Designers can apply the articulations to improve existing designs or prepare them for future designs. Researchers can use the expanded design language to analyze maker technologies in the context of school maker settings. Teachers can make better decisions on how and when to use different maker technologies when students work through design processes. Finally, the language might be obtained by students who can use the language to describe and analyze qualities of maker technologies and their impact on their design process and products. This in turn also improves students' competence to navigate a complex design process (see section 2.2.2), for example, by making conscious considerations on where in the design process a particular technology might work best, how, and for what purposes. It can, for example, be beneficial to consider the size (see P3) of maker technologies when prototyping design ideas. Some maker technologies might be more suited for early and rapid prototyping. In later phases of the process, students might need to integrate their early prototype with other materials such as wooden cases, fragile paper, or cardboard constructions. In such cases, size matters, so it has a direct influence on the form and material properties of the final design.

Besides digital domain knowledge of maker technologies, digital domain also refers to a broader understanding of the relationship between digital technological developments and society at large, for example, what kinds of values, world views, and interests other designs have embedded in their products and understanding the consequences of the choices made by the original designers. In the next section, I unfold the idea of digital domain knowledge from a critical perspective.

5.1.3 (1.3) Critical Perspective

As discussed in section 2.2.3 and chapter 4, critical digital literacy is an important aspect of digital design literacy, especially when related to student empowerment. In response to the discussion on critical digital literacy in section 2.2.3, I contribute knowledge of how to articulate the concept for K–12, how it can be beneficial to students' critical understanding of the digital domain, specifically the World Wide Web, how it can be practiced in K–12 classrooms and has informed the Digital Design Literacy Framework by highlighting the importance of a critical and (retrospective) reflective mindset. It is important for designers to develop a rich design repertoire and competence to critique and retrospectively reflect on digital artifacts. Findings in P5 and R1 suggest that Danish K–12 emphasizes a limited instrumental and instructional use of technology, whereas teaching related to critical reflections on epochal key problems involving digital technology are less apparent. In P5, I focus on distancing students to reflect on problems with online data tracking to give students new insights into the design of the World Wide Web. Providing students with opportunities for adding a critical dimension to their repertoire is essential when related to digital design literacy, as the critical dimension is often backgrounded in K–12 education. In the words of Bawden, my research suggests that students are taught to master keystrokes rather than mastering ideas (2008, chap. 1).

In P5, I explore the epochal problem of online data tracking, an issue that affects a large portion of children's digital interactions—is it a problem that is generally desirable to resolve. However, if students are to resolve problems related to online data tracking, they need to develop a repertoire related to this domain. I argue that critical and retrospective reflection is key if students are to cultivate their repertoire toward contemporary issues surrounding online data tracking and engage critically with similar sociotechnical issues. I contribute examples of students working in collaborative critique sessions, and how this expanded their repertoire with new critical and conceptual understandings of how online data tracking is central to the design of contemporary online services and that the tracking is intentionally hidden from the user. This is an example of how interplay between the details of a technology ("the visible artifact") and its holistic impact on societal developments ("the less visible whole") contribute a critical understanding of digital designs. From a repertoire perspective, my work in P5 can be viewed as an invitation for students to explore and critique the peculiar issues with online data tracking to develop a repertoire to draw on later. Not by drawing a rule, as this would ignore the uniqueness of the situation, but rather, to the introduce students to the unfamiliar and unique as something both similar to and different from their familiar habits. Findings from P5 suggest: Students generally lack knowledge and understandings of online data tracking, how it works, its extent, what data is tracked, and how is it used; students lack a vocabulary to articulate themselves critically; students lack a proper conceptual model of how the Internet is designed; students have not previously engaged in critiquing digital technology such as online data tracking; students were surprised and scared by the number of websites that track their everyday Internet interaction and felt powerless against tracking practices; students expressed concerns but also benefits of online data tracking.

P5 contributes several exemplary cases that highlight these findings, as they characterize the varied engagement of students, starting with the students' lack of knowledge and a vocabulary for addressing issues related to online data tracking with a critical gaze. However, my studies in P5 also reveal that students can develop a richer understanding of the issue.

Pangrazio proposes the use of visualization tools to scaffold critical thinking (2016) but does not provide exemplary cases of how to do this in K–12 classrooms. Furthermore, there is a need to develop a nuanced understanding of what the critical dimensions of digital design literacy entail (see section 2.2.3). The contributions presented in P5 follow up on the work done by Gainer (2012), Frechette (2014), Hinrichsen and Coombs (2014), and Pangrazio (2016) by contributing knowledge of how to articulate critical digital literacy as essential to digital design literacy. I expand and nuance the concept of critical thinking in relation to digital design literacy with new conceptual handles, nest it as essential for digital design literacy and provide exemplary cases of the successful usage of the Lightbeam Firefox extension to scaffold critical thinking (see P5). I specifically contribute a strategy for using data visualization software to contextualize and defamiliarize students with digital networks, tools, and practices to support them in critiquing commonly held assumptions, ideas, and views when interacting on the World Wide Web. P5 provides concrete exemplars of how students and educators can use visualization tools to approach and facilitate activities that focus on developing critical digital literacy. This contribution is valuable to teachers, as it provides them with exemplars of how to engage students in making critical inquiries and reflections on the relationship between digital artifact and social conditions. In continuation of

Pangrazio's suggestion of using visualization tools to scaffold critical thinking, I suggest that teachers and researchers explore using digital artifacts that do the work of agonism (DiSalvo 2012), adversarial designed artifacts. I argue that Lightbeam works not only as a visualization tool but also more broadly as an adversarial design. Through agonistic tactics, Lightbeam scaffolds students in revealing the relations between a heterogeneous array of entities through interaction with visual representations, giving students the tools to prompt recognition of political issues and enable critical thinking to reveal hegemony.[39] Such interactions scaffold the students' development of a digital design repertoire with a critical consciousness that is also transferable to students' everyday interactions with digital technology. I further argue that adversarial designed tools can, through agonistic tactics, scaffold students in critical and retrospective reflection, or at least, help them get exposed to critical thinking regarding the digital domain. Insights from P5, R1, R2 and the discussions presented in this section, have contributed to the Digital Design Literacy Framework by highlighting the critical dimension of digital design literacy. Using Lightbeam to engage students in critical reflections on online data tracking, proved to be successful as an adversarial design and helped expose the value dimensions in technology.

In continuation of my discussion on critical digital literacy, I also discuss making as emancipatory and empowering (see chapter 2). Making in education research that focuses on STEM, usually encourages functional empowerment, whereas the critical and democratic empowerment is largely neglected. My work touches upon the empowering potential of working critically and reflectively with digital technology that rests on personal experiences and habits, thus emphasizing elements of critical and democratic empowerment, as opposed to management and functional empowerment (Kinnula et al. 2017). While my experiment in P5 sought to empower students in the sense of making critical reflections and scrutinizing the status quo, they did not get to a stage to challenge the oppressors (the data trackers) or the existing conditions of their interactions on the World Wide Web. Finally, the Digital Design Literacy Framework provides an argument for how to frame student empowerment within a literacy framework and how digital design can scaffold various types of empowerment.

Based on my revisit of P5 and new theoretical considerations, I want to point toward the need for students not only to create digital objects but also to reflect critically and retrospectively upon how other digital objects are designed. Critical thinking is oriented backward, unlike design and making, which shape the future through the creation of objects in a forward-moving manner.[40] Fig. 22 illustrates the idea that

[39] Hegemony is defined as the way in which one group develops dominance over another group by obtaining implicit consent from the subordinate group through social manipulation (DiSalvo 2012, 34–35).
[40] This is, of course, a simplification, as the two often are used in tandem.

students should be the protagonists in the design process as they engage with wicked problems. It suggests that through students' engagement in design, they develop competencies in designing and reflecting on digital technology and that these competencies can lead to literacy and even empower them to make more informed judgments about digital technology and its societal relationship. Finally, I consider my combination of design and digital literacy and the introduction of a critical digital dimension to be a contribution in itself.

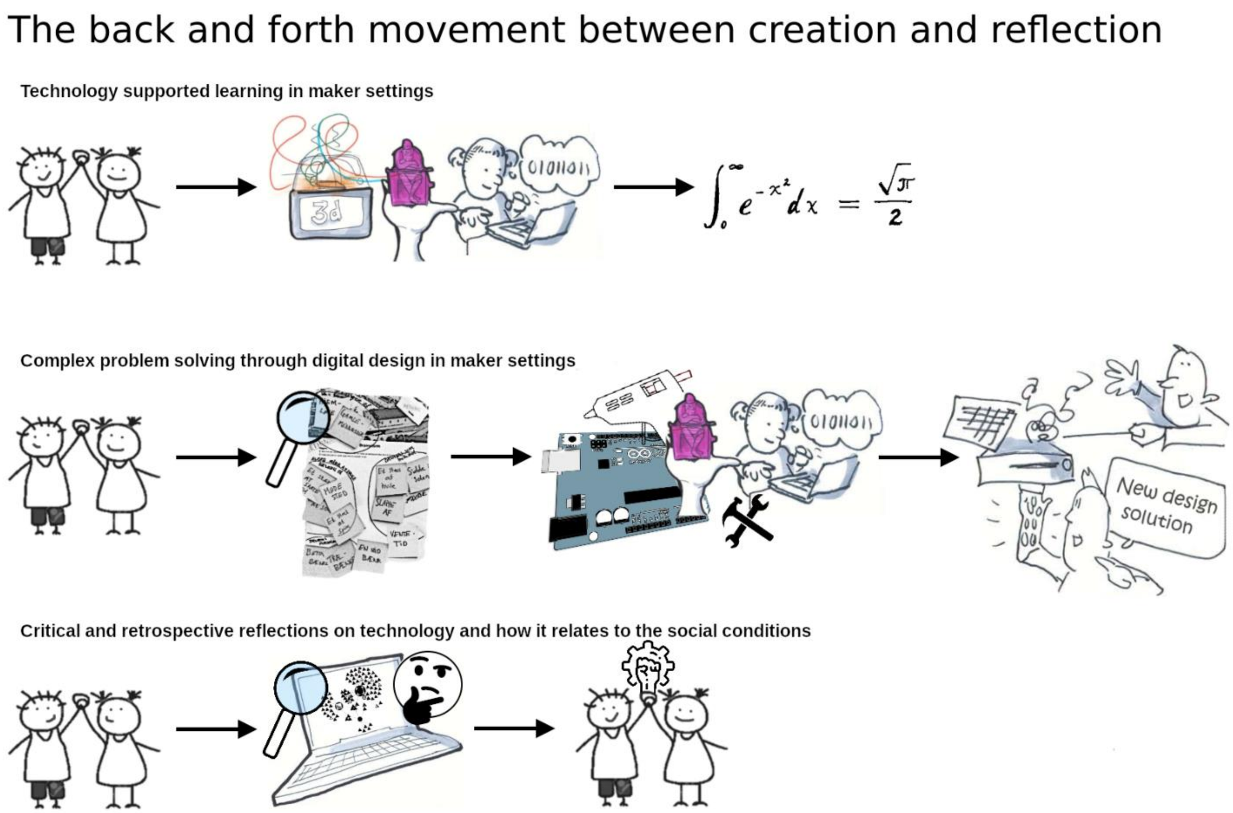


Figure 27—The back and forth movement between reflection and creation. The critical and retrospective reflective involves a back and forth movement between pointing out material particulars and relating them to interpreted wholes.

5.2 (2) Measurement and Assessment Trajectory

Throughout my research, I have been interested in the potential for sustainability of the introduction of digital design and the implementation of maker settings in K–12 education. With this aim, I have investigated the development of stance toward inquiry among students in the large-scale FabLab@school.dk project. The field of making in education has seen endeavors to quantitatively assess the development of specific competencies among students (Martinez and Stager 2013) in individual initiatives and ranges of individual initiatives (Blikstein et al. 2017). However, none of these studies address large-scale projects such as FabLab@school.dk, and there is a lack of research into the assessment of such implementations. Noteworthy efforts at assessing design competencies have been focused on small-scale assessments (Goldman et al. 2012). Accordingly, the turn toward digital design lacked attempts to assess digital design literacy on a larger scale in formal K–12 education. Hence, there is an absence of measurement tools to make a quantitative assessments of digital design literacy (see section 2.2). This is problematic when trying to introduce and sustain digital design as a new K–12 subject. This is because, in the age of measurement, what is valued in educational systems is in large part determined by what is currently measurable (Biesta 2010). What is valued as literacy is influenced by the degree to which comparative quantitative assessments are possible. To make a new educational subject relevant, it is, therefore, crucial to be able to evaluate student development and assess their competencies. While one can critique this modus operandi of education, it is nonetheless the reality in which education systems currently function in the context of Danish K–12. Being able to quantitively assess students is valuable to teachers as it has become a necessary part of their job. My endeavor at this can be found in papers P3, P4, R1, and R2. In these papers, I argue for the relevance of introducing digital design literacy in K–12 education while also providing quantitative data to support this claim. R1 and R2 are, in themselves, early moves toward introducing digital design education in several Danish K–12 schools. In R1, I present a snapshot of 1,156 Danish K–12 students aged 11-15, use, experiences, and knowledge of digital technologies, both in and outside of school, about design and creativity, and about their perspectives on hacking and privacy issues. I found that students are big consumers of digital media and technology, few students have knowledge of maker technologies, most students do not act on their creative ideas, and finally, students lack knowledge of what is meant by a design process. Findings from the two reports suggest that there is a strong focus on instrumental usage of digital technologies, whereas the focus on design and critical thinking on technological developments and how it relates to social conditions is backgrounded if even taught. Based on these findings, I developed the DeL tool (see P1). The DeL tool enables quantitative assessment of students' stance toward inquiry when asked to describe what steps they would take when confronted with a wicked problem. The DeL tool allows schools to measure students' stance toward inquiry quantitively and thus work within the current mode of operation in the age of measurement. Hence, my contributions made along the measurement and assessment trajectory provide sound arguments for introducing digital design literacy in K–12 and show that is it possible to measure different competencies of digital design literacy, for example, stance toward inquiry. Furthermore, it can be beneficial for teachers trying to articulate the sort of mindset their students should be taking when confronted with wicked problems. To this end, The Digital Design Literacy Framework provides teachers with a relational schema with clear definitions of how to understand stance toward inquiry as competence within a literacy framework and relate this understanding to a larger educational discourse.

Findings from using the DeL tool show that Danish K–12 students who had not yet received design education primarily took a rational stance towards inquiring into wicked problems (see section 2.2.2). These students assumed that they had already "gathered" enough information about the problem without going into the field to investigate. In P4, I applied the DeL tool to assess whether students who had received design training would have further developed a designerly stance towards inquiry. My results suggest that students are just starting on the path toward becoming more design literate but that they primarily had developed routine expertise during their first experiences with doing digital design in maker settings. It highlights the need for teachers to focus on developing students' stance towards inquiry but also that it is a challenging task for teachers. This calls for new teaching approaches and teacher training, which I discuss in P2.

The primary contribution along the measurement and assessment trajectory is the DeL tool, as presented in P1, to assess a part of students' mindset, their stance towards inquiry. My application of the DeL tool generated insight that a designerly stance towards inquiry when dealing with wicked problems is an important digital design competence and that students generally lack this competence. Instead, they approach wicked problems from a stance of technical rationality. The theoretical discussions on stance towards inquiry in P1 and the findings from using the DeL tool to assess the type of stance towards inquiry that students take have in turn informed the design of the Digital Design Literacy Framework by highlighting both one's stance towards inquiry as an essential abstract and internal digital design competence and the importance of developing a designerly mindset.

5.3 (3) EDUCATOR TRAJECTORY

As outlined in section 2.2.2, theory on design competence does not inquire into a formal K–12 nor does it consider the challenges of this context. There only exists a small volume of studies of K–12 teachers teaching practices in maker settings. There have been attempts to create frameworks and guidelines for teachers to implement, and successfully utilize maker settings for educational purposes such as STEM, but not for digital design literacy (Bekker et al. 2015; Kylie Peppler, Halverson, and Kafai 2016a; Blikstein, Martinez, and Pang 2016). At the time of this writing, there were no empirical studies of teachers trying to introduce digital design through making in K–12 education. In this context, teachers have little time for preparation and development of the needed competencies with maker technologies and digital design. Furthermore, the field of making in education lacks an understanding of the challenges that teachers encounter when teaching digital design to students. Such research is needed as teachers as an essential factor when trying to introduce and sustain digital design as a new subject in K–12. Hence, knowledge of teachers' role in digital design education is important.

In P2, I show that the introduction of digital design in K–12 requires new pedagogical practices to enrich traditional methods of teaching, and hence, teachers training is needed. However, there is an absence of practical examples, theory, methods of how teachers can translate digital design education into K–12. To generate insights into these issues, I carried out the Video Design Game workshop (see section 3.3), which successfully scaffolded the participating teachers to observe, reflect, and generalize based on video snippets from their practice. I consider the workshop to be a contribution in itself, as it would be difficult to sustain digital design literacy in K–12 if teachers are not involved and do not feel competent. The workshop enabled teachers to reflect critically on their teaching practices and come up with new methods and techniques.

From my work along the educator trajectory, I report on the challenges that teachers face when teaching. These challenges are (1) understanding and navigating a complex design process, (2) managing digital technologies and design materials, and (3) balancing different modes of teaching involved in design and making in education (see P2). I point to impediments for such teaching and teachers' limited possibilities for meeting demands presented by teaching digital design literacy. P2 also lays out an argument as to why (1) and (2) above are essential competencies to digital design literacy (thus, the two also reside along the conceptual trajectory). I refer to challenges (1) and (2) as being important digital design competencies to develop, whereas (3) relates to the teachers' pedagogical practices when teaching digital design. As noted in section 1.1, the three research trajectories are intertwined and have mutually influenced each in my conception of digital design literacy. For example, the challenge of navigating a complex design process is connected to the student's stance of inquiry, as it points toward the early phases of the design process in which students are expected to name and frame problems as suggested by, for example, Schön (1984).

As reported in R1 and R2, the schools involved in my research had almost no experience in developing and facilitating learning processes in relation to students working with design processes combined with maker technologies. Both P2 and P3 provide concrete examples of how digital design may be taught and developed in the domain of K–12, bridged with reflections on these examples from a theoretical standpoint. P2 show examples of how teachers developed new insights into modes of teaching digital design. Teachers display discomfort with and underestimation of the roles that uncertainty and wickedness play in design processes. On a theoretical level, P2 demonstrates how a combination of design theory, in-school practice, and peer-to-peer learning created a framework toward educating design educators. The study shows how the framework can facilitate and support the co-development of new teaching practices. My research suggests that a focus on design thinking and complex problem-solving can strengthen teachers' abilities to structure and manage design processes through making in K–12 while keeping students motivated and shifting education's focus from predictable learning outcomes to reflective and transformative educational practices. The framework also allowed me to investigate K–12 teachers' development of core competencies to transfer descriptions of expert design competencies to fit within the context of K–12 education.

The challenge of managing materials also relates to the contribution put forth in P3 as I provide a needed framework to articulate particular qualities of maker technology. Such a framework can help teachers and students to expand their repertoire. An articulation language of maker technologies can help individuals judge which materials and tools are best suited for the situation, thus developing what we might call their repertoire of skills and tools to manage and use design materials successfully (see section 4.1 for argument on the relationship between skill sets and toolsets). The descriptive framework in P3 has also been employed in the teacher training (see P2), to prepare teachers for complex design situations in which material judgments require attention to materials' richness and complexity. If the designer is not prepared to handle the complexity of situation, methods and techniques cannot with any guarantee guide anyone through such situations. Gaining a repertoire of using a range of materials is essential if one is to be successful in working with digital and craft materials. However, developing a repertoire takes time. Thus, I argue in P2 that we need to shift teachers' focus from pre-defined learning goals (e.g., using predetermined materials) and fixed technologies (as closed entities) to an understanding of the different properties and qualities of using diverse materials and technologies as partners in design processes. My research suggests that understanding technologies and materials as mutable and generative tools in a complex design process allows teachers to have more flexibility concerning modes of teaching.

However, there are still multiple challenges involved with integrating digital design as a subject in K–12. Teachers are not design experts, cannot engage in a master-apprentice relation, and generally lack digital design literacy themselves; they have never worked through a complete design process which is expected of their students. Teachers need new practices to integrate design and digital technologies in school maker settings and carefully balance explorative and iterative approaches to real-world problem-solving. In response to these challenges, P2 contributes both exemplars and knowledge of what and how to develop teaching practices and resources for teachers to teach digital design through making. The main contribution is along the educator trajectory and involves a discussion of how to create a framework for educating reflective design educators who can support students in developing digital design competencies. The framework is valuable for the making in an education community as it presented techniques for preparing teachers to overcome the challenges of (1) navigating a complex design process, (2) managing digital technologies and other design materials, and (3) balancing different modes of teaching involved in design and making with digital technologies in K–12 education. By combining design literature with experiences from the teachers' in-school-practice, and peer-to-peer learning, P2 demonstrates how a framework that can be used to educate reflective educators. Some of the teachers who participated in the course started to develop an appreciation of the complexity and wicked design processes. These teachers asked their students to reflect on the relevant qualities of their design in relation to the wicked problem, rather than judging students' design solutions as either "right" vs. "wrong" during the explorative stages of the design process. In sum, I have contributed to the field of making in education by offering a description of the opportunities, challenges, and a framework for the professional development of teachers' competence to teach digital design in K–12 maker settings. P2 show opportunities for teachers to develop new mindsets, expanding their repertoire of working with design materials, and new educational practices.

6 CONCLUSION

This dissertation is a response to the question of how to bring design as a new liberal art of technological culture into K–12 education through the emerging educational possibilities enabled by maker activities, maker settings, and maker technologies.

This dissertation is a summary of my four years of academic research and education. The results of my research are presented in the five included papers, two reports, and this dissertation overview. My work has been driven by an overarching research interest in understanding digital design as a new literacy in formal K–12 education as part of the uptake of maker settings, technologies, and activities in K–12 schools. The contributions presented in this dissertation fall within the field of making in education—an emerging subfield of IDC and CCI. This dissertation addresses the lack of a language for articulating what constitutes digital design literacy and how to introduce and sustain this in K–12 through making. My work has been carried out within the context of the Danish folkeskole, yet I find it reasonable to propose that the notion of digital design literacy is applicable and relevant for an international audience. The included papers stand as contributions in their own right, each making specific arguments relating to established research and discourses within the making in education community. Throughout this dissertation, I have summarized, connected, and further developed the arguments made in the included papers. Moreover, I have revisited the research reported in the included papers to articulate digital design as a new literacy that collectively frames my contributions.

The combined work of the included papers, the discussions in this dissertation, and the Digital Design Literacy Framework has contributed to answering the research question posed in this dissertation: *How can digital design be introduced, sustained, and articulated as a new literacy through making in formal K–12 education.* The answers to this question are unfolded along three research trajectories that all shed light on the digital design in making in education from different but interrelated perspectives. I want to note that, because of the drifting in my project, practical limitations, and constraints, my contributions do not address or answer my overarching question exhaustively. This was not the intention, as the question is posed to generate knowledge regarding the introduction, sustainment, and articulation of digital design literacy in making in education and inspire new inquiries rather than achieve full closure. I wish to point out that I am addressing a very complex topic, and I identify many unclear issues and challenges still ahead relating to digital design literacy; such is the nature of constructive design research where one has to design a not-yet-existing research context.

In chapter 3, I presented how I have pursued my research questions in the context of maker settings that aim to scaffold educational activities related to digital design literacy to prepare students to identify, engage with, and resolve future wicked problems that emerge in the world. My work has been driven by a constructive design research set up around questions, programs, and experiments combined with a mixed-methods approach, employing both quantitative and qualitative research methods and design for creating the context for the collection of empirical material. I have presented and discussed the concrete experiments undertaken in my research project with detailed descriptions of how the various experiments are connected and have informed the contributions made in this dissertation. In these experiments, I have engaged in research, design, and teaching activities that have framed my academic inquiries. Furthermore, my constructive design research approach is suggestive, as it aims at producing techniques, tools, articulations, and concepts for reflection that further educational practice and research that seek to combine design, digital, and critical literacies for K–12. For these reasons, my research process has prompted a variety of avenues for future research.

This dissertation's research contributions can be traced along three interconnected trajectories, each containing both overarching theoretical aspects as well as concrete educational activities and concepts for reflection and action: (1) *conceptual trajectory*, (2) *measurement and assessment trajectory,* and (3) *educator trajectory*. Each of the three trajectories pertain to one or more aspects of my research question but are also intertwined and have mutually influenced one another throughout my project. This has led me to combine the knowledge outcome from all three trajectories by shedding light on digital design through making in education from different but interrelated perspectives. Hence, my contributions extend the turn toward digital within making in education by addressing digital design as a challenging and unfamiliar but also an important literacy, if students are to understand, shape, and design the future of technological developments. This includes addressing new educational challenges for teachers, integrating new maker technologies, working within the current mode of operation in the age of measurement, and an expanded language for articulating aspects of what constitutes digital design literacy. Thus, this dissertation concludes by presenting the Digital Design Literacy Framework which answers the question of how to articulate digital design literacy in K–12 education when brought into a new literacy studies context. The framework contributes a conceptual understanding of digital design as a new literacy, operational definitions, and a differentiation between competence, literacy, and empowerment and relates these to critical, digital, and design literacy. The framework is situated in a larger genealogy from traditional literacy toward digital design literacy and presents arguments for legitimizing digital design as a new literacy in K–12. I claim that digital design consists of numerous competencies, none of which have previously been explored in the making in education literature, and that the usage of these competencies' transfers to a literacy when students can successfully employ their competencies in an open-ended design project. It is, therefore, crucial for students to engage with larger design projects if they are to become digital design literate. Thus, it is not enough for students to be competent in using, for example, makers technologies; students must use their competencies in solving or identifying wicked problems in order to become digital design literate.

Along the *conceptual trajectory*, I contribute the Digital Design Literacy Framework to articulate digital design literacy, in the respect that I aim not only at using the concept to illuminate my work but also at developing the concept itself through the arguments and discussions made in this dissertation. I have outlined how a conceptual understanding of design, digital, and critical literacies can be interrelated, mutually benefit one another, and can be synthesized and articulated holistically as digital design. The outcome of my discussions on design, digital, and critical literacy and its constituting competencies and the findings from the included papers has led to the articulation of seven important competencies and challenging aspects of digital design literacy. These competencies are articulated as *mindset*, *knowledge set*, *skill set*, and *toolset*. The Digital Design Literacy Framework highlights designerly stance towards inquiry, and critical thinking and (retrospective) reflection as essential mindsets, process navigation and material management as essential skill sets, design process and digital domain as essential knowledge sets, and finally, maker technologies as an essential toolset. Based on an exchange between design theory and practical exemplars of students and teachers doing design, my studies show how these seven competencies are central to digital design literacy, that they are challenging for students and teachers alike, and that these challenges create impediments for teaching digital design literacy. I have summarized this in the Digital Design Literacy Framework with which I answer my research question from a conceptual perspective. The Digital Design Literacy Framework can help introduce and sustaining digital design literacy in K–12 by providing a language for articulating aspects of digital design literacy and frame it within a larger new literacy studies discourse, thus minimizing conceptual confusion regarding the relationship between literacy, competencies, skills, abilities, and so on. Since maker technologies are an essential component of making in education and digital design education, I have also contributed a language for articulating and analyzing the design qualities of maker technologies, specifically their form properties and the coupling between user action and functionality feedback. Researchers can use the expanded design language to analyze qualities of maker technologies. It can also support teachers and students in making better judgments and arguments on how and when to use different maker technologies in students' design processes which, ideally, should transfer to students' material repertoire. A common language can help to introduce and sustain the use of maker technologies as part of students' design processes. Furthermore, it can improve student's ability to communicate material qualities effectively with themselves and with others.

Along the *measurement and assessment* trajectory, I have contributed knowledge on two levels. On the first level, I have contributed an initial understanding of the state-of-the-actual in regard to Danish K–12 students' usage, experiences, and understandings of digital technologies, design thinking, and their thoughts on critical online privacy issues. My findings show that it is indeed possible to further develop these competencies through making in education. As reported in R1 and R2, students' in schools in which they worked through a complete design process structured around the FabLab@school.dk design process model had, on average, become better at imagining intentional change with technology, working proactively with technology, understanding how new technologies are emerging in the world, and understanding how technology can positively and negatively affect peoples' lives. Such knowledge is valuable when trying to introduce a new subject in K–12. Without such knowledge, it becomes difficult to know the level of digital, design, and critical literacy that students possess. Hence, it becomes difficult to plan and design curriculum that suits students' current competencies. On the second level, I have contributed an assessment tool to gauge students' stances toward inquiry, the Design Literacy (DeL) assessment tool. The DeL tool provides valuable insights into how to assess design literacy among K–12 students (see P1). In applying this tool, I show that students who have received digital design education can internalize basic knowledge about design but the competence to take a designerly stance towards inquiry was not present with the students. Instead, students generally develop routine expertise in their first encounters with design processes, whereas adaptive competencies demand more training of both students and teachers. The contributions made along the measurement and assessment trajectory help answer the question of how to introduce and sustain digital design literacy in K–12. The contributions made in P1 and P4 are, in themselves, examples of how the DeL tool can be used to introduce and sustain digital design literacy by providing teachers with ways to follow students' progression in developing a designerly stance towards inquiry. When introducing a new subject in the age of measurement, policy makers expect to have methods for assessing students' competencies in order to assess the degree to which students have developed their competencies, which in turn enables sustainment of digital design as a new K–12 subject in the age of measurement. This is especially true for the Danish educational system, where the educational policy and the legitimization of new subjects require evaluation tests of student development. The DeL tool is a first step toward providing quantitative assessment of what we value—digital design literacy—instead of valuing what we can currently measure.

Along the *educator* trajectory, I provide knowledge of how to facilitate and support co-development of new teaching practices based on three challenges that teachers face when teaching digital design literacy to K–12 students: (1) understanding and navigating a complex design process, (2) managing digital technologies and design materials, and (3) balancing different modes of teaching involved in design and making in education (see P2). I consider the first and second of these challenges to be important competencies of digital design literacy and have thus informed the Digital Design Literacy Framework, whereas the third challenge relates to teacher pedagogy and in-school teaching practices. In order to answer the question of how to sustain digital design literacy in K–12, I provide a scaffolding framework for educating reflective design educators who can support students in developing digital design literacy in formal K–12 maker settings. The contributions made in P5 help to introduce and sustain digital design literacy, particularly the critical and reflective aspects. I provide exemplary suggestions on how teachers might engage students in exploring and critically reflecting on how their personal data being tracked online by introducing teaching with adversarial designed software and visualization tools. I show that using the Lightbeam extension for Mozilla Firefox, can scaffold students in uncovering what would otherwise be hidden elements of the World Wide Web and initiate critical reflection and groups' discussions of the contemporary issues regarding online data tracking.

Finally, I consider the successful development and implementation of the FabLab@school.dk project to be a contribution in itself from the perspective of design practice and exploration of what might be possible. On a concrete level, the included reports and the DeL tool present a quantitative measure of students' state-of-the-actual in regard to digital technology and design. I count the two reports as part of my research in partnership with collaborators from my research community, municipalities, and schools. The two reports and the outcome of using the DeL tool show that the efforts made throughout my PhD project have had an effect in changing education, as students who had received design training in maker settings improved their understandings of maker technologies, gained important experience with a range of maker technologies, and found the work with maker technologies to be motivating. The project also revealed that learning outcomes and motivation are very dependent on schools and teachers and that the FabLab@school.dk project successfully initiated development of design literacies among students.

In summary, the main contributions of this dissertation are as follows.

(1) I have expanded the emerging field of making in education by furthering research on the turn toward design. Introducing, articulating, and sustaining digital design as a new literacy raises awareness of the educational potentials offered by the turn toward digital design in making in K–12 education. I have positioned the turn toward design within the field of new literacy studies, thus situating my work within larger educational and literacy discourse. Such positioning is important if digital design literacy education is to be recognized in domains outside the field of making in education. Hence, the contributions presented in this dissertation should be considered an expansion of how to leverage K–12 maker settings to introduce new subjects that are relevant in a world that is incurably relying on digital technologies.

(2) I have identified and analyzed existing literature conceptions of design and (critical) digital literacy, and I contribute consolidated conceptual articulations and a definition of digital design literacy. I demonstrate how digital design can be considered a valuable literacy to develop among future generations of K–12 students.

(3) Based on the findings from students and teachers doing digital design and bridging with existing theory on digital literacy and professional design competencies, I contribute articulations on seven digital design competencies which I argue to be essential to digital design literacy. These articulations are elucidated through schema and text and synthesized in the Digital Design Literacy Framework (see chapter 4).

(4) I contribute the DeL tool, which can be utilized in K–12 to make quantitative assessments of student development of stance towards inquiry; an important digital design competence. The tool supports K–12 schools in introducing and sustaining digital design literacy by working within an age of measurement.

(5) I contribute strategies for teaching critical digital literacy in K–12. Using Lightbeam, I successfully initiated critical reflection and group discussions on the contemporary issues regarding online data tracking. I suggest that teachers and researchers experiment with visualization tools, and more broadly, adversarial designed artifacts.

(6) I present a framework for training teachers to be reflective educators, that is, developing new teaching practices and digital design competencies. I showcase how the framework can facilitate and support peer-to-peer development of new teaching practices. The framework is valuable for teachers who are to introduce digital design as a new subject and can help sustain digital design education.

In the following and last section of this dissertation, I outline some directions for future research related to digital design literacy in K–12 that I find interesting to pursue.

6.1 Future Work and Research Directions

In reflecting upon my four tears of research, it has become clear that not all of my interests have been addressed adequately in this PhD dissertation because of various reasons such as limited time for interventions in schools or because of the dissertation deadline that must be met. From my work, I find various research prospects that would be interesting to explore in the future, including:

- Critical making and design with K–12 students:
  The idea of using critical making (G. D. Hertz 2014) and design activities as a pathway to develop critical digital literacy could potentially lead to new pedagogies that go beyond the more established ways of making and design in K–12 maker settings. As I outlined in section 2.2.3, there is an emerging interest in the IDC-related research communities to develop students' mindset to thinking critically through making and design. However, there is a lack of knowledge of how to do this. Here, I find the topic of critical making in education to be an interesting prospect to explore, especially because of the turn toward more critical and democratic empowerment as discussed by Iversen et al. (2017) and Iivari and Kinnula (2018). In the future, I seek to appropriate the ideas of critical making and activities to a K–12 education.
- How maker technologies affect and guide students' design process:
  As maker technologies are a central part of making in education and the settings for which digital design literacy is taught, it would be interesting to get a better understanding of what maker technologies and "kits" presume and how they affect students' design process. Such reflections include thinking about what a kit provides and prescribes and its designer's intention with the kit. Related questions include how we might design maker technologies from a non-functionalist perspective that can scaffold more humanistic and critical discussion and engagement.
- Combatting the oppressors:
  Related to the notion of critical digital literacy and as a follow-up to my studies in P5, I believe that there are potentials in having students develop their own tactics to combat the oppressors of the Internet.
- Further exploration and conceptualizations of digital design competencies:
  As mentioned in chapter 4, it would be of interest to the making in the education community to make more bridges between theory on design expertise and exemplars of K–12 students working through a design process. A concrete example of this could be to investigate how to understand the judgments and decisions that students' make in their design processes.

- Longitudinal study of repertoire development:
  One of the most challenging aspects of introducing digital design literacy is to have teachers and students develop a repertoire of design processes, design materials, and modes of teaching. However, a repertoire takes time to develop—time that might or might not be available in K–12 education. I suggest that a longitudinal study could provide new valuable insights into repertoire development and develop abilities to communicate to the students in both a language of and about digital design.

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8 INCLUDED PAPERS

Christensen, K. S., Hjorth, M., Iversen, O. S., & Blikstein, P. (2016). Towards a formal assessment of design literacy: Analyzing K–12 students' stance towards inquiry. Design Studies 46, 125–151.

Hjorth, M., Smith, R. C., Loi, D., Iversen, O. S., & Christensen, K. S. (2016). Educating the Reflective Educator: Design Processes and Digital Fabrication for the Classroom. In FabLearn Europe (pp. 26–33). Stanford, CA, USA: ACM.

Christensen, K. S., & Iversen, O. S. (2017). Articulations on form properties and action-function couplings of maker technologies in children's education. Entertainment Computing 18, 41–54.

Christensen, K. S., Hjorth, M., Iversen, O. S., & Smith, R. C. (2018). Understanding design literacy in middle-school education: assessing students' stances towards inquiry. International Journal of Technology and Design Education, 1–22.

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Hjorth, M., Iversen, O. S., Smith, R. C., Christensen, K. S., & Blikstein, P. (2015). Digital Technology and Design Processes: Report on A FabLab@school Survey Among Danish Youth (Vol. 1). Aarhus University, Denmark.

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Towards a formal assessment of design literacy: Analyzing K-12 students' stance towards inquiry

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We present a tool for quantitative assessment of K-12 students' stance towards inquiry as an important part of students' development of design literacy. On a basis of design thinking literature, we position designerly stance towards inquiry as a prerequisite for engaging with wicked problems. The Design Literacy (DeL) assessment tool contains design of a qualitative survey question, a coding scheme for assessing aspects of a designerly stance towards inquiry, and a description of how, we have validated the results through a large-scale survey administration in K-12 education. Our DeL tool is meant to provide educators, leaders, and policy makers with strong arguments for introducing design literacy in K-12 schools, which, we posit, function within in an age of measurement.

Keywords: design education, design research, reflective practices, evaluation

This paper supports the claim made by current design studies literature that design thinking offers major educational opportunities to support the new literacies needed for the 21st century (Balsamo, 2009; Burdick & Willis, 2011; Pacione, 2010). Design thinking provides educators with a substantiated knowledge base for addressing some of the intangible and interdisciplinary practices, attitudes and knowledge students must pursue, in order to succeed in work and life in the 21st century (as advised by organizations such as OECD's Partnership For 21st Century Learning). Framing design as a form of literacy among many (e.g. mathematical literacy, technological literacy) implies that students should develop basic design abilities, such as inquiry, ideation, and externalization. These designerly ways of thinking are examples of aspects of design from which everyone may benefit when interacting with the world.

In this paper we present a tool for assessing K-12 students' *stances towards inquiry* when asked to solve a *wicked problem*. The tool is meant to assess whether students take a designerly stance towards inquiry in early stages of the design process. However, we do not, claim that our tool assesses all aspects of what it means to take a designerly stance towards inquiry. Rather, our tool focuses on aspects of design that are oriented towards studying *the existing* in

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the early stage of a design process. The early stage of the design process tends to be oriented towards being empathic to learning in order to gain a deep and holistic understanding of the problematic situation (Kelley & Littman, 2005; Kembel, 2009; Löwgren & Stolterman, 2004; Nelson & Stolterman, 2012). In this early stage designers utilize a diversity of ethnographic and/or anthropological techniques, many of which have later been tailored for design (Hanington & Martin, 2012; Kelley & Littman, 2005). One of many ways that designers approach wicked problems, is to discern the problem's preconditions for future design. To do this the designer needs to be able to observe, describe and understand the context and environment in which the problematic situation is present. This presupposes personal reflection on first intentions (Nelson & Stolterman, 2012), and reframing of the problematic situation (Cross, 2011; Schön, 1984, 1990). Contrary to this, our previous field observations, showed that the K-12 students' design processes in maker settings ' … often resulted in simplistic solutions and finalization.' (Smith, Iversen, & Hjorth, 2015). The focus of the tool presented here, is to better understand students' approach to the early stages of design processes. We investigate this from the two perspectives of a designerly stance towards inquiry, or a stance of technical rationality.

To successfully introduce a designerly stance towards inquiry, and by extension design literacy, as part of K-12 education, we need to understand the modus operandi of the current educational institutions. In his seminal work, educational philosopher G.J.J. Biesta (2008, 2010) has argued that today, education operates in an 'age of measurement.' In this age, what is valued in education is to a large part determined by what is measured. Educational outcomes are valued by institutions' capacities to perform on quantitative assessments. In other words, what is valued in education is strongly influenced by the content of assessment tools. We recognize the criticism of this problematic situation of valuing what is measurable, but nonetheless, it is what educators and policy makers expect to base many of their decisions on. Therefore, we take the contemporary focus on large-scale quantitative assessment as a given. Thus, if we value design as educationally desirable for the general public, we need new ways to assess this new design literacy.

The idea of integrating design thinking as a subject in general education has been suggested previously (Baynes, 1974; A. Cross, 1980, 1984). However, the idiosyncratic nature of design poses great difficulties for large-scale assessments: you cannot force the many dimensions of design into a formula. Design researchers such as Cross (2011), Nelson and Stolterman (2012), and Dalsgaard (2014) describe design as a particular form of engagement with the world. The designer approaches problematic situations by engaging with these situations through reflective conversations with stakeholders, the design situation, and its artifacts. As described in Kimbell and Stables (2007), these conceptions of design do not readily lend themselves to large-scale quantitative assessment such as e.g. surveys. Nevertheless, we present a tool for assessing aspects of *design literacy* on a survey. More specifically, our tool assesses students' *stance towards inquiry* (Schön, 1984, p. 163) — an important aspect of design literacy in K-12 education. Our assessment tool is meant to provide educators, teachers, and policy makers with strong arguments for introducing design in K-12 — arguments which should prove persuasive in the age of measurement.

To this end, we introduce the Design Literacy (*DeL*) assessment tool, which contains three levels: (1) design of qualitative, wicked survey question, (2) a coding scheme for assessing aspects of a designerly stance towards inquiry, and finally, (3) an example of analysis and quantitative data validation for transparency and guidance.

The design of the DeL tool is part of the ongoing Danish FabLab@School.dk research project, in which we study the design, implementation, and facilitation of educational activities in collaboration with local municipalities, schools, and teachers. Thus, our research project is empirically based in the FabLab@school.dk project.

This paper is laid out as follows. First, we provide a literature review of design literature arguing for the introduction of design thinking in general education. Second we describe maker space settings as the context for introducing design literacy. Third, we unpack the concept of design literacy, based on our review of related work on new literacies. Fourth, a detailed account of the DeL tool is presented in relation to preparation, execution, data analysis, and interpretation. Finally, we discuss the validity of the DeL tool and its potential contributions and limitations.

1 Design thinking in K-12 education

This section presents literature that touches on design thinking and its relationship to public education in general, and how a stance towards inquiry is an important design fundamental. We review key aspects of what constitutes wicked problems, and present influential design scholars' arguments about how a stance towards inquiry supports the designer when engaging with problematic situations that have characteristics of being wicked. We later utilize these insights to develop an open survey question that may be used to assess aspects of design literacy among K-12 students.

As stated in the introduction, introducing design as a subject in general education is not new (Baynes, 1974; A. Cross, 1980, 1984). However, some of the issues raised back in the 80s exist to this day — one of them being how to assess students' design literacy. More recently, Svihla et al. (2009), Nelson and Stolterman (2012), and Keirl (1999, 2006a, 2006b) have argued that design should be for everyone. It is argued that design and technology have significant roles to play in citizenship education and democracy (Kolodner, 2002; Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998). According to these works, designerly ways of engaging with the world enable individuals to act as agents of change and creators of preferred futures, abilities that are echoed in descriptions of 21st century skills. This is reiterated by Burdock and Willies according to whom 21st century skills 'sound' like 'designing' (2011: p. 546). Chris Pacione's agenda-raising *Interactions* article puts forth the argument that design should be 'put back in the hands of everyone' (Pacione, 2010), a statement in line with those of Nelson and Stolterman (2012). Pacione suggests that we should not focus on educating the general public to levels of mastery. Instead, Pacione describes 'design for the people' as a form of literacy similar to that of mathematical literacy: basic skills and techniques that serve us in our daily lives. The idea that design should be for everyone motivates our work on identifying important aspects of design literacy, which we can assess through quantitative measurements.

According to design research, it is crucial for the designer to develop his stance towards wicked problems (Buchanan, 1992; Coyne, 2005; Rittel & Webber, 1984). Such a stance entails personal reflection on the first intentions that set the designer on a specific path of inquiry towards action. Such arguments may be found in recent design research literature by Cross (2011), Nelson and Stolterman (2012), Lawson (2006), Löwgren and Stolterman (2004), and Krippendorff (2006), all of whom reference Schön's pragmatic epistemological understanding of design. Similar observations and concepts may be found in educational research on the difference between *routine expertise* and *adaptive expertise* (Lin, Schwartz, & Bransford, 2007; Svihla et al., 2010), which argues that most of today's formal education designed to produce *routine experts*. In Schönian terminology, schools tend to direct students to adopt a stance of *technical rationality*. Routine experts see wicked problems as tame, and focus on answers that are readily at hand, easily accessible, or drawn on a set of finalized solutions. Although hard to define (Nelson & Stolterman, 2012: pp. 63–66), we understand these approaches as part of the designer's *stance*, which everyone can learn and develop. Claiming that our tool can assess all dimensions of the design mindset would be naïve. But since no tool for the assessment of the design mindset in K-12 education is available, we decided to be the first to break new ground with the development of one such tool.

Current design research literature already discusses design in relation to education. However, this is often limited to professional subjects such as engineering, industrial, computational, or architectural design in higher education (e.g. Curry, 2014; Eastman & McCracken, 1997; Lewis & Bonollo, 2002; Oxman, 2004). Furthermore, there is a body of studies devoted to the comparison of expert and novice designers (Cross, 2004; Ho, 2001). Closely related to Schön's concept of problem framing is the important finding on design expertise that novice designers usually take a depth-first inquiry stance towards wicked problems, whereas trained designers predominantly take a top-down and breadth-first stance (Cross, 2004). Students who seek a single, 'correct' solution seem less able to perform (Portillo & Dohr, 1989; Simmonds, 1980) when approaching wicked problems with a technical rationality stance, erroneously seeing the problem as well-defined and tame, and barriers to success may occur (Cross, 2011: pp. 48–60; Nelson & Stolterman, 2012: pp. 105–117; Portillo & Dohr, 1989; Schön, 1984). Thus, while there is a small amount of literature relating design thinking to children's education, there is a body of literature indicating the necessity of recognizing the complex nature of wicked problems and of approaching these problems accordingly. Since real-world challenges are, per definition, 'wicked,' (Coyne (2005) even posits that almost all problems are wicked in some respect), students who are expected to engage with the real world at some point can reap great benefits from the ability to recognize and approach wicked problems from a designerly inquiry stance. For this reason, we focus our assessment tool on students' stances towards inquiry, when challenged with a survey question that is wicked and that embodies the following five aspects: (1) societal challenge, (2) dilemmas, (3), ethical issues, (4) multiple stakeholders, (5) unfamiliar domains.

Before employing the above-reviewed theories to examine design literacy among K-12 students, it is necessary to establish a space where design activities may take place. In the section that follows, it will be argued that maker settings may provide schools with spaces for 'learning by doing' – what Schön describes as a 'reflective design practicum' (1987). In turn, this allows researchers to study students' design processes 'in the wild.'

2 *Maker settings: a context for design in K-12 education*

There is a growing interest in incorporating 'maker settings' such as Hackerspaces, Makerspaces, and FabLabs (Figure 1) in curriculum-based education. According to Martinez and Stager (2013), these types of settings present new opportunities for children to better acquire skills, not only in subjects such as engineering and science, but also in regards to design and creativity. By deploying a multitude of toolkits, machines, and design materials for making and inventing, students will supposedly be able to take control of their lives and learning through the 'act of creation with new and familiar materials' (Martinez & Stager, 2013). Maker settings provide researchers with new opportunities for investigating the potential benefits of applying design thinking as part of K-12 education. Examples of such investigations may be found in the work of Smith et al. (2015), El-Zanfaly (2015), and Katterfeldt and Schelhowe (2008).

The trending turn towards design thinking and practice in schools' maker settings builds on technological developments, for example, 3D printers or

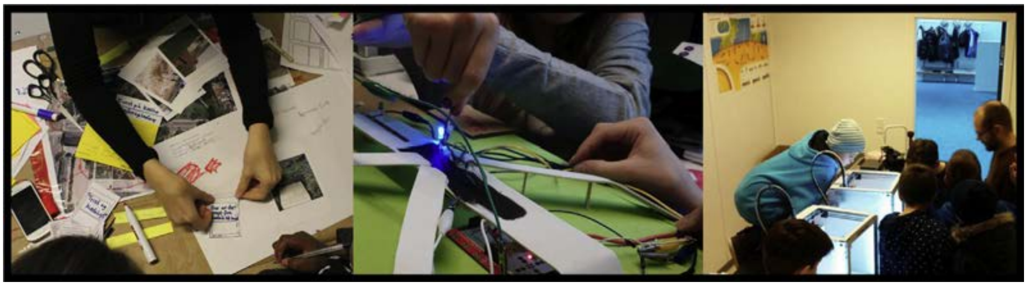


Figure 1 Examples of design activities in K-12 maker settings

physical computing platforms for children (Blikstein & Krannich, 2013). These developments have drawn attention to the so-called 'maker movement,' a broad term for a do-it-yourself culture that is gaining attention in research communities such as IDC[1], CSCL[2] and ICLS[3]. These scholarly efforts often relate to technology, design, and hands-on making, and how the associated artifacts and activities may improve general education and prepare students for a world that relies increasingly on digital technologies (Blikstein, 2013; Martinez & Stager, 2013; Papert, 1980; Walter-Herrmann & Büching, 2014). Much of this research revolves around terms such as 'DIY,' 'hacking,' 'making' (Hatch, 2014), 'crafting,' and 'tinkering,' among others. Common to these terms is that they have to do with some kind of creation or design with materials, both physical and virtual (Tanenbaum, Williams, Desjardins, & Tanenbaum, 2013; Wang & Kaye, 2011). Historically, maker settings have been community-driven by people with common interests, often in computers, machining, technology, science, digital art or electronic art, enabling them to meet, socialize, and collaborate (e.g. *The Geek Group*, founded in 1994). Currently, there is a great surge in maker settings in a wide range of educational settings – from K-12 to museums, and higher education.

The increase in the deployment and distribution of maker settings in educational contexts has resulted in an academic turn towards research into the possibilities of maker settings in K-12 education (Walter-Herrmann & Büching, 2014). Current researchers, such as Blikstein and Krannich (2013) and Buechley, Eisenberg, Catchen, and Crockett, A. (2008), have suggested maker settings as the ultimate construction kit and place for students to plan, design, and share projects (Walter-Herrmann & Büching, 2014). Neil Gershenfeld argues that maker settings can help students uncover the 'hidden core' of modern technology, revealing the model behind the black box – to use technology as an agent, to make abstract concepts more concrete and thus comprehensible (Gershenfeld, 2007). Gershensfeld's focus on educating students for careers in science, technology, engineering, and mathematics (*STEM*) is echoed in Blikstein and Krannich (2013), and Eisenberg (2002). Others, such as Dittert and Krannich (2013), add to this by analyzing how these settings enable bottom-up ideation processes, and allow children to better grasp digital technology, which in turn offers new educational opportunities that make digital design and engineering more transparent and easier to internalize. Blikstein describes this emphasis as a shift from computer skills to computational fluency and technological literacy through the means of making with digital technologies. Here, the emphasis is on basic engineering knowledge, and the nature and limitations of the engineering process (Blikstein in Walter-Herrmann & Büching, 2014, p. 205). Furthermore, a range of scholars has argued for the possible benefits and challenges of introducing design as part of schools' curriculum (Burdick & Willis, 2011), in subjects such as innovation or entrepreneurship (Fitton, Read, & Dempsey, 2015; Mikhak et al., 2002; Wardrip & Brahms, 2015). Other researchers have taken a 'crafty' approach. Here, a focus on art and soft materials is utilized to develop the children's ability to engage in the creative processes of crafting in mixed physical and digital materials (Buechley, 2006; Buechley et al., 2008; Lo & Paulos, 2014; Mellis, Jacoby, Buechley, Perner-Wilson, & Qi, 2013; Qi & Buechley, 2014). Our work with the DeL tool builds on the notion that the introduction of maker settings in schools presents a call and an opportunity for an increased focus on how children actively engage with design processes in education — an opportunity for investigating design literacy among students.

3 *Design literacy as a new literacy*

When we argue for design literacy, we are transferring ideas from the field of design thinking to the fields of education and literacy in general. The concept of literacy embodies a multitude of educational theories (Coiro, Michele, Colin, & Leu, 2014). Unfortunately, design literacy remains a contested concept in both education and design literature. This section presents our perspective on how design literacy may be positioned within the emerging field of *new literacies*.

In this paper, we draw on the sociocultural literacy theories and preliminary definitions laid out by Lankshear and Knobel (2008) and Buckingham (1993). Gee (2015) first introduced the concept of 'new literacy studies,' and argued for a better understanding of literacy '*in its full range of cognitive*, *social*, *interactional*, *cultural*, *political*, *institutional*, *economic*, *moral and historical contexts*' (Gee, 2015). Buckingham (1993) followed up with the concept of 'new literacies,' referring to the new forms of *literacies* made possible by new social paradigms and discourses that are emerging as new digital technologies enter our world. However, new literacies do not necessarily have to involve digital technologies at their core. The definition of new literacies remains broad in scope, open and complex, as there exist various conceptualizations of new literacies used by different research discourses when referring to new literacies (Coiro et al., 2014: pp. 12–13). A short list would include 21st century literacy (OECD), internet literacy (Hargittai, 2009; Litt, 2013), digital literacy (Burdick

& Willis, 2011; Denner & Werner, 2011), new (multi-) media literacy (Mayer, 2005), technological literacy (Barnett, 1994; Keirl, 2006b: p. 200; Pearson, 2008), information literacy (Greene, Yu, & Copeland, 2014), ICT literacy (Denner & Werner, 2011; Gençtürk, Gökçek, & Güneş, 2010), and visual design literacy (Reitan et al., 2013). In the *Handbook of New Literacies Research*, Coiro, Knobel, Lankshear, and Leu (2008) note that all these terms 'are used to refer to phenomena we would see as falling broadly under a new literacies umbrella' (p. 10). We argue that design fits nicely under this umbrella.

Following the new developments in educational scholars' understandings of literacy, new methods and techniques for measuring the new literacies are called for (Burdick & Willis, 2011; Quellmalz & Haertel in Coiro et al., 2014: p. 941). There is already a strong international tradition of assessing established literacies through quantitative measures (e.g. TIMSS, PIRLS, PISA, ICILS). As pointed out by Biesta (2008), the international quantitative assessments of literacy have had a significant impact on the educational system – focusing attention and resources on what is measured. If we value design literacies and want these to attract attention and have an impact on schools, then we need tools to quantitatively assess these literacies. Therefore, we propose an assessment tool directed at assessing students' ability to reflectively engage with, and make inquiries when confronting wicked problems (Rittel & Webber, 1984) and messy situations (Ackoff, 1974; Horn & Weber, 2007). Work on assessing design capabilities in education has been done by Stabels and Kimbell (2000, 2007) and Bain and McLaren (2006), however our DeL tool aims to provide researchers, policy makers and educators with valuable insights into students' stances towards inquiry as a part of being literate in the 21st century. Thus, the DeL tool is even applicable to school systems which do not yet have design-related subjects. This way, the introduction of design literacies to education may be based on quantitative knowledge of students' stance towards inquiry when faced with challenges that have characteristics of being wicked. Although the rise of maker settings in education has been a main influence in our development of the DeL tool, we posit that the tool may be used for assessing stance towards inquiry in other contexts as well. Furthermore, it provides teachers with knowledge about an important aspect of design: the concept of 'stance.'

4 *Development and application of the DeL tool*

The development of the DeL tool was initiated by the Child–Computer Interaction Group[4] at Aarhus University as part of the three-year-long research project FabLab@School.dk[5], carried out in collaboration with thirty-nine Danish schools. FabLab@School is a worldwide network of educational digital fabrication labs, created by the Transformative Learning Technologies Lab (TLTL) at Stanford University.[6] FabLab@School.dk is the Danish implementation of the project. The initial aim of the international

FabLab@school project was to develop literacies within STEM by means of digital fabrication in education. However, FabLab@school.dk was tailored to a Danish context by framing maker settings as hybrid learning laboratories, which combine digital fabrication, design thinking, collaborative idea generation, and creating solutions to complex societal. Therefore, we needed a tool for assessing aspects of design literacies, in order to measure the abilities specific to the design perspective applied in the Danish context. This work was based on a survey developed at TLTL to measure literacy with an Exploration and Fabrication Technologies index (EFTi) (Blikstein, 2014; Blikstein, Kabayadondo, Martin, & Fields, 2016).

The next sections present an account of the development of the DeL tool. We describe the three elements of our tool, and how others may reinterpret our tool for use in their contexts, in order to carry out similar assessments of K-12 students' design literacy.

Our DeL tool consists of three elements:

- Design of qualitative survey item that embodies aspects of being wicked
- A scheme for coding aspects of a designerly stance towards inquiry
- Analysis and quantitative data validation

These three elements constitute our DeL tool. What follows is a more detailed description of these three elements, how we developed the DeL tool, applied it to our context, and finally, how others might implement and enact similar assessments through a quantitative survey.

5 *Design of a wicked question for the DeL tool*

Our question was designed to assess the students' stance towards inquiry, as opposed to *technical rationality* (Schön, 1984: p. 163), by utilizing an open-ended survey item. To assess stance towards inquiry, the students were asked how they would approach a specific wicked problem. At the time the survey was being planned, a much-talked-about problem in the Danish media was that elderly residents suffering form senile dementia would disappear from their nursing homes, sometimes resulting in their deaths by freezing, drowning and so on. It was a real-world problem as well as a wicked problem. The wording of the open-ended question translates from Danish as follows:

> 'At the beginning of 2014, nine grandparents disappeared from their nursing home because of loss of memory (owing to dementia). The problem for the nursing home is to create security for the elderly without taking away their freedom.
>
> If you were asked to solve this problem, what would you do?'

First of all, the question was chosen with the students in mind. The problem was current, it dealt with grandparents, a group of people that most of the students could be expected to relate to, and it was an important topic, since it was a matter of life and death for the grandparents involved. Thus this question is tied to a Danish context. It is therefore important to reflect on how the wicked problem posed in the survey question relates to the context in which the survey is to be administered. For example, our question might not apply in an Italian context, if we assume that caring for the elderly — giving them shelter and food, helping them to walk, and so on — is seen as a family responsibility.

We invited seven children (aged 11—15) to collaborate on the question design on four occasions, in order to make sure that the question made sense to K-12 students. The question's interpretability was tested by letting the children read it aloud and discuss it before the tool was tested 'in the wild'. Thus, the final DeL question described above is the outcome of several iterations discussed by researchers and children. These discussions served to make the question relatable to the children, whilst maintaining our aim of investigating students' stance towards inquiry.

We argue that a question such as the one above touches on five specific aspects as depicted in Figure 2. These aspects are based on research on wicked problems and they constitute the basis for our coding scheme in the DeL tool. We exemplify how we coded the students' responses later, in Section 5, but first we will explain how our open-ended survey question embodies the five aspects. These explanations are in many cases paraphrasing the list of aspects of a wicked problem given in Horn and Weber (2007):

- It is a *societal challenge*, which means that it is connected to other problems and subject to e.g. economic and political constraints, and perhaps resistance to change. Politically, the elderly are a hot topic, since a declining birth rate in Denmark makes the elderly a large part of the voting population. Economically, since the economic crisis of 2008, budget cuts have hit the entire public sector, including nursing homes. This is amplified by the demographic development. Thus, the problem of the disappearance of elderly nursing home residents with senile dementia is connected to other societal problems.
- It is a *dilemma* in the sense developed by Löwgren and Stolterman (2004), which means that there is no unique, 'correct' view of the problem, there are different views of the problem and contradictory solutions, there are numerous possible intervention points, there is considerable uncertainty and ambiguity, and thus it may only be answered by alogical, illogical, or what may be considered designerly, thinking. The most explicit dilemma in our question is that of freedom vs. security.

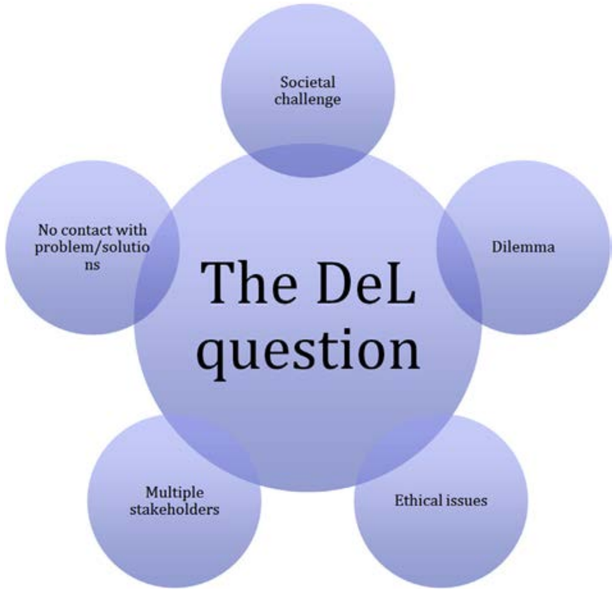


Figure 2 Aspects of the survey question used in our implementation of the DeL tool

- It raises *ethical issues*, since it may entail consequences difficult to imagine and foresee. Decisions are influenced by ideological and cultural constraints, for example, how different groups interpret concepts such as 'security' and 'freedom,' how much freedom senile-dementia-sufferers are entitled to.
- It involves *multiple stakeholders* – the nursing home, families, the elderly – which potentially leads to multiple value conflicts concerning the nature of the challenge, its causes, boundaries, and solutions. The elderly may for example feel entitled to freedom, whereas nursing home staff may not want to run the risk of losing an elderly resident.
- Finally, more often than not, the students have no experience with dementia, and thus the *students are out of contact with the problem and potential solutions – it is an unknown domain to most students*. This requires students to inquire into the domain or context of the problem, if they were to solve it.

6 Coding scheme

Through the assessment of the collected responses, we developed a coding scheme, in order to distinguish reliably among categories of responses. The three categories listed below were derived from theoretical considerations, whereas coding of the responses was done from the specific content of particular responses, albeit with inspiration from the five aspects of the question listed above. We openly coded each response, in order to capture details of the responses, and examine how they expressed concerns for any of the five aspects of the question posed. This process of open coding consisted of multiple iterations of reading and coding using an incident-by-incident method resulting in three levels. Based on another coding process, responses were assigned to one of three levels:

- *No interpretable answer/'I Don't know'*

This level included blanks and responses such as 'I don't know' or 'I don't care,' as well as text we were unable to interpret.

- *Technical rationality*

Essentially, students with a stance of technical rationality assumed they had sufficient knowledge of a domain that was more or less unknown to most of them. This level included two types of responses. In the first type, students showed no concern for the wicked aspects of the question we posed, nor did they suggest an inquiry into the problem. Students assigned to this category may have recognized one or more wicked aspects of the question, but they did not suggest inquiry. Neither type of response framed the question as a wicked problem in need of inquiry. Instead, responses assigned to this category suggested complete solutions that were readily at hand, easily accessible, or drawn from a set of finalized solutions, and they approached problems as though these were separable from solutions. The students in this category accepted their own beliefs and assumptions without reflection on their bases. We interpreted these responses as approaching the wicked question with a stance of technical rationality.

- *Designerly stance towards inquiry*

All responses that indicated some form of reflective inquiry into the problem space were included in this level. The responses explicitly or implicitly recognized wicked aspects of the question posed, and sometimes even presented additional wicked aspects that were not explicitly part of our original question design (this is of course possible, since the nature of wicked problems demands that they cannot be exhaustively formulated). In the following table (Table 1) we have included examples of responses representing both stances. If a student suggested inquiring into any of the five aspects (or other aspects) of the question posed, they were considered to take a stance towards inquiry, rather than technical rationality. This means that students did not have to recognize all aspects of the wicked problem to be assigned to the category of 'stance towards inquiry'.

In order to make our coding process transparent, we have included examples of how we have assessed students (Table 1). The table also functions as a guide of others who wish to make similar assessments of design stance.

Table 1 Examples of students' responses, the codes we used to categorize their stances, and finally, the category to which the response was assigned

(1) Response example	*(2) Our codes*	*(3) Categorized stance*
Simple! You let them have a 'Tele-tracker' in their clothes, so that you can always follow them wherever they are, and they will not even notice it!	• Suggests that initial idea is a final solution • Simplifies relationship between problem and solution • No consideration of ethical dilemmas (with tracking) • Makes assumptions (it is easy to fool the elderly)	1. Technical rationality
I would teach them to use an iPhone, which they could always carry with them (like my own grandmother), with the app 'find my iPhone' installed. The nursing home would then have the information from the elderly, so they could always log in and see where they were, if they were away.	• No consideration for important stakeholders (who will teach the elderly?) • Make assumptions (generalize individual solution to different domain) • No consideration of economic constraints	1. Technical rationality
First of all, I would visit the elderly and examine the conditions of their illnesses and the situation of the nursing home. This could lead to a better understanding of what is possible, and what is not possible.	• Inquiry into the domain (field studies of nursing home) • Inquiry into illness of elderly • Consideration of possibilities and constraints	2. Stance towards inquiry
Develop ideas and prototypes through an iterative, participatory design process.	• Inquiry through iterative process of idea development and prototyping • Use methods of participatory design (assume that problems are wicked)	2. Stance towards inquiry
I would start by examining what is actually meant by 'without taking their freedom from them.'	• Inquiry into ethical issue ('not taking away their freedom')	2. Stance towards inquiry
I would investigate why they ran away, and what made them do it. I would also contact the nursing home staff, and ask why they do what they do.	• Inquiry into framing of the problem (identify different explanations for the same problem) • Make inquiry regarding stakeholders	2. Stance towards inquiry
I would start by investigating how a nursing home functions. I would not try to solve a problem about which I know very little.	• Inquiry into domain • Considers lack of knowledge	2. Stance towards inquiry

6.1 General guidelines

After having collected students' responses to the DeL question, we suggested that researchers initiate a coding process consisting of three phases: (1) pull response data on the wicked problem from the survey, (2) read and openly code each response, and finally, (3) categorize codes as one of the three levels, in order to assign students to one level (*no interpretable answer/don't know*; *technical rationality; designerly stance towards inquiry)*. It is important to include more than one researcher in the coding process, as it increases the reliability of the data (see Section 7.4).

The coding process is characterized as qualitative. But as stated earlier, we aim to take quantitative measurements that enable a comparison of populations of K-12 students. Therefore, it is necessary to assign the coded responses to a limited set of categories, and have the data be nominal. Additionally, it is important to compare K-12 students' responses to the survey question posed with responses from more or less trained designers, in order to identify the validity the question. In the next section, we will present some of the findings of our own assessment, and outline how other researchers might do the same.

7 Analysis and quantitative data validation

In Section 6, we accounted for the five aspects of a wicked problem that we identified as important to our tool, and how the particular question discussed here fit these aspects from a theoretical analysis point of view. In Section 7, we analyze chosen responses, which fit the different aspects. Through this, we were able to note that our data suggests that all five aspects, which are included in Figure 2, are present in the question posed. Thus, from a qualitative analysis, it seems that at least some students interpreted the challenge included in the question in the manner intended. However, in order to demonstrate that the DeL tool can function as a quantitative assessment tool, we needed to demonstrate that the tool was able to distinguish among the degrees to which different populations are design literate. Part of this involves demonstrating that an assessed lack of designerly stance towards inquiry was not due to misinterpretation of the question, unreliable coding, or pure chance. Throughout this section we will move back and forth between the specific question and more general considerations of how it applies to the tool in general, and thus to others who might wish to assess a designerly stance towards inquiry using a different question.

Validation of the question was done in several steps. The question was given to a group of 2nd year bachelor students of digital design and information studies at Aarhus University, Denmark. In all instances, the question was administered as one item in a survey consisting of 227 items relating to digital technology, hacking, and design. Finally, a comparison of the scores by two researchers tested the reliability of the scoring process. For calculations we used *R Project for Statistical Computing*[7].

7.1 Digital design students

Formulating a strong question that would assess students' designerly stances towards inquiry in a valid way was challenging. We are aware that the framing of the question asked could have prompted respondents to come up with a specific technical solution, rather than to suggest a process of reflective inquiry. Therefore, the survey was tested on three different groups with different amounts of exposure to education in design thinking. An example of this is that 50% of a group consisting of twenty-four digital design students in their second year of university gave responses that suggested that they took a stance towards inquiry, when tested on this item. The students were asked to respond to the entire survey, so that they would not know which question we were particularly interested in. They were also given an introduction, which was almost identical to the one given to the K-12 students. Nearly half students did not suggest a technical solution, but stated something along the lines of: '*I would start by investigating how a nursing home functions. I would not try to solve a problem about which I know very little*.' (digital design student). That approximately half of the digital design students took this stance towards inquiry suggests that someone trained in design would be more likely to interpret the question as a wicked problem in need of further study.

Responses from the digital design students were compared to those of the information studies students, who had not formal received training in design (yet), but who had been attending university for the same amount of time, and whom we might be expected to have backgrounds comparable to those of the digital design students. Among the information studies students, twelve percent displayed a designerly stance with respect to inquiry. However, on average, the digital design students were more likely to express an inquiring stance (M = 0.50, SE = 0.10) than the information studies students (M = 0.12, SE = 0.041). This difference was statistically significant: $t(30.7) = 3.4128$, $p = 0.002$. Digital design students score significantly higher on this test than do information studies students. This suggests that the question measures some aspects of design literacy. As the responses indicate, this aspect has to do with a stance towards inquiry.

7.2 *Interviews with school children*

As mentioned in Section 6, the DeL question was developed together with small groups of children aged 11–14 year olds on four occasions. During the early phase, students were asked to read the questions from the entire questionnaire aloud, in order to reveal which words and wordings were difficult to understand. Furthermore, in two cases, the students were asked to discuss their answers in pairs, in order to reveal how the students interpreted the questions. After completing the preliminary version of the survey, these students where interviewed about their experiences of responding to the questionnaire. These students all understood the DeL question, but they did not identify it as a wicked problem. Since all children engaged in the development of the question were able to interpret the meaning of it, we found it reasonable to assume, that children (aged 11–15) would generally understand the questions as intended.

7.3 *Using the DeL tool to assess K-12 students*

We applied our DeL tool as part of a larger survey among eleven- to fifteen-year-old students at thirty-nine schools in four municipalities in Eastern

Jutland, Denmark (Vejle, Silkeborg, Aarhus, and Favrskov). A team of six researchers from Aarhus University administered the survey at the schools in the period between August 25th and September 12th 2014. In order to evaluate whether it was possible to use the DeL tool to assess the level of design literacy among the population of students, we chose to test it on a large number of students from a wide range of backgrounds. A thorough description of the entire survey study, the components of the study and the outcomes are available in (Hjorth, Iversen, Smith, Christensen, & Blikstein, 2015).

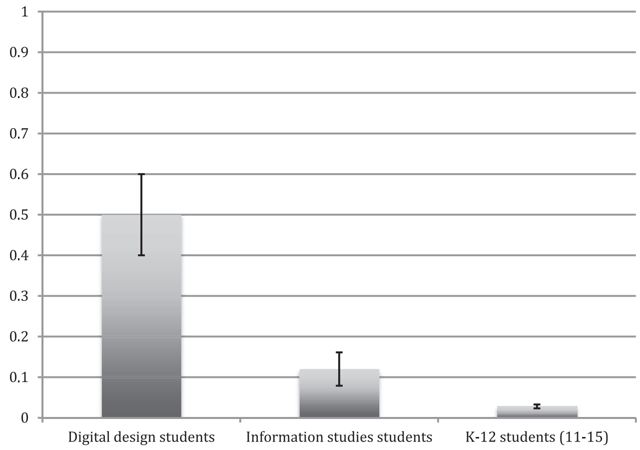
As researchers, we introduced the research project and the survey to the students, and were present in the classroom during the entire survey session, in order to provide help with questions and technical problems. Studies suggest that researchers' assistance increases reliability, because fatigue-effects are slower to set in Marsden and Wright (2010). To further increase reliability, the introduction was based on a document including the most important points to communicate to all the students involved. The survey was administered through a website that could be accessed on computers, tablets, and phones. We let the students use their own phones/devices, which many students appreciated. We recommend that students have access to mobile broadband, which solved some technical issues we experienced with the schools' local networks. Some students who started responding to the survey before technical problems arose had to start over again. A few classes even had to reschedule the survey to a different day, since our survey provider had a server breakdown.

Contact with the schools was established through a letter to the principals, asking them for 45 min with a grade 6, 7, or 8 class of their choice, and while many chose 7th graders, we did our best to get 6th and 8th graders to participate. In our data set, we ended up with a total of 1433 entries. Some of these where test runs, some were double entries, and in the end, 1156 entries met the established criteria (appropriate age, number of items answered, and only one entry per person).

7.3.1 Comparing school children to digital design students

As stated, 50% of the digital design students answered that they would investigate the problem further (stance towards inquiry), and 12% of the information studies students took this approach. Among the students from K-12, less than 3% of the students suggested taking a stance towards inquiry (see Table 2). As in the case of comparing students from digital design and information studies, we did a two-sided t-test to compare the mean scores of the students from the K-12 with the digital design students. On average, the digital design students were more likely to take a stance towards inquiry ($M = 0.50$, $SE = 0.10$) than the students from K-12 schools ($M = 0.028$, $SE = 0.0048$). This difference was statistically significant: $t\ (23.1) = -4.5255$, $p = 0.0002$.

Table 2 The degree of students from different groups, who had a stance towards inquiry on the DeL question (with indication of standard error)



Since the difference between the 11- to 15-year-olds and the digital design students was so large (and statistically significant), and since this matched our hypothesis that a stance towards inquiry as an important part of design literacy was not nurtured in Danish K-12 schools, we are led to conclude that the question measures a stance towards inquiry to an extent that makes it possible to compare different populations of school children.

7.3.2 *Comparing school children to information studies students*

Our initial hypothesis was that a stance towards inquiry would not be more frequent among the students from K-12 schools than it would be among information studies students. First, since information studies students have lived a significantly longer time than K-12 school students, there is a greater chance that they have been exposed to design thinking. Second, students of information studies may sometimes have a particular interest in design processes, as they are often part of software design. In fact, information studies students at Aarhus University are required to take a design course in the second half of their 2nd year (4th semester). Thus, if applying our tool leads to the conclusion that it is more common for students of K-12 schools to take a stance towards inquiry than it is for information studies students, that would present a problem. However, if there was no significant difference between the two groups, or if it was more common for information studies students to take a stance towards inquiry, this would strengthen the validity of the DeL tool.

As already stated, 12% of the information studies students took a stance towards inquiry, when measured with the DeL tool, whereas less than 3% of the K-12 school students were assessed as taking this stance. To test for significance, we once again did a two-sided t-test. On average, the students of information studies were more likely to take a stance towards inquiry (M = 0.12, SE = 0.041) than the students from K-12 (M = 0.028, SE = 0.0048). This difference was statistically significant: t (60.6) = 2.1151, $p = 0.04$.

In summary, the population of digital design students has a much higher frequency of responses assessed as a stance towards inquiry than do the populations of students from information studies and K-12 schools. Furthermore, the information studies students demonstrate a higher frequency of stance towards inquiry than do the students from K-12 schools. This makes it probable that our tool is capable of reliably assessing a stance towards inquiry applied to population of school children.

7.4 Inter-rater agreement and reliability

In order to gain insights into the reliability of the assessment process two scholars were each asked to rate 84 responses. This was done individually and without prior discussion of typical cases. When responses were compared, it turned out, that most disagreements could be resolved from discussion leading to agreement. However for the sake of testing inter-rater agreement and reliability, the ratings, which were done prior to the discussion, were used. There was a 93% inter-rater agreement. The resulting inter-rater agreement and reliability (Tinsley & Weiss, 2000) as calculated using Cohen's Kappa (Cohen, 1960), was K = 0.84 with the 95% confidence interval between 0.72 and 0.96. It is common in literature on inter-rater agreement and reliability to interpret a Kappa-value above 0.80 as 'very good' (Altman, 1990) or 'almost perfect' (Zegers et al., 2010). However, as pointed out by Kottner et al. (2011), this should be dependent upon the intended use of the rating system. Since we do not propose for the DeL tool to be used on individuals, we are confident, that a Kappa-value of 0.84 is testament to a good inter-rater agreement and reliability.

8 Discussion

As stated elsewhere in this paper, we see our tool for assessment of stance towards inquiry as an important part of our argument for teaching with the goal of design literacy in K-12 education. Within the current educational climate, such quantitative assessments tend to gain political attention and thus to influence policy. At the very least, we have designed a tool, which seeks to measure what we value rather than ending up valuing what we can measure. However, the tool has further possibilities. By singling out designerly stance towards inquiry as an important part of design literacy, we draw attention to this prerequisite for engaging in design in a design thinking perspective. In our qualitative studies (Smith et al. 2015; Smith, Iversen, and Veeraswamy, 2016), we have observed time and time again, how students tend to come up with finalized solutions, when they are faced with wicked problems. By highlighting stance towards inquiry as an assessment item, it is our hope, that teachers in maker settings in Denmark and in any design related subjects throughout the world will be inspired to teach students to inquire into the problematic situation as a part of their design work. It is this ability to inquire, which prepares the students to take on the real-world problems that await them outside the comforting and constraining walls of schools.

The DeL tool is not intended for assessing design literacy in individual learners. Instead, we envision the DeL tool as a helpful instrument for researchers to assess students' stances towards inquiry as a general measurement of design literacy. The DeL tool provides us with an initial vocabulary and framework for discussing design literacy as part of K-12 education. Moreover, in an age of measurement, the tool provides teachers, school managers, and policy makers with hard evidence for making a strong argument in favor of design-oriented learning in K-12 education.

We are aware of limitations of the DeL tool, especially the extent to which the tool actually measures the multifaceted and sometimes even diverse skill set that we label 'design literacies.' As indicated in the introduction, the DeL tool only assesses an aspect of the students' stances towards inquiry as a marker of students' design literacy. In our tool we assess students' responses by operationalizing the perhaps false dichotomy of designerly stance towards inquiry as opposed to taking a stance based on technical rationality. This operationalization simplifies the complex and interrelated aspects of design thinking, and we are aware that expert designers also utilize technical rationality, e.g. when proposing an initial design vision. However, our operationalization of the two stances with which to approach a wicked problem, made for quantitative investigations of students tendency to approach a wicked problem with strong presumptions about the situation and suggestions of finalized solutions, as opposed to taking a more emphatic, investigative and understanding approach – what we've described as a designerly stances towards inquiry.

Further, the DeL tool does not deliver any measurement of the students' abilities related to important aspects such as retrospective thinking, framing and re-framing, collaborative ideation, or prototyping – argued for in current literature on design studies. The DeL tool is not intended to assess the progress of an individual student. Consequently, we do not treat the DeL tool as capable of making an accurate or dimensionally stable assessment of design literacy, but rather as an indication of the group of students' general orientation towards design literacy.

The DeL tool has been tested in situ on students in K-12 schools and university students. We do not have any data to support the use of the DeL tool for younger children. Some adjustments may be needed to assess students with a less developed written language than 11-year-olds. As noted above, the

DeL tool also has to be adjusted to socio-cultural contexts. This includes considering aspects related to demographic, geographic, age-related, and general cultural aspects. We have not tested the tool outside a national context, and do not have any concrete data to support how the tool would work outside a Danish context. In future work we will be collaborating with the TLTL group at Stanford University in order to test the DeL tool internationally.

As with all online surveys, the DeL tool requires a stable Internet connection and an internet-enabled device for each participant. During the assessment phase we encountered some network breakdowns, despite the fact that all schools declared their Internet access to be well functioning. In most cases, teachers and technical staff were unable to resolve technical problems, and we sometimes had to leave the schools empty-handed, and reschedule the survey. An off-line version of the survey might positively influence the number of responses, and thus limit the workload for implementing the DeL tool.

The wording of the question may have caused students to expect that they had been tasked with coming up with a finalized solution. This is particularly probable, as the educational systems, according to Biesta (2008) follows a discourse of learnification. Students are expected to know answers to specified problems. This might even be especially emphasized within STEM education. One does not do well on a math test by considering the math problem as wicked; instead, students are expected to see them as tame. The same may be said for tests in English (how to spell correctly, or structure grammar) or chemistry (balancing a chemical reaction).

Another point of critique would be that there might be a correlation between the degree of familiarity with the local context (dementia/nursing homes) and tendency to provide a finalized solution based on technical rationality. This can be seen in a few of the children's responses, in which they claim to have enough knowledge and experience with the context to suggest a solution. However, insight into the context could also work in the opposite direction, since such insight might make it easier to recognize the dilemmas and thus the wickedness inherent in the problem. We do not have data that suggest in which direction, insight into the context influences responses. In coming version of the tool, we will be asking respondents to state their prior knowledge of and experience with the domain.

The DeL tool was administered as part of a larger survey measuring the digital, technological, and design literacy of students (Hjorth et al., 2015). The students spent approximately 45 min completing the 227 questions in the survey. If more time was allocated to the DeL tool, we imagine that the students would find time to provide more comprehensive answers to the question posed. We have not tested whether response time has any influence on whether or not they take a stance towards inquiry.

We envision the DeL tool as a freely accessible online tool for K-12 schools to use to develop and refine their design education. This is not feasible in its present form. The preparation, implementation, coding, and analysis of the DeL tool are time-consuming, and demand some familiarity with assessment of quantitative data. In its current form, the DeL tool is suggested as a research tool only.

9 Conclusion

The aim of the DeL tool is to capture and assess the state and development of students' design literacy, when design education in maker settings is introduced into K-12 education. We conclude that the DeL tool provides valuable insights into how to assess design literacy among school children. It allows us to note that Danish K-12 students seem to primarily approach wicked problems as tame problems. That is, they do not approach wicked problems with a designerly stance towards inquiry. Instead, K-12 students seem to approach the wicked world with a stance of technical rationality, drawing on formalized, routine expertise. We conclude that students' stances towards inquiry should be taken into account when educators plan design processes in maker settings in education environments: If students are to engage successfully with design processes in their education, they need to become aware of the wicked nature of design problems, and through experience, learn how to apply a designerly approaches to inquiry and frame wicked problems. On the other hand, we have identified the capacity for dealing with wicked problems as an aspect of design thinking, which all students can benefit from. After all, the world they are going to inhabit is full of wicked problems. Thus, our data indicates the necessity for focusing on the understanding of designerly stances towards inquiry into wicked problems in K-12 education.

We propose the use of the DeL tool to gain insight into preconditions for design in education, rather than at the individual student level, for which it has not been validated. By using our DeL tool to investigate preconditions for working with making and design in education, it is possible to work with design in ways that are solidly grounded in data about students' stances on wicked problems.

Finally, we wish to invite others to join the ongoing work of developing this tool. Especially, we would like to see the development of a way to assess students' stances with regard to knowledge and knowledge generation through a design process.

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Notes

1. http://www.idc-sig.org.
2. http://www.isls.org/conferences/cscl.
3. http://www.isls.org/conferences/icls.
4. http://www.ccid.dk.
5. http://fablabatschool.dk.
6. https://tltl.stanford.edu/project/fablabschool.
7. http://www.r-project.org.

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Educating the Reflective Educator: Design Processes and Digital Fabrication for the Classroom

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ABSTRACT
Design thinking and digital technologies are increasingly introduced in education to develop children's design literacy. This shift demands a change in teachers' mindsets, capabilities and approaches to design and technology as well as new teaching practices. This paper reports on a research-based master's course developed to address and study the challenges that educators experience when teaching design in K-12 classes. We investigate three aspects that we argue are crucial when developing teachers' capability to teach design literacy to children: (1) ability to navigate a complex design process, (2) managing digital and analogue design materials and (3) balancing different modes of teaching. This paper demonstrates how a combination of design theory, in-school practice and peer-to-peer learning created a framework towards *educating design educators* – a framework that allowed us to investigate K-12 teachers' development of core competencies for bringing design and digital fabrication to diverse students. In addition, the study shows how the framework can facilitate and support co-development of new teaching practices.

CCS Concepts
• Social and professional topics~K-12 education
• Social and professional topics~Computing literacy

Keywords
Design literacy; Design education; Digital fabrication; Education; K-12; Expertise; Reflective educator; Design Thinking

1. Introduction
The research field of interaction design and children is currently experiencing an increasing attention towards integrating constructionist principles and digital fabrication technologies into formal and informal K-12 education [4, 34]. This turn is addressed by Schelhowe who has emphasized how digital fabrication[1] in education not only supports STEM (Science, Technology, Engineering, Math) related competences but also provides children with an opportunity to learn fundamental societal issues such as digital citizenship and complex problem solving [25]. Thereby, Schelhowe has broadened the scope of digital fabrication in education to also include a design focus on digital fabrication technologies; children should learn to become digital citizens and creative thinkers through processes of digital fabrication in education. This design focus has recently developed into a growing field of research that combines digital fabrication technologies with design thinking to teach design literacy to children [14, 29]. This newer research field provides theoretical [9] and empirical [29] grounds for the educational value of introducing design thinking, combined with digital fabrication, into K-12 education. As in [29] and [9], design literacy is here used to denote the aspects of design thinking, from which anyone may benefit when interacting with the world. Common notions are that design literacy should be taught through open-ended processes of working with real-world problems.

Existing empirical data supporting the key role of design thinking and digital fabrication is often based on informal settings [21] such as after-school computer clubs, university-workshops, and summer camps, where more and different resources are typically available if compared with traditional school settings. These studies, while documenting significant opportunities for students learning through design processes [16, 29], do not provide directions on how to successfully integrate design thinking and digital fabrication into K-12 classrooms and accordingly on how to prepare teachers for such integration. Thus, while there is an emerging field of research into how students can and should work with digital fabrication technologies in design processes [3, 16, 24], what the potentials of such work are for the students [16, 19, 20], and how to assess students' learning [9, 23], there is a lack of knowledge of how to prepare teachers to teach through design processes with digital fabrication in formal education.

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[1] Digital fabrication is a term, which has been used with diverse meanings. Here, we use the term rather inclusively (as it has been in much of the literature) to encompass the use of a range of digital technologies (e.g. 3D printers, laser cutters and programmable electronics) to create physical products or prototypes.

The research presented in this paper takes on the mission of understanding how to work with school teachers in order for them to successfully utilize design processes to address real-world or *wicked* problems [10] with their students. The course presented here was developed based on previous research into the challenges experienced by K-12 educators when teaching design processes in digital fabrication. Brennan [7] has described how teachers implementing open-ended design processes in digital fabrication in North-American classrooms experienced a loss of control and behaved in ways that were not in tune with students' expectations and the assessment culture that they were part of. In our research in Danish public schools [31], we similarly identified three central challenges to teaching through design processes in digital fabrication: (1) navigating a complex design process, (2) managing digital and analogue design materials, and (3) balancing different modes of teaching. To investigate alternative ways to prepare teachers to take on such challenges, we developed a master's course that integrated research-based knowledge and practice-based activities along three axes: (1) theory-based lectures and workshops, (2) peer-collaboration, and (3) teachers' practice in schools. This mix of activities enabled an integration of different fields of practice with the goal of *educating the design educator* within a context based on the underlying assumption that one does not become a designer or design educator by simply reading about design or design education. The design processes described in this paper rest on academic concepts of design thinking voiced by design researchers as [10], [22], [18], and [28], while the approach to teaching design is based on the design studio approach [27]. As shown in [29], digital fabrication offer opportunities to support what design researcher Donald Schön defines as a *reflective practicum* [26] – and such settings are essential if children are to engage in *designerly thinking and practice*. The main contribution of the paper is a discussion of how to create a framework for *educating reflective design educators* who can support students in such a reflective practicum. In our approach this so far involves preparing teachers for overcoming three central challenges of (1) understanding a complex design process, (2) managing digital technologies and design materials, and (3) balancing different modes of teaching involved in design and digital fabrication in education.

In the following, we present our method of investigating these challenges through a master's course. Second, we introduce the course and unfold three central challenges to design teaching in K-12, which the course is based on. Third, we introduce a framework for educating the reflective educator and present three examples from our case. We conclude the paper with a discussion of how our cases show opportunities for moving towards a new mindset, gaining a repertoire of working with diverse materials, and generating new educational practices.

2. Method

The case study presented in this paper aimed at investigating how teachers might become competent reflective educators in K-12 digital fabrication settings. Since there was no existing practice to investigate, this study was carried out as a research-through-design study, in which we created 'the object' of study and carried out research based on our own intervention in the field [17, 32]. In the present case, we developed the master's course on Design Processes and Digital Fabrication with the aim of investigating how to address three central challenges for teachers. The challenges, which we had uncovered in our previous research, were: (1) understanding a complex design process, (2) managing digital technologies and design materials, and (3) balancing different modes of teaching. We collected empirical data for the current research contribution by following specific teachers through the course. Apart from observations collected during the course's seminars, we shadowed two groups of teachers - during their group work and while applying their design process in the classroom at their schools. Additionally, we surveyed each teachers' knowledge and experience of working with design and technology before and after the course. Finally, we monitored each study group's design process, documentation and reflections via their online portfolios, and used final examination papers and submissions as a basis for the analysis. Each examination paper included a guide to understand each teacher's design process, and reflections on the practice of teaching design thinking to students.

Participants in the course were signed up based on interest and had been selected by project managers in the three collaborating municipalities for the FabLab@School.dk project. Therefore, almost all of the teachers had some (although often limited) prior experience with the technologies, and were especially motivated to work with digital fabrication in education. Participating teachers represented a wide range of subjects, from language to science, mathematics, crafts, and in some cases, 'FabLab' courses.

The analysis of how our framework and master's course supported teachers in overcoming the three mentioned challenges was split in two parts. We first analyzed video recordings from the course as well as classrooms' activities. Second, we compared findings from the videos with insights from teachers' (pre and post course) surveys and end-course examination papers. Based on the two sets of qualitative data, we engaged in an affinity-diagramming process [2, 13] and selected data to focus on and ultimately understand (1) whether a framework combining design theory, in-school-practice and peer-to-peer collaboration could be an effective tool to educate design educators, and (2) how the framework addressed the three previously observed challenges. Affinity-diagramming techniques enabled identification of coherent patterns in the three areas/challenges identified in the previous research.

3. The course

The *Design Processes and Digital Fabrication* course described here is a 5 ECTS[2] master's level module at Aarhus University, Denmark. The course was run as a pilot course in the Spring and Fall of 2016. The Spring course (February-June) is the focus of this paper and was attended by 26 participants from three participating municipalities. Participants were either practicing teachers (20) or educational leaders of central FabLabs in education (6) with the responsibility of servicing teachers in different municipalities. The master's course was developed within the FabLab@School.dk project, an ongoing Danish research project at Aarhus University in cooperation with Vejle, Silkeborg and Aarhus municipalities. The project is part of the global FabLab@School initiative founded at Stanford University.

The Danish research project focuses on FabLabs as hybrid learning laboratories, which combine digital fabrication, design thinking, collaborative idea generation and development of solutions to complex societal challenges. Emphasis is put on the creative process – from early ideation, sketching and mockup to actual prototyping. This focus on teaching design literacy calls for training teachers in approaches and mindsets involved in scaffolding students' design of possible solutions to wicked problems. However, as shown in [31], K-12 teachers tasked to

[2] European Credit Transfer System. 60ECTS is equivalent to a full year's work.

utilize design processes and digital fabrication to scaffold children in acquiring design literacy, face at least three challenges of (1) understanding a complex design process, (2) managing digital technologies and design materials, and (3) balancing different modes of teaching. Consequently, it is crucial to better understand what capabilities teachers need and how they might realistically develop new teaching practices to support students' design literacy. The master's course in Design Processes and Digital Fabrication was designed to get a direct first understanding of what capabilities teachers need to teach design literacy to K-12 students by addressing the three challenges identified in our previous research. Before providing further details on the current study, we will unfold the three challenges that were identified as part of a previous study named DesignThink in the next section.

3.1 Challenges for teachers

In connection with the intervention DesignThink, we studied teachers' implementation of a learning design, which was developed by us and implemented over an 8-week period by a group of teachers in their respective school environments. Through teachers' reflections on a blog and during interviews, we identified three central challenges experienced by the teachers: (1) understanding a complex design process, (2) managing digital technologies and design materials, and (3) balancing different modes of teaching. These challenges were identified among teachers teaching utilizing a design studio approach while focusing on teaching for design literacy. Based on our data and analysis, we argue that these challenges point to important aspects of reflective educator expertise.

The approach of the DesignThink intervention forged a focus on the ability to generate reflection and knowledge through an iterative and explorative process. This was counter to the more linear approach of producing functional, aesthetic or realistic products that the teachers' perceptions and experiences reflected. The teachers had little experience with addressing real-life contexts and in structuring more complex processes of digital fabrication in education. Accordingly, the teachers faced the challenge of *understanding a complex design process*.

Teachers in DesignThink worried about not being competent in handling digital technologies. We found that they were equally challenged in managing and handling analogue design materials, and that they did not appreciate the different qualities and affordances of externalizations such as sketches, mock-ups, etc. Accordingly, teachers did not develop unique design materials for framing and feedback of the students' process, or have knowledge or experience in moving between diverse, analogue and digital, during the ideation and fabrication process. They had trouble *managing digital technologies and design materials*.

The DesignThink intervention challenged teachers in several ways as they had to manage and switch across diverse roles: instructional classroom teacher; activities facilitator; and coach for each design group, to support students' processes through dialogue and reflective questions. The act of managing and continuously shifting across diverse roles challenged the traditional authoritative 'expert-role' that teachers often play. Teachers felt challenged by the notion of losing control of their classroom, and by the requirement to *balance different modes of teaching*.

The master's course at the center of this paper was developed based on this initial research, to investigate how teachers could develop a better understanding of addressing real-life problems through complex, iterative and explorative design processes.

3.2 Scaffolding the design process

The goal of the course described in this paper was to create and investigate a framework that, by combining design theory, in-school-practice and peer-to-peer learning, could be used to *educate design educators* and to enable the co-development of new teaching practices. A cornerstone in the course was a design process model (Figure 1) that we developed and refined through previous research interventions [29] to help teachers structure and navigate design processes. The model includes six important steps in design processes: *Design brief*, *Field studies*, *Ideation*, *Fabrication*, *Argumentation* and *Reflection*. Each step includes a set of concrete activities. We used model and concrete activities to scaffold teachers' practice throughout the course.

We have observed substantial benefits for novice design educators experimenting with the model in their own practice. We have also tracked how an increased confidence in using the model often implies increased capability to freely navigate and iterate across different parts of the process. Our model has been specifically tailored to the context of K-12 school. We emphasize research, investigation and field studies in the beginning of the process with a focus on exploring the (real-world) challenge for certain user groups or communities. We included *argumentation* as a separate and specific focal point, to emphasize argumentation in relation to produced prototypes or products. Reflection instead deals with the learning and reflection on overall process and learning outcome.

Figure 1: The FabLab@School.dk Design Process Model.

With the Design Process Model as key scaffold for teachers, we created the course here discussed to investigate ways of training K-12 teachers to overcome the three previously mentioned challenges.

4. Teaching design: A framework for educating the design educator

As previously stated, there is a growing focus on advocating design literacy through digital fabrication in K-12. Hence, it is crucial that we understand what capabilities a teacher needs in such contexts. Drawing upon well-established design literature on design practice and design thinking [10, 11, 18, 28], we believe that there are specific approaches and mindsets that are key for teachers to successfully scaffold design processes in the classroom (e.g. an appreciation of the complexities of the design process and a repertoire of past design processes and products). The literature provides cohesive insights into scaffolding students of different design disciplines (e.g. architecture and interaction design) to develop design thinking and expertise. A common insight in this body of literature is that students typically develop those skills by engaging in long-term projects, while focusing on real-world problems. This approach is referred to as *the Design Studio* [27, 35], which according to Stevens [33] represents a master-apprentice relationship at the heart of architectural education throughout its history.

The design studio approach was our starting point for understanding how to teach design literacy through digital fabrication in K-12. As depicted in the center of Figure 2, our course included three types of activities: workshops and lectures, peer-collaboration and in-school-practice. These activities were constantly informed and influenced by design theory as well as practice-based theory on how to teach design literacy in specific settings. Practice-based theory was often created when teachers shared their own practice with each other during peer-collaboration sessions – activity that typically influenced teachers' own practices in return. In the following sections we describe in more detail the three categories of activities that constituted our course.

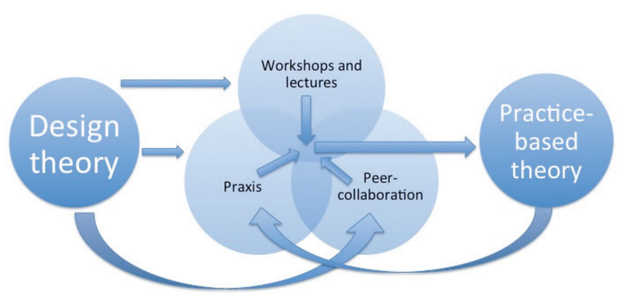

Figure 2: The framework for the master's course

To investigate and learn how to address the challenges uncovered in our previous research, our aim was twofold: (1) teach teachers by using existing literature and their own practice and (2) initiate the development of new practices of teaching. Additionally, the structure of the course reflected our assumption that design expertise is best learned by mixing practice with reflection on practice, and analysis of practice through existing literature.

4.1 Workshops and lectures

The course was founded on a mixture of literature on digital fabrication in education and pragmatist design literature, which was taught through lectures, group exercises and pre-work. Some literature was selected specifically to introduce the constructionist ideas of digital fabrication in education [3, 25], while other literature focused on developing an appreciation of the design process, and on understanding the notion of design thinking [10, 18, 28]. Some literature introduced ideas and techniques of ideating and prototyping with digital and analogue design materials [6, 8], while a set of teaching materials we had produced based on the design process model, guided participants through the whole design process. Finally, the literature included impediments for and an appreciation of different modes of teaching for design literacy through design processes and digital fabrication in K-12 [1, 19].

The theoretical part of the course was structured as three main seminars (6 days) of workshops and lectures over the course of 14 weeks. During these face-to-face sessions the focus was primarily on: lectures; group work based on own practice; participant presentations of own practice; class discussions; and guidance and feedback from peers and course instructors. As we highlight later, discussions and group work during these sessions sometimes triggered creation of practice-based theory for teaching design literacy in the context of the participating schools

4.2 In-school-practice

The theoretical part of the course was structured around teachers' practice, and participants were told to implement a learning design targeted at engaging their students in creating solutions for a real-world challenge. The challenge selected was *eWaste* – due to its complex nature, unquestionable environmental impact, relevance to technology practice as well as tech industry, and its potential to trigger awareness of local and global structures as a positive byproduct. Participants were equipped with research and data on eWaste through lectures and literature, which was connected to the 6-steps design process model as a framework for the design challenge. This was a starting point for participants (in groups, see below) to create their own learning design to be carried out in school with their own students. The eWaste challenge was divided into four case-areas, which teachers could choose from to focus their teaching: (1) What novel PROCESSES or SYSTEMS can alleviate or resolve the eWaste issue? (2) What novel DESIGNS and PRODUCTS can have limited eWaste impact? (3) What novel PRACTICES can help us deal with eWaste? and (4) What novel SOCIAL DYNAMICS can help us create eWaste-free futures? Based on the case and the design process in school, participants were asked to develop a teaching guide, which could be used by other teachers. This represented an important step for becoming and being a design educator.

4.3 Peer-collaboration

To enable a transformation of experiences in the Deweyian sense [12], we scaffolded a reflection process around the participants. Specifically, we set up loops of reflection-on-action [28] activities to expand teachers' repertoire using cases from their learning designs' implementation. This was achieved by creating study-groups of 4 participants who were required to spend 8 full workdays together during the 14-week course. Each group had to co-develop a learning design based on the eWaste case, and to use their study-groups to reflect on, change, and iterate on their design together. Meetings were typically scaffolded with a set of tasks to focus on – for instance, playing a design game to clarify goals for students' learning or activities, using video-recorded reflections of own teaching to initiate common discussions, planning the following weeks activities in the learning design, and reflecting on the design process by connecting theory and practical experiences. The study-groups were asked to document and reflect on their design process using a blog as a collaborative portfolio and reflection tool.

5. Investigating challenges through the case

By connecting peer-collaboration and in-service practice with a theoretical perspective on design thinking and digital fabrication in education, we aimed at investigating teachers' potential to take on the three identified challenges to integrating digital fabrication in a design literacy perspective in K-12. In the following setions, we will discuss, how the course served to scaffold teachers' development of a better understanding of (1) design processes, (2) materials, and (3) modes of teaching.

5.1 Understanding a complex design process

In [31], we described how teachers lacked an understanding of the complex design process. More specifically, "[r]ather than an explorative design process, their perceptions reflected a more linear discourse of developing new ideas and functional and aesthetic products." A central aim of the course framework was to gain knowledge of how to develop teachers' perception toward a more complex, iterative, and explorative understanding of the design process. Apart from using the design process model to scaffold more structured steps in the process, participants were asked to develop goals, activities and design materials to fit each step. Moreover, they had to create a framework to scaffold their students' work, helping them to move from specific activities to reflective and iterative phases. In the next section we overview a presentation and subsequent class discussion where the inclusion of teachers' own practice lead teachers to gain new insights into the open-endedness and complexity of design processes.

5.1.1 A HAT: Judging student's ideas

A general problem of teachers' understanding of the complexity of the design process is that it counters traditional curriculum-based learning. We observed that teachers often had a tendency, even in the early stages of the design process, to evaluate students' ideas against the design brief instead of for instance helping students develop ideas further before judging them. In brief, teachers were more focused on whether or not ideas were "right" or "wrong", instead of helping students develop ideas through iterations.

This phenomenon was palpable when one group during a presentation mentioned their challenges with students, who developed *design fixations* [15] on irrelevant ideas. Students had been tasked with coming up with ideas for a product that could create awareness about eWaste and a group of students wanted to make a hat – for teachers this was a "wrong" idea. However, during a seminar, discussions between researchers and teachers generated a shared understanding that a hat could in fact become a good product for creating awareness about eWaste. This example well demonstrates that teachers can display discomfort with and underestimation of the roles that uncertainty and messiness play in design processes. Rather than judging and discarding students' idea as irrelevant, teachers could have explored with students how the idea had come about and what visions and design they were planning on developing. Discussions about research findings, user groups, development of multiple ideas (not just one), discussions of prototyping, materials, and technologies, could all have been fruitful ways of testing the students' idea in relation to the given task. This would have structured the students design process, and given them ownership and understanding of their own ideas, driving the process forward while developing solutions to the requirements of the design brief. In short: a better understanding of how design processes can develop in different ways and the role of working through iterations while not knowing the outcome, would have helped these teachers avoid premature judgements and helped students develop, iterate and evaluate their idea more thoroughly.

By combining design thinking literature with experiences from the teachers' own practice and collaborative reflections in groups, some of the teachers developed a budding appreciation of iterative and messy design processes. These teachers asked their students to reflect on the relevant *qualities* of their design in relation to the wicked problem, rather than judging 'right' vs. 'wrong' solutions during the early stages of the design process.

5.2 Managing digital technologies and design materials

In the work reported in [31], students and teachers struggled with the idea of exploring concrete challenges and building knowledge through use of different design materials. With materials ranging from post-it notes, posters and sketches to mock-ups and prototypes incorporating digital technologies: "…the teachers found that they lacked competences to support the students in transforming their own and given design materials into relevant design concepts." Participating teachers often felt challenged in supporting their students in making meaningful connections between analogue design materials and the subsequent work with digital materials (e.g. Arduinos, 3D software and printers, and LittleBits). Therefore, students became too focused on using either digital technologies or analogue design materials.

In our course there was a variety of different materialities, from design games developed for specific activities with the teachers to a focus on analogue and digital materials as flexible and transformative materials in the design process. From seminar 1, teachers were tasked with making sure that every activity with their students resulted in concrete design output, which students could carry into the next phase of the design process. This focus on design materials was also evident in the chosen literature (which for instance included [5, 8, 25]). In the following example, we describe how all groups of teachers came to a new understanding of the affordances of different types of externalizations. The example links one group's new insights to their reflections on using different materials at the appropriate time during the design process.

5.2.1 The Video Design Game

Reading about the use of materials in design processes was an important part of the course. Additionally, it was essential that teachers during the course could gain hands-on experience as well as practical appreciation of engaging with diverse materials. Teachers worked with design materials during seminar two of the course. Here, they were asked to create a video to describe, analyze and reflect on a feedback session from their own practice [30]. Each participant filmed a short session involving themselves and a group of students. During the course, each study group watched the videos and described their related observations (using post-it notes). We then used a poster and a game design for teachers to share their post-it notes. The game design acted as a scaffold for better understanding the situations in the videos. An important point of the work was to familiarize teachers with the need to have a practical outcome – in this case conceptualizations or rules-of-thumb – and to demonstrate how the outcome could be developed though a structured process, without predefining results.

The Video Design Game helped teachers enrich their understanding of the role of externalizations in ideas' communication and assessment. The value of interacting with the students' physical models and sketches emerged as an important point for the five teachers' groups involved in this reflection-on-action. The video game work demonstrated to teachers their lack of physical engagement with materials and mock-ups: they 'spoke about' but did not 'engage with' students' materials. In one group a teacher had however worked specifically with visualizing through sketching students' ideas and articulations while engaging with their prototypes. This group (group 5) constructed a principle for giving feedback on student ideas: "The spoken word should never stand alone". This rule of thumb focused on the importance of drawing, sketching or engaging with models while giving feedback. This group developed a very strong focus on externalizations and in their final exam paper, they reflected:

"The work with mock-ups and rapid prototyping has maintained student interest through the process and caused students to be motivated longer in the process without giving up. This externalization of students' ideas, which is recurring in our process, gives students concrete objects they can see, feel and transform continuously. They get a physical object, which they can talk about and develop further together. This also creates a more shared language among the students."

Further, this group demonstrated in their final exam paper how they learned to balance digital and physical technologies throughout the design process with their students. In their case technologies were introduced only when they added value to the design process. For example, one group of students were designing a talking trashcan in order to create awareness about eWaste. In the early phases they worked with quick mock-ups (horizontal prototypes) and only when it was time to test the interaction they added a homemade tinfoil switch and a MakeyMakey to the garbage bin to control sounds. For this group, working with diverse design materials as a central focus throughout the design process turned out to be a concrete and effective way of 1) focusing their own practice of creating a maker setting for an iterative design approach in the school context, and 2) keeping the students engaged and focused through the entire 10-week design process.

Multiple factors enabled an appreciation of how to manage different materials: literature and lectures; demand for material outcomes for all activities throughout the design process; and facilitated games and discussions with design materials. In the concrete example of the Video Design Game, teachers experienced working with a design material (the game) to respond to a demand for material outcomes and the experience enabled them to understand and appreciate the importance of externalizations.

5.3 Balancing different modes of teaching

In [31] we identified challenges that originated because of teachers' lack of experience with the modes involved in teaching through design processes. Specifically, teachers felt a loss of control of their traditional 'expert' roles and lacked the capability to navigate the design process in the classroom context. To address these challenges, the previously mentioned Video Design Game was centered on teachers' roles. Since to our knowledge there is no body of literature on K-12 teachers' roles in design processes, we decided to use Schön's description of professional design educators' roles in design processes [26] and asked teachers to engage with the that piece of literature. In Schön's archetypical case, Quist teaches the architectural student Petra by enriching and developing her ideas for a school on a slope and does so through a combination of sketching (demonstrating) and meta-communicating (telling). In our seminar with teachers, we discussed the differences between Quist's design studio with architecture students and a K-12 classroom setting, of which another empirical example was given. It was crucial for participants to realize that knowledge of how to teach design processes and digital fabrication in K-12 did not yet exist, and that they were engaging in co-developing a new practice. After discussing the examples, teachers were asked to create videos of each other's practice and to describe, analyze and reflect upon the roles involved. In the following section we discuss an example of how one group of teachers developed new insights into modes of teaching design in K-12 by discussing one of the produced videos.

5.3.1 *Shifting perspectives*

In the Video Design Game workshop, group 4 spent a lot of time discussing different teacher roles and modes of engaging with students. An important area of discussion centered on the effect that teachers could have when they took the role of "telling" that often caused students to steer in specific directions. Teachers felt the dilemma of which role one should take when giving feedback on students' ideas. In the final stage of the Video Design Game, while developing new principles for teaching design and digital fabrication, the group elaborated: "attention to use of teacher authority – do you wish to point to a direction or not?" In their final examination paper, Group 4 included transcript of a short video of a teacher who was about to stop the development of an idea while playing the "telling" role:

"…I'm actually in doubt about whether or not this is possible. In any case, you have to direct this towards…well…here, I think you should think about…well…No, you know what? I won't shoot it [the idea] down. I think we should choose one of your solutions, and then work with that, and then we might realize at some point, whether it is possible or not. Perhaps…let's say we built something onto these glasses. Can you foresee any problems, any design problems we might have to face?"

In the final exam, Group 4 reflected on how the teacher in the example was about to "shoot down" an idea that he believed "wrong". The teacher was concerned that the students would not be able to create any meaningful prototype, and therefore he was on the verge of terminating their idea in an authoritative, telling role. In the example, he instead decided to engage with the students' idea, taking on a more democratic and explorative role. Group 4 reported this development to be a consequence of lessons learned when playing the Video Design Game.

We addressed the challenge of balancing different modes of teaching using three strategies: teachers were asked to read classical literature on the teacher role in Quist design studio [26], and to engage in lectures and group discussions on this archetypical example in comparison with examples from their own practice. This mix of theory, practice and peer-to-peer learning enabled teachers to create new insights on their own teaching. The exam papers from several groups suggest that the teachers reflected on their role and authority with more nuanced perspectives, and began to co-develop new teaching practices based on the course.

6. Discussion: Educating the reflective educator

In this paper we discussed a framework for introducing K-12 teachers to design processes and digital fabrication. Research and analysis of teachers' work using this framework was possible thanks to a master's course that we deliberately designed with a dual purpose (1) for K-12 teachers to develop the capabilities needed to school children with design literacy and (2) to investigate teachers' acquisition of such capabilities *(educating the reflective educator*). As demonstrated in our examples, some teachers developed better understandings of the nuanced complexities of the design process, how to manage diverse materials, and how to balance different modes of teaching. As identified in previous research, these three areas were all challenges to teachers' integration of digital fabrication in K-12 education. While we are aware that our analysis may have different results in different situations or contexts, we present three aspects, or qualities, of our framework that positively reinforced and supported the teachers in the following sections.

6.1 Towards a new mindset

Understanding and navigating design processes is not an easy task, and the teachers in our course did not become professional designers, or design educators, over the course of one semester (single subject). However, our analysis of the case suggests that through the 3-way structure of design theory, design practice and peer-work and reflections, teachers developed a more complex understanding of design processes and the mindsets necessary to scaffold and navigate a complex design process for and with their students. In the post-survey, teachers were asked through an open-ended question what they felt they had gained from the course. On this item, 7 out of 19 respondents (37%) stated that they had experienced a shift in their mindset; 6 (32%) stated that they had gained a better understanding of design processes; and two teachers stated that they had acquired more language for talking about design processes in K-12 education. One teacher stated that she had learned "…to look at design differently and as a process, which fits well into schools in 2016, since it is actually mandatory to teach creativity, critical thinking and cooperation [in Danish schools in 2016]." On a Likert-scale in the post-survey 18 out of 19 teachers (95%) agreed that their students had become better at design processes, while 13 (68%) agreed that their students had become better at repeatedly ‘trying again’ and not giving up.

More work is needed to assess teachers’ and students’ capabilities in the context of teaching design and digital fabrication in K-12. What our analysis however suggests is that by combining literature with peer collaboration and the development of a hands-on design process, it is possible to enrich teachers’ capabilities and to boost their confidence in taking on the challenge of supporting K-12 students in working through the complexities of the design process and in developing design literacy.

6.2 Gaining a repertoire of working with diverse materials

During our master's course, teachers had the opportunity to appreciate how to manage different (digital and analogue) design materials thanks to literature, lectures and practice-based work. Additionally, we emphasized the focus on materials by requesting within all activities to provide material inputs and outcomes, and by facilitating at each seminar a series group discussions mediated through unique design materials. This work led many groups of teachers to include reflections on externalizations in their exam papers and to reflect on the principles for teaching design processes and digital fabrication in K-12 developed during the course. Our data suggests that an emphasis on creating design materials to scaffold certain goals of particular design activities, prompted teachers to carefully consider materiality throughout the process. As a consequence, they were in a position to scaffold students’ step-by-step process using analogue design materials and digital technologies.

In both pre- and post-surveys, teachers were asked to choose, from a list with 16 relevant options, the 5 most and 5 least important parts of a design process. Their answers display an interesting shift. On the pre-survey, 25% of the responding teachers had selected building models (e.g. in cardboard) as one of the five most important parts of a design process. On the post-survey, this number had risen to 40%. Further, whereas 40% had selected building models (e.g. in cardboard) to be among the five least important parts of a design process in the pre-survey, none of had chosen the building of cardboard-models as the least important aspect on the post-survey. Overall, this suggests a significant shift in teachers’ understanding of the value of analogue materials in the design process.

Gaining a repertoire of using a range of materials takes time. However, for some teachers the appreciation of different types of materials lead to an understanding of how to manage a diversity of digital and analogue design materials in various phases of the process. Thus, we argue that an increased repertoire of working with materials could increase teachers’ ability to frame and manage a complex design process.

6.3 Generating new educational practices

By mixing the theoretical example of teaching roles with own practice and peer-to-peer collaboration in the Video Design Game, both teachers and researchers created new insights around different modes of teaching, including the need to balance the traditional authoritative *know-it-all* teacher role with a more democratic and explorative teacher role that focuses on framing, investigating and posing questions. The wicked problem of electronic waste offered teachers the opportunity to work with the framing and exploration of a real-world problem as part of their own practice. The central qualities of this problem was that it is real, current, global and in need of exploration and re-interpretation by teachers. Without predefined outcomes to the design process, teachers had to continuously review their ways of *framing* teaching activities, rather than defining outcomes. This exercise in ‘loosing control’ in a traditional curriculum-led sense prompted development of new teaching practices and principles. Whereas the master-apprentice relation in the design studio [27] is a tested approach, K-12 educators do not have the same expertise as design educators, and their students lack the motivation and capabilities of full-time design scholars. Hence, teachers in K-12 settings must develop new practices to integrate design and technology into the classroom and to carefully balance explorative and iterative approaches to problem solving with challenging school contexts including for example required learning goals, assessments, diverse groups of children, schedules, and multiple subjects throughout the week.

Overall, the focus on complex problem solving through the eWaste case gave weight to understanding a wicked problem, generating insights from field studies, and working in structured ways to generate relevant solutions. There were many possible levels of engagement in the problem, which gave different groups of teachers and students the possibility to identify and frame the level they preferred to engage in: from creating ideas, prototypes or products for the Ghanaian youth, to focusing on their own local environment, by for instance creating a hat or a trashcan to create awareness in their own school. Simple applications of technology to students’ immediate ideas were not in focus – instead, the scope of the design brief and approach broadened the necessity to build a repertoire for designing – using both analogue and digital materials. Our research suggests that this enabled teachers to shift their focus from pre-defined learning goals (e.g., using set teaching materials) and fixed technologies (as closed entities) to an understanding of the different *properties* and *affordances* of diverse materials in different steps of the design process. Our research suggests that understanding technologies and design materials as flexible materials in a complex design process, allows teachers to have more flexibility with regards to modes of teaching.

7. Conclusion

Based on analysis of qualitative and quantitative data gathered from the master's course on design processes and digital fabrication, we demonstrated how a framework that combines design theory, in-school-practice, and peer-to-peer learning can be used to *educate reflective educators*. The framework functioned to address three central challenges that we found to be crucial in the development of capabilities for K-12 educators: (1) developing teachers' mindsets, (2) gaining a repertoire of working with diverse materials, and (3) generating new educational practices. More research is needed to identify other relevant aspects of becoming a reflective educator with digital fabrication in K-12. Further, there is need for research that links teacher mindsets, repertoires and practices to students' attainment of design literacy in schools. Within this context, our research suggests that a strong focus on design thinking and complex problem solving can strengthen teachers' abilities to structure and manage design processes in digital fabrication in K-12, while keeping students motivated and shifting education's focus from predictable learning outcomes to reflective and transformative educational practices.

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Articulations on form properties and action-function couplings of maker technologies in children's education

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ABSTRACT

In this paper, we present a framework to expand the design language used to articulate form properties and types of feedback that happen between children's actions and the intended functionality of maker technologies. Based on field observations in Danish schools we analyze children's (aged 11–14 years old) interactions with three maker technologies used to work through design processes in school maker settings. Our findings are beneficial on three factors for designers, researchers and teachers involved in work within maker contexts. (1) Reflections on form properties of maker technologies, (2) analysis of relationship between user action and technology function (action-function couplings), and (3) how this relates to feedback when children use these technologies to design digital prototypes. Designers can use the presented framework to improve existing, or prepare them for future designs. Researchers can use the expanded design language to analyze maker technologies in the context of school maker settings. Finally, teachers can make better decisions on how and when to use different maker technologies when school children work through design processes. (Do it yourself/together.)

1. Articulations on form properties and action-function couplings of maker technologies in children's' education

In this paper we present a framework for analyzing *form properties* and *couplings of action and function* in relation to *feedback (action-function coupling)* of what we define as *maker technologies* used in primary and lower secondary education (*school* from here). With form properties we referrer to the various aspects that constitutes the formgiving of artifacts. Action-function coupling has to do with how the action of interacting user is related to the functionality of the artifact (in this case maker technologies), and how this functionality is communicated through feedback.

The framework is an initial attempt at developing a design language to describe and analyze form properties and interaction couplings of action and function, based on three maker technologies used within school maker settings. The framework aims to support designers, researchers and teachers in articulating form properties and couplings of action and function of these technologies. Such articulations are a fundamental element for people involved in a knowledge-constructing design culture, not only for designers, but also critics, clients, children, teachers, etc., so they can share thoughts, debate, challenge, extend or simply reject [1].

Our definition of a maker technology, is a technology that is used in maker or hacker spaces. Their design focus on giving its user the ability to make and design new analogue and digital artifacts, and blend the space of digital- and/or the physical interaction. The technologies that we have been working are consumer products as opposed to professional industry products. The first are meant to enable personal and collaborative DIY/T design. Professional technologies can also be defined as maker technologies, but since we are working with school children, we restrict ourselves to consumer products that are available in the Danish public education.

Scholars have already given various accounts of successful teaching and learning with maker technologies, and have described the promising educational potentials for children[1] [2–4]. Recently more attention been given to broadening the design language of maker technologies as can be read in [5–8]. The framework contributes to the field of Interaction Design and Children by expanding the *design language* [1, p. 140, 9, p. 18], used to describe, analyze and discus the design and implementation of maker technologies in schools.

Our work has its empirical basis in interventionist field studies of children's (aged 11–14) interaction with maker technologies as part of a design process. We used anthropological ethnography

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[1] In the remainder of this paper, the term 'student' referrers to children.

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methodology [10] as the overarching frame for data collection. We combine our empirical studies with previous published literature that touches upon description and analysis of children interacting with maker technologies. Our studies resulted in articulations of possible form properties, and action-function couplings, which we argue are important aspects when trying to understand interaction qualities of maker technologies, and how individual technologies differ from one another. We compile our findings into a descriptive framework that we argue to be relevant for researchers, designers and teachers, and how they can articulate themselves about maker technologies. Our framework does not prescribe how to design or implement maker technologies, but aims support reflection on decision-making, or in the words of Stolterman: "*support by being 'prepared-for-action', not 'guided-in-action'*" [11].

Our intended purpose with this paper, and the FabLab@school.dk[2] research project, is to transform the current state of design education in primary and lower secondary. One of the ways that we do this, is through the design of frameworks and language that can help articulate how to successfully deal with some of the new educational challenges that design and making presents in schools [12]. We position our design research activities as a context driven study of current practice in schools [13]. As argued by Fallman and Stolterman [13,14], this calls for a certain level of commitment to involvement and participation in helping to create a preferable future. It requires design researchers to not stand on the sideline as a detached observer, but to participate in the activities they are involved with. Following this advice, we not only observed the situation, but also planned and facilitated the individual lessons in cooperation with the local teachers. Thus, our empirical investigations are shaped and guided by the particular settings that we participated in. Later, we will describe in detail how we participated with schools in developing design education in maker settings. Authors like Nelson & Stolterman, Löwgren & Stolterman (2004) and Fishkin (2004) [1,15,16], have long argued for the benefits of developing a *design language* that can provide designers and stakeholders with richer and more nuanced ways to articulate aspects of interaction designs and the process. A well-developed design language supports people (not only expert designers) in being able to express design ideas and qualities. One such endeavors can be seen in Blikstein's conception of *selective exposure* (how different parts of a digital artifact are exposed or hidden) [7]. We align ourselves with this work, in order to provide designers, researches and teachers with an extended language of qualities on three maker technologies (Picture 1).

This paper is laid out as follows. First, we provide a literature review of design literature and the introduction of ideas from the maker movement into children's education, followed by an overview of different maker technologies. Second, we give a brief historical overview of design research, from its focus on semantics to the contemporary focus on embodied interaction. Third, we unpack the concepts of form properties and feedback within the field of embodies interaction. Fourth, an account of the methods used to analyze three different maker technologies. Fifth, we present our framework on form properties and feedback. Finally, we discuss the validity of our framework and its potential contributions and limitations, followed by our conclusions

2. Related work

In this section we review related literature in order to inform our arguments for the formation of a framework for articulation of maker technologies' form properties and action-function couplings. First we review contemporary understanding of maker phenomenon within educational contexts. This is followed by an overview of frameworks currently available for analyzing and describing maker technologies used in children's education. Lastly, we present theories from existing design literature to inform our framework, and what constitutes artifact form properties and action-function couplings.

2.1. Maker movement and its place in children's education

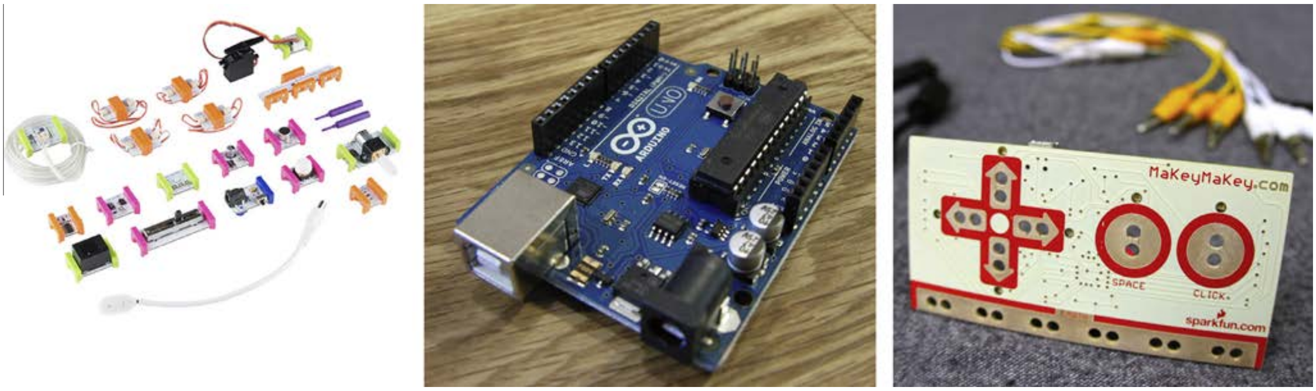
There is a growing interest in incorporating maker settings in children's education. According to Martinez and Stager [17], these types of settings presents new opportunities for children to acquire new knowledge and skills, not only in subjects such as engineering and science, but also in regards to design and creativity. By deploying a multitude of toolkits, machines, and design materials for making, students will supposedly be able to take control of their lives and learning through the "*act of creation with new and familiar materials*" [15]. Maker settings provide researchers with new opportunities for investigating the potential benefits of applying design thinking as part of children's education. Examples of such investigations may be found in the work of [12,18,19]. These scholarly efforts often relate to technology, design, and hands-on making, and how the associated artifacts and activities may improve general education and prepare students for a complex world that increasingly relies on digital technologies [3,5,17,20,21]. Much research revolves around terms such as "DIY," "hacking," "making" [22], "crafting" [23], and "tinkering" [24]. Common to these terms is that they have to do with some kind of creation or design with materials, both physical and virtual [25,26]. Historically, maker settings have been community-driven by people with common interests, often in computers, science, or electronics, enabling them to meet, socialize, and collaborate (e.g. The Geek Group, founded in 1994 [27]). Currently, there is a great surge in maker settings in a wide range of contexts – from lower-primary to museums, and higher education.

We focus on *design education* as described by scholars such as Schön [28,29], Löwgren & Stolterman [1] and Cross [30]. This paper is framed within the context of children working with design thinking and practice, such as dealing with complex societal challenges. Our analysis should therefore be viewed in terms of how maker technologies gets appropriated by children actively working through a design process, not in terms of structured tuition and well-defined learning goals.

2.2. Educational maker technologies

We have seen a rapid expansion of educational technologies that focus on empowering children to engage in making. Today's educational maker technologies are informed by research and technological development that stretches back to the 1980s [20,31]. These developments had a strong commitment to cognitive constructivist theory of education inspired by Piaget. Later, Papert developed the concept of constructionism in order to focus on construc*tion* rather than a philosophical –*ism*. Papert exemplified his ideas through the design of the Logo programming language, and later Lego Mindstorms [20,21,32]. Examples of technologies that are based on the similar design principles can be found in technologies such Bloctopus [33], LilyPad Arduino [34], LightUp [35], LittleBits [36], ShrinkyCircuits [37], Scratch [38] and Arduino [39]. The designers of these technologies often claim that they supports specific learning goals, e.g. Scratch for learning to program, or LittleBits for learning electronic circuits. However, learning goals are not always communicated clearly through the technology. As is always the case with technology, the use context becomes a strong factor in determining the intended use. Scratch might be intended to help children learn to program, but it can also be used in other contexts with different

[2] http://fablabatschool.dk/ (accessed 20-01-2016).



Picture 1. The technologies studied in this paper: (1) Arduino Uno [39], (2) Makey Makey [40] and (3) LittleBits [36].

goals. Thus, Scratch is a means to an end, where this end might be learning how to program, but it might also be something different from what the Scratch designers intended.

2.3. A brief historical overview of design research and its contemporary focus on embodied interaction

As pointed out by Sanders [41], various mindsets and approaches exist within the field of interaction design. These mindsets and approaches all employ different takes on how to design and communicate knowledge and meaning through interaction between an artifact and its user. Two examples of different mindsets and approaches are *participatory design* (PD) and *human-computer interaction* (HCI). The different mindsets can be described as a continuum between an *Expert Mindset* and a *Participatory Mindset.* The expert mindset entails *designing for people*, and refer to people as "subjects," "users," "individuals," etc. Opposite to this mindset stands the participatory mindset. This mindset focus on *designing with people*, refer to people as "partners," "experts," and "co-creators" within domains such as living, learning, working, etc. We align ourselves with the PD mindset since we are partnering with locale schools. In this paper, we will specifically focus on two other seminal paradigms within design practice and research: *the semantic- vs. the direct mindset and approach*.

2.3.1. The semantic mindset and approach

The semantic approach is often based on an expert mindset [41]. This mindset focus on the semantics of artifacts and human cognition, and was popularized by Norman [42,43]. This mindset focus on representation and interpretation of semantics, i.e. symbols, signs, icons and metaphors. The basic idea is that the appearance of the interactive artifact communicates its meaning through reference to metaphors or existing concepts that people might be familiar with [44,45]. A classic example of this approach, is the use of labels and icons on videogame controllers (Picture 2). In order for people to understand the meaning of the signs on the arcade controller (Picture 2), they need to interpret the icons (X, L1, Start, etc.) and how each button is mapped to a specific, but changing, function in the game. One might think that the 'Start' button starts the game, or that the 'Select' selects items in the graphical user interface (GUI) represented on the TV screen. However, people familiar with interacting with a PlayStation knows that the 'Start' button is used to pause the game, and that 'X' selects items rather than the button labelled 'Select'. Furthermore, there are regional difference in terms of how the buttons are mapped. In Japan the 'O' button is used to select items in the GUI, and 'X' is used cancel operations, which is opposite in European versions

Picture 2. Example of the use of iconography and presentation on an arcade controller.

of the same games. From the semantic mindset, this would be considered bad design.

Despite the possible ambiguity of semantic interpretation, the semantic approach is useful for purposes like natural spatial mapping [42,43]. To illustrate natural mapping, consider the use of labelling on kitchen stoves with different arrangements of burners and controls in Fig. 1. On the left, the knobs are not laid out as the stoves, whereas they are on the right, thus making it more intuitive to understand which knob controls which stove.

The semantic mindset approaches design research with an expert mindset to collect, analyze, and interpret data in order to develop specifications or principles to guide and inform design of products and services, thus making it easier for users to compare to an existing concept or product ("this is like...", "this is the same as the other games..."). However, interaction with digital artifacts such as computers is often abstract and do not have natural spatial meaning, nor any standardization for what different signs referrer to (e.g. the above arcade controller). Little attention is put on the actual *actions* of the interacting user. Rather, semantic appearance is seen as the primary way to communicate meaning to people, which might create arbitrary couplings between actions that trigger a particular function. In contrast, the direct mindset focuses on how meaning is communicated in respect to people's sensory body perception actions.

2.3.2. The direct mindset and approach

In this paper, we also take on a mindset and research approach that focus on "embodied interaction". Embodied interaction was popularized by Dourish as the "*the creation, manipulation and sharing of meaning through engaged with interaction with artifacts*" [46]. Dourish states that in order to design for free and playful interac-

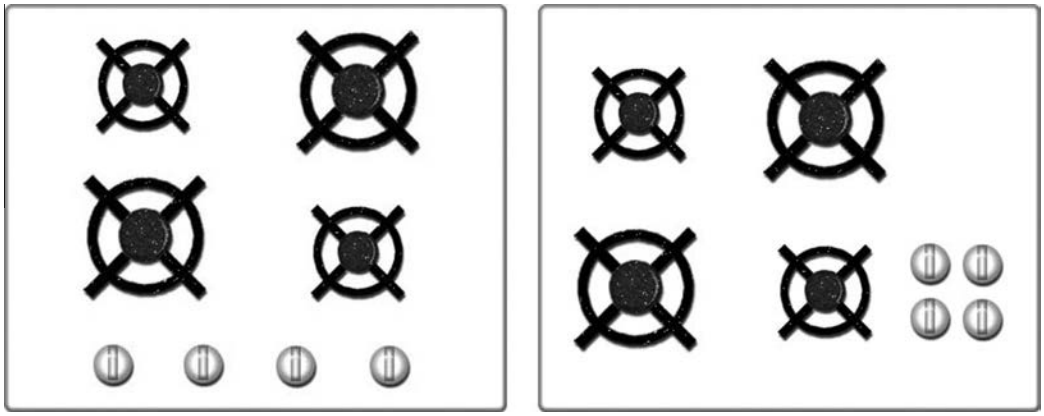


Fig. 1. Poor (left) vs. good (right) mapping.

tion, the interactive artifact in question should "*make information available to the user to guide their activity moment by moment*" [46, p. 160].

As an extension on Dourish's early work on embodied interaction, Djajadiningrat et al. describes two options for approaching the creation of meaningful appearance and action with digital artifacts [47] (Fig. 2).

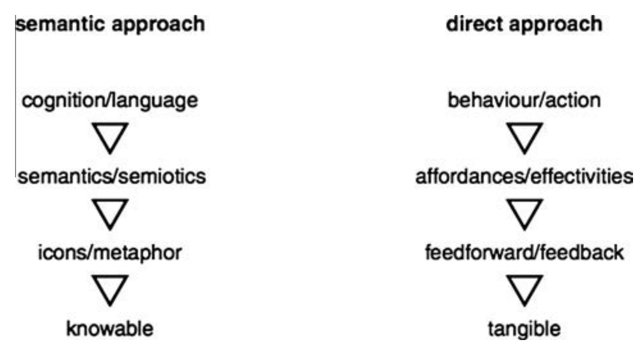


Fig. 2. The semantic vs. the direct approach (taken from [47]).

The first option is the semantic approach as previously described. The second is the *direct approach*. This approach starts from the aesthetics of human behavior and action, with focus on how meaning is communicated and felt through sensory body perception. The aesthetics we work with is that of interaction, not of semantic interpretation. The direct approach regards perception, motor-skills and emotion as important factors when considering how meaning is communicated and felt through interaction, and not "*as a kind of sauce that be poured over the design once the hard-core functional and usability work is finished*" [47]. We use the direct approach, as the design field move from graphical representations on a screen, to physical and tangible artifacts, as is also the case with maker technologies [48].

The direct approach offers many analytical opportunities for the field of making within children's education. Here, tangible artifacts are often part of the making process, e.g. robots, microcontrollers or simple electronics. We align ourselves with Djajadiningrat et al. in that "good" interaction design respects all of human's skills: cognition, perceptual-motor and emotional skills. However, we will focus on children's perceptual-motor and bodily sensory interaction with maker technologies. With perceptual-motor and bodily sensory perception, we referrer to what people can perceive with their senses and what they can do with their bodies.

2.4. Types of feedback

In order to frame our direct approach analysis, we appropriate the work of Wensveen et al. [49]. In their paper, Wensveen et al. focus on how people's action and the artifact's function are coupled through *feedback* and *feedforward* of how information and meaning is communicated to people. In this paper, we only focus on feedback.

Feedback is a common concept within interaction design. We will be using the same definition of feedback as Wensveen et al. [49, p. 179]: "[*feedback is] the return of information about the result of a process or activity*". Feedback is used as a technic for avoiding the people getting lost in their interaction, which informs them about how their actions is coupled to the function of the artifact in question. The following example illustrates the idea of feedback (Picture 3).

The form of the vinyl record and the circular platter are similar, and the hole in the middle of the vinyl fits the small metal pin in the center of the platter on which the vinyl is placed. When the DJ pushes the start/stop button on his turntable, he feels the button move by a gentle resistance followed by a click sound and a red light. He hears and sees the platter starting to spin. By looking at the inscribed spiral groove in the record, he is able to see the different parts of the music on the record. He lifts the tonearm that is constrained to move from the outer to the inner part of the record. He drops the pick-up needle on the record and hears the music, not only through the speakers, but from the actual connecting point of the pick-up and the record.[3]

The example illustrates feedback: the click resistance and sound of the button, gives instant feedback that makes it clear that actions were successful. The functionality of the turntable is further reinforced as platter spins. The form of the vinyl suggests that it should be placed on the platter. Touching the platter have direct effect on the audio output, and it can be felt how the rotation speed of the platter is directly coupled to the tempo and pitch of the music.

The coupling of action and function is tied to communication of feedback information. We define couplings of action and function as a continuum from *direct and natural coupling* (intuitive interaction by unification on as many aspects as possible) to *indirect and unnatural coupling* (non-unification function leads to non-intuitive interaction) [47,49]. By unification of action and function, it becomes possible to generate feedback that informs and guides people's interaction. Wensveen et al. [49] distinguishes between

[3] Most turntables also use semiotics to communicate the individual functions of buttons., e.g. start/stop. However, the point is that people are able to feel, see and hear how their action affects the function of the turntable.

Picture 3. Photo of the various parts of a DJ turntable.

three types of feedback information: *functional, augmented* and *inherent*. These three types of feedback makes the basis for different ways of communicating meaning and information to people, which we will operationalize in our analysis. Thus, in order to restore intuitive interaction, the designer needs to focus on how information is communicated through feedback.

2.4.1. Functional feedback

When the DJ sees the platter starting to spin, he immediately receives information about his actions, and his initial needs and desires to hear music are met. The feedback relates directly to the main function of the artifact; playing music off vinyl records. Functional feedback is therefore defined as "*the information generated by the system when performing its action*" [47,49]. Thus, the functional feedback is direct coupled to people's actions. When this is not possible, which is often the case with digital technologies, additional information is needed.

2.4.2. Augmented feedback

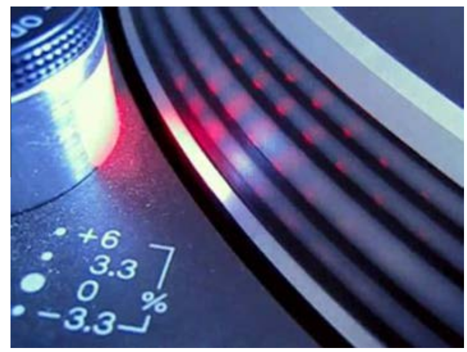
Augmented feedback is defined as "feedback coming from an additional source that does not stem from the action itself, thus appealing to cognitive skills rather than perceptual motor skills". It refers to information not coming from the action itself. E.g. when the DJ needs to calibrate on pitch on his turntable, he uses a light that flashes onto the side of the platter (Picture 4). This creates a pattern that functions as augmented feedback, which referrers back to the labels next to the lights, which informs the DJ about the internal state of the turntable.

2.4.3. Inherent feedback

Finally, inherent feedback is "*information provided as a natural consequence of making an action. It is feedback arising from the movement itself*" [50]. When designers succeed in unifying function and action, they appear as natural couplings [49]. The movement, feel and sound when the start/stop button on the turntable is pressed can be characterized as inherent feedback. Inherent feedback is the information that is returned from acting on the action possibilities, and therefore appeals primarily to people's bodily perception and motor skills.

2.5. Material form properties

In addition to the direct approach, we also align ourselves Bergström, Vallgårda and Sokoler [51–53] in that interactive artifacts are highly reliant on *material formgiving* in terms of how people experience their interaction digital artifacts. This makes sense as we move from graphical representations on a screen, to the physical and tangible world [48]. The focus on material formgiving is also based on the direct mindset and approach [54].



Picture 4. Pitch calibration augmented with light.

Material form influences how people can interact with interactive artifacts with their bodies. It also becomes important in children's design processes, as different forms afford different uses. E.g. some forms might be better suited for one particular kind of prototype[4] than others. We find it just as important to how understand these material qualities influence children's use of maker technologies, as it is to understand how a they afford a specific kind of learning. Some students may like to focus on semantics, but in our experience, most like to focus more on material form and aesthetics. Examples of this can be seen when children focus on making robots look emotional by attaching eyes or hair, or focus on making game-controllers pleasing to wrap your hands around [12,55,56].

We define *form properties as the material, tangible and physical appearance and form elements of an artifact*. Form properties can be described such as size, texture, weight, layout, arrangement, and structure. We have identified three possible form properties that we find to be essential to reflect upon when using and designing maker technologies for children's education; *size, robustness* and *connectability*.

The overall message of this paper is that research within school maker settings, purposed to support design education, cannot only use traditional HCI methods. Instead it becomes necessary to apply methods from the field of interaction design, in order to handle the complexity of the particular design situation that the children are engaged with. Instead of developing deep understandings of design as a unique human activity of inquiry and action in which the children are engaged, HCI focus on applied psychology and computer science, individual use of technologies, mostly for instrumental purposes, often articulating properties such as usability and utility. Instead, our theoretical underpinnings stem from a tradition of aesthetics.

[4] Tentative representations of design ideas that show off functionality etc.

3. Method

Our study is part of an ongoing research project on making and design in children's education. The research is conducted by the interdisciplinary Child Computer Interaction Group at Aarhus University. In order to empirically ground our framework, we conducted a large-scale intervention in collaboration with locale schools in Aarhus, Denmark. The intervention was designed to be an initial introductive course of the Danish FabLab@school.dk project[5]. We did our intervention in collaboration with three 7th grade classes with a total of 64 children aged 13–15, during a two-month period between August and October 2014. In total, 45 h of course activity was documented, transcribed and analyzed. We got permission to use and own the visual data from the intervention from both children and their parents, and to include the children in our research. Because of ethical reasons, we have censored the children's faces in the pictures to follow.

The course was framed around a design process model (Fig. 3) for establishing and supporting student's work through a design process. No children nor teachers had experience working with maker technologies as part of a design process, but had to figure out how to use them as they moved through the different phases (design brief, field study, etc.). Our primary source of qualitative data stem from the 'Fabrication phase'. In this phase the children designed prototypes of their ideas.

Four researchers were present throughout the intervention; two design researchers and two anthropologists. The two design researchers had the overall responsibility to facilitate, scaffold and organize each lesson. Meanwhile the anthropologists focused on observing, taking photos, recording video, writing notes and do semi-structured interviews throughout, using visual anthropological and ethnographical techniques [10,57]. The design researchers also asked questions about the student's experiences with maker technologies, as they were being supported at the 'tech help desk' (Picture 6). We also had the children take the role of the photographer from time to time (Picture 5). We used a reflexive approach to classify, analyze and interpret our visual material [57, pp. 117–140]. We are aware that our analysis may have different meanings in different situations. In our work, the situation is that of a lesson on design processes using pre-made maker toolkits in order for children to construct prototypes of their ideas. Thus, the same images may be given different meanings in different situations, but are often interconnected in some way [57, pp. 131–134].

In our analysis of the coupling between action, function and feedback, we primarily draw on the collected visual data and transcriptions of semi-structured interviews. Specifically, we focused on footage and transcriptions that involved either use of maker technologies, or discussions among the children. The form categories that we present in the next chapter, are primarily based on analysis and interpretation of photos and videos where the children interacted with the technologies. We also compared our field notes with the our visual data in order to better contextualize our analysis [57, Ch. 5]. Thus analysis of the students' design process is based on field notes, video recordings, and interviews that have been condensed into coherent patterns using affinity-diagramming techniques [58].

Our framework is based on maker technologies that were present at the school. These technologies were; (1) Arduino Uno [59], (2) LittleBits [60], and (3) Makey Makey [61]. Thus, our framework is by no means exhaustive, and misses other influential maker technologies. Our analysis is relational as our articulations are based on comparisons between these three maker technologies. Therefore, our framework would change if more technologies were to be included.

[5] A brand name for a specific type of maker settings.

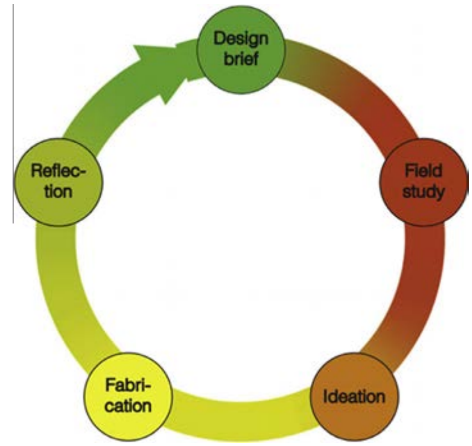


Fig. 3. The FabLab@School.dk design process model to support teachers and students.

4. Form properties & couplings of action and function

In the next two sections we will present our framework of maker technologies used in educational maker settings, and provide an account of the language that constitutes our framework. The account is based in part on theoretical reflections, and in part on analysis of data from our interventions.

4.1. Artifact form properties

Here we present articulations on form properties of maker technologies that inhabit most maker settings in Danish schools. We exemplify each form property by comparing the selected maker technologies. This is followed by an overview of the three maker technologies that we base our overall analysis on. Our list of properties is tentative, in the sense that more form properties probably exists, and that what we propose might change in time. But this is a beginning in expanding the design language of maker technologies. Lastly, the term 'main artifact' points towards the dimensions of e.g. the Arduino Uno without attached components.

4.1.1. Size (small-to-big)

This may be an obvious form property to consider. However, it is less obvious how it matters for the experience of children using the maker technology in school maker settings. An important insight that we have encountered throughout the children's design process, is that one-size-fits-all is not a sustainable solution when iterating on design ideas and externalizing these as prototypes. Instead, the designer should think about how the technology fits different parts of the design process. Big tangible artifacts make iterations of design early prototypes easy, simply because they are easier to grab and handle with both hands, rather than just fingertips. Collaboration around a table is also made easier, since more than one pair of hands can be in action at the same time. In later phases of the process, the student might need to fit their initial prototype with other materials such as wooden cases, fragile paper or cardboard constructions. Either way, one size clearly does not fit all (Fig. 4). This is one area in which the Arduino platform shines. Because of its designers' commitment to Open and Libre soft- and hardware, countless forks (hacks that redefine original designs) are made for many different purposes. The Raspberry Pi platform also offers varying sizes of their platform, which makes

Picture 5. A group of children taking photos as they work on their prototype.

Picture 6. The tech help desk where the children could ask questions about maker technologies and get inspiration for design moves.

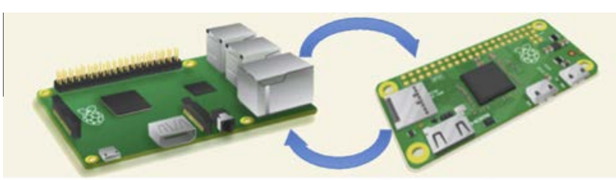


Fig. 4. Same platform, but different sizes for different phases of the design process.

it easy to transfer design ideas from one size to another (Fig. 4). As an example we may think of a student making wearables, who needs to move from a simple "on-the-desk" externalization made with LittleBits, to integrating it with textiles and cloth using the LilyPad (also an Arduino fork). Similar situations occurred as students tried to fit their initial externalization into their context mock-ups.[6]

Based on our qualitative analysis, we found the following to be considerable questions to ask in terms of size; how does the size affect children's motor-skills in handling the maker technology? Do certain sizes work better or worse for certain age groups (like with Duplo and Lego bricks)? How does size effect collaborative group work? Is it possible to have more than one pair of hands working on the same artifact? What phases of the design process does the artifact size lend itself to? What material constraints does size mean when going from one prototype to another?

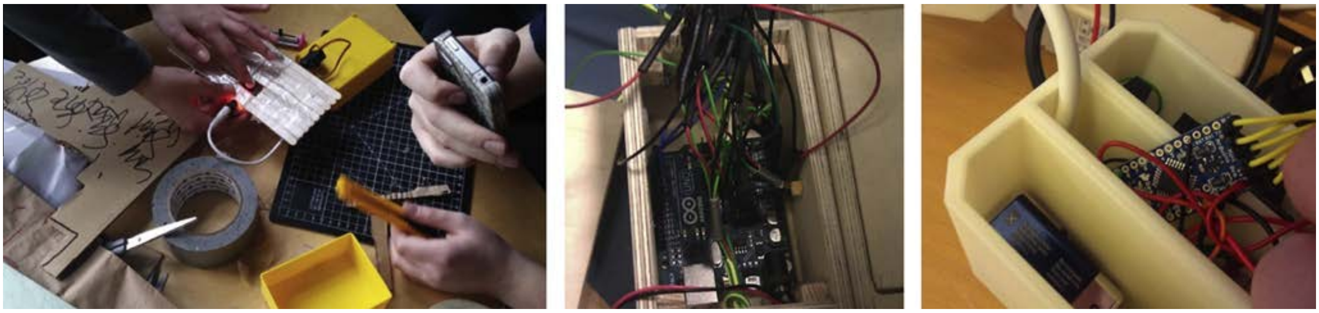
We decided on the placement of the form properties in our tentative framework on similar questions. We have chosen to articulate the form property of size as a continuum from small-to-big. The framework is relational, so the individual technologies placement on the continuum will change as more technologies are added (see Picture 7).

Each of the above technologies can be connected to various electronic components. These components have different sizes, which poses constraints that influence the overall dimensions of the constructed prototype. LittleBits are in themselves individual components ("bits") that snap together using magnet connectors. The bits vary in size depending on their function, but are in general larger than more traditional components used on the Arduino platform. While traditional electronic components like resistors or LEDs offers more flexibility in terms of availability, price and functionality, their size also hinder simultaneous collaborative construction of circuits because of the precise motor-skills required to deal with small wires and components. As a consequence, we observed that the workgroups generally split up when using Arduino. One child would focus on circuit design, while the other children would focus on constructing mock-ups of the context in which the prototype was supposed to be placed. Contrary to this, we observed that workgroups using either LittleBits or Makey Makey would simultaneously collaborate on construction, since less precision was required, and more than one pair of hands could tinker with the components (Picture 8). Children working with Arduino or LittleBits mostly ended up experimenting on a table, and primarily used their hands while the rest of their body would remain stationary in a chair.

On the contrary, we observed that workgroups using the Makey Makey were more prone to use their whole body. Whereas both LittleBits and Arduino are based on traditional electronic components, the Makey Makey utilizes any conductive material as its components. This meant that the children were able to easily extend their prototype in terms of size and use different physical materials (tinfoil, fruit, etc.) to construct simple buttons. This allowed the students to fully customize the size of each components (the conductive materials), and experiment with different forms. The size of the main artifact sits in between LittleBits and Arduino Uno.[7] However, the functionality of the Makey Makey primarily focus on creating button-inputs, e.g. arrow up/down, which constraints what is possible in terms of analogue input (e.g. a potentiometer (Picture 8)), or other advanced interaction.

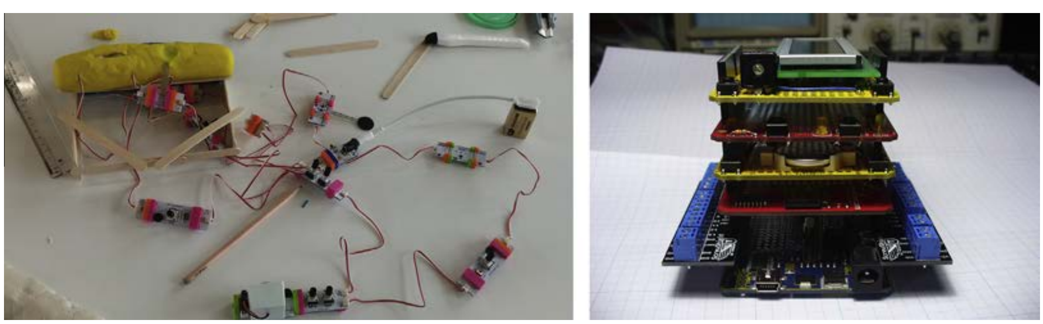
[6] Artifact of the surrounding context where the design idea is intended to be used.

[7] After the writing of this paper, a new USB dongle version of the Makey Makey has been released named Makey Makey GO. See www.makeymakey.com (accessed 10/1/2016).



Picture 7. Left: Students struggling with fitting LittleBits into their fragile mock-up. Right: Arduino Uno fits the first iteration of the box, Arduino Micro in the second.

Picture 8. Left/center: Example of Makey Makey used to create a game controller using their whole body. Right: Potentiometer.



Picture 9. Left: Prototype that is constrained by the size of the connected components. The prototype was intended to illustrate a pressure sensitive stairway. Right: Arduino board with five shields on top.

The Arduino Uno not only supports traditional electronic components, but also "shields" that are placed on top of the main controller board (Picture 9). Using such shields makes it so that one does not have to build i.e. a motor controller. However, using such shields quickly results in very large dimensions that gets hard to implement in mock-ups.

Based on the above observations and analysis, we have grouped the four technologies in terms of size (Table 1).

4.1.2. Robustness (fragile-to-sturdy)

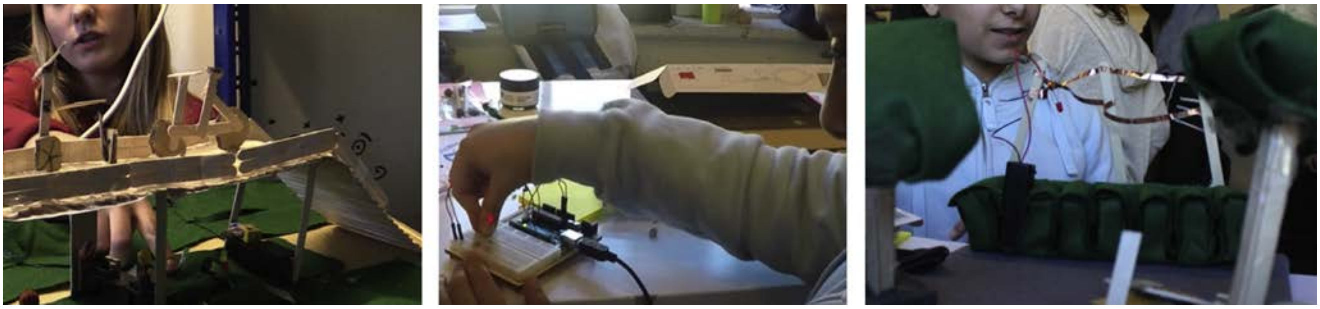
We found robustness to be an important form property when children handle maker technologies. We focus both on the main artifact, and the connections between different components.

Robustness has to do with how much of a beating the artifact and its connections can take before they get damaged, fall apart and eventually break. Many students found it be a source of frustration when a newly made prototype broke because of the main artifacts and connected components' fragility. Thus, robustness of the used technology affects how much time and energy the children had to put into rearranging or reconnect components that slipped out of their socket or similar (Picture 10). Fragile connections meant that they had a hard time tinkering with placement of the components in their mock-ups (Picture 9).

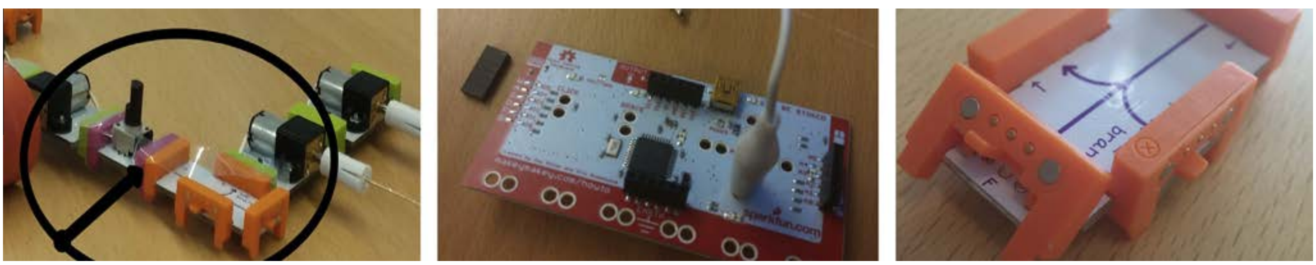
Making traditional electronic components robust was difficult for both children and teacher, as they lacked knowledge of elec-

Table 1
Size of artifact from small to big. The two dots on the components indicates the spectrum of possible sizes.

Technology	Size of main artifact	Size of components
Arduino Uno	(small———————∗—————big)	(small-∗—————————∗——big)
LittleBits	(small–∗—————————————big)	(small———————∗——————big)
Makey Makey	(small————————————∗—big)	(small-∗————————————∗-big)



Picture 10. Examples of the robustness of connections made with Arduino. Left: The workgroup decided to go without the main Arduino board, because they found their connections be unreliable, and used a battery and tape instead. Center & right: The first prototype was made on a breadboard and Arduino Uno, and was quite robust. However, when the child decided to transform the design from the breadboard to her mock-up, she experienced problems making the connections robust using copper tape (right).



Picture 11. Left: Tape being used to hold the magnetic connectors together. Center: Broken bit connector. Right: Broken bit connector.

Table 2
Robustness of artifact and its connectors.

Technology	Robustness of connectors	Robustness of main artifact
Arduino Uno	(fragile——————∗——————sturdy)	(fragile————————————∗–sturdy)
LittleBits	(fragile—∗———————————sturdy)	(fragile—∗————————————sturdy)
Makey Makey	(fragile—————∗————————sturdy)	(fragile————∗—————————sturdy)

tronics. This meant that techniques normally used to strengthen connections, e.g. soldering or heat-shrink tubing, was not applied.

The magnet connections on the LittleBits meant that less time was used trying out different circuit designs. However, the strength of the magnetic connections was not always sufficient when moving from a simple design placed on a table, to implementing it into a mock-up (e.g. having the row of bits hang as a string as shown on Picture 10). The children would apply tape in order to keep the magnetic connections together (Picture 11), but it was not a sustainable solution in the long run. Furthermore, we observed bits were the connectors got damaged, and was relatively hard to repair.[8] The same was observed with the Makey Makey board, though the crocodile wires were quite robust, and easily replaceable.

A final point to consider is school economy. If things break, they need to be replaced or repaired. We found that children's handling of artifacts was quite harsh, especially if they do not own the maker technology themselves. Broken connectors on Makey Makey (Picture 11) or LittleBits were not a rare sight in the schools we collaborated with. While of little concern for academic research institutions, price is relevant factor to consider when designing for educational institutions. Having schools buy new products every time something break is not sustainable. At the time of writing this article a new temperature sensor bit for LittleBits cost 18 USD to replace. Compare this with a SparkFun Digital Temperature Sensor Breakout - TMP102, which is more than haft the price, and the sensor TMP36 alone costs ~1 USD dollars. Whether one is more intuitive to use is beside the point. The point is, that in order to be economically feasible and sustainable for a wide range of schools, robustness and price are an important relationship to consider. Such considerations might not be important for first world countries, but as reported in Blikstein [62], these properties are very important when introducing maker technologies in third world countries. Similarly, there are big differences in school budgets, even in first world countries (see Table 2).

[8] Relative since it requires both skills and time to do repairs.

4.1.3. Connectability (low-to-high)

In working with different maker technologies, the connectability between different platforms is an important property to consider. When moving from one phase of prototyping to the next, one might need to switch to another technology. Thus, having the freedom to transfer work from one platform to the next becomes essential. This allows the maker to explore new possibilities that might not have been possible on the platform which he started off using. In other words, we define connectability as the degree of freedom in connecting different platforms together, be it code, circuits or mixing different technologies together (e.g. connect Arduino to LittleBit components). Blikstein have described different historical design paradigms of what he describes as constructionist toolkits, their development and theoretical underpinnings [5]. Blikstein makes a distinction between two design paradigms; the "Cricket model" and the "Breakout model" [63].

Connecting these paradigms through various "in-between" interfaces extents the life of these technologies. The Arduino bit for LittleBits is a good example of how connectability from one platform to another is possible. Write the Arduino code once, and it will run on all other Arduino platforms (roughly speaking). Another example is Makey Makey, which is a fork of the Arduino platform. Everything that is possible on the Makey Makey can be transferred to other Arduino based platforms, and vice versa. Here the use of Open and Libre software and hardware becomes important factors. It allows for various types of interfaces between these platforms, potentially increasing connectability among them.

LittleBits are often thought of as being open hardware, it even says so on the actual bits. However, the circuits of the bits are visible, and are already in the public domain (e.g. simple LED circuits). What might be less obvious is that the magnet connectors which sets the LittleBits platform apart from other maker technologies, is closed source. This makes it difficult for hackers to design new bits, that can be connected to other platforms that are not certified by the product owner. Thus the connectability of LittleBits is lowered since no one is allowed to extend upon the original design – expect if they get permission from the right holders.

We are not suggesting that the Arduino platform should be considered as an "end-all-be-all" technology. Rather, we suggest that designers of maker technologies targeted towards use in children's education, should consider how the technology can be connected to already existing and widespread maker technologies (Table 3).

Table 3
Connectability from low to high.

Technology	Connectability
Arduino Uno	(low————————————∗–high)
LittleBits	(low–∗————————————high)
Makey Makey	(low—————————∗———high)

4.2. Couplings of action and function

The coupling of action and function it strongly tied to communication of feedback information [49]. We distinguish between three different types: *functional feedback, augmented feedback* and *inherent feed*. We analyze each of the three maker technologies in relation to how they unify two aspects of action and function from the physical world: *time* and *location*. These two aspects will help us to articulate characteristics of action, reaction and function of the three maker technologies, and how they reinforce natural couplings of time and location. The ideal of creating natural interaction is an assumption we take, as we cannot be sure as to whether its designers intended their product to be intuitive.

4.2.1. Time

In analyzing the coupling of user action and technological functionality, we shall first use the concept of time; *the time between action of the user, till they receive feedback information on functionality*. As an example we shall use the action of circuit design with Arduino Uno, LittleBits and Makey Makey from scratch.

With Arduino Uno, there is a long delay from physically placing wires into the correct pins, connect electronic components and finally code a program that makes the physical design react to people's desired function. The reason is that the process from coding, designing circuits and uploading code, to receiving feedback, primarily depend on augmented information. Thus, there is no instant or natural coupling in time between the mentioned actions, and the feedback information that people receive (Fig. 5). As a consequence, it takes more time for people to go from action to reflection upon their design decisions, debugging of code, or fixing circuits. Working with Arduino Uno also requires people to take

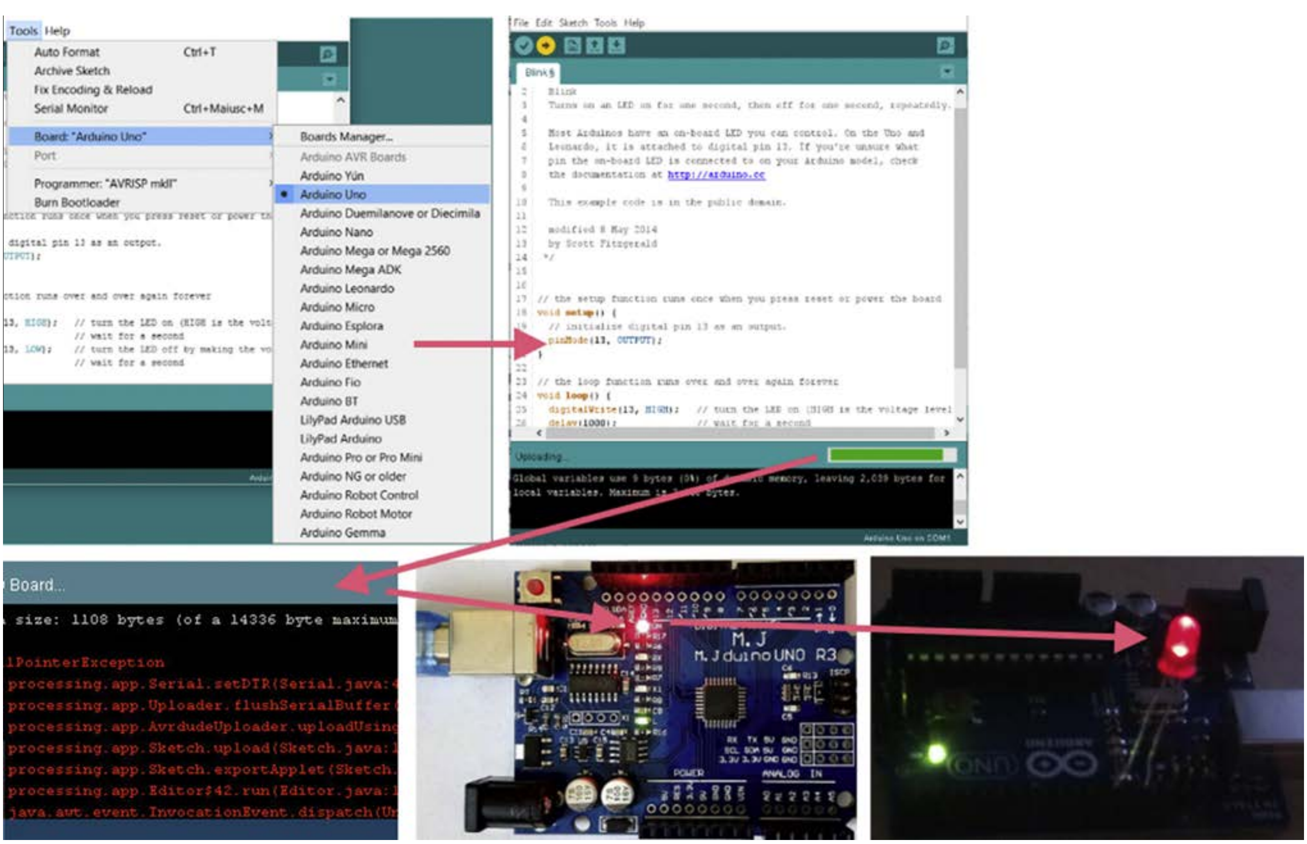


Fig. 5. Five time consuming steps from action to functionality feedback.

action in a chronology order, before finally being able to reiterate upon their design.

The opposite can be said about LittleBits, where typing and uploading code is replaced with active components, or *bits*, that snap together using a magnet connector. Each bit has a specific purpose; power, input, output and wire. Action is kept in the physical world, rather than focusing on programming and uploading code. There is no need to communicate feedback through augmented information, in order for people to see the consequences of their actions (putting the bits together), the reaction (connectors snap together using magnets), and finally experience the functionality of the connected bit. Instead, LittleBits primarily relies upon functional feedback and inherent feedback. In terms of functional feedback, people receive feedback information at the same time as they are interacting with the bits, it quickly becomes clear whether or not their actions were successful in terms of desired outcome. The inherent feedback of LittleBits is highly attached to perceptual motor skills, e.g. the "snapping" sound when connecting bits, the sensorial the push and pull of the magnetic field. The combination of the two makes for a strong natural feedback system. E.g. the user is not in doubt as to whether or not the bits are connected. The inherent feedback is closely related to *location*, which we will talk about in the next section (Table 4).

Table 4
Overview of coupling between action and functionality feedback in relation to time.

Technology	Time
Arduino Uno	Augmented feedback: Long delay from action of making circuits, to program and upload code, to functionality feedback. The bridge from action to function is realized through augmented information, using text, icon, etc., on a GUI. Acting on a physical input device like a keyboard, is only coupled to augmented information provided by a GUI. The user only receives functional feedback if actions are done in a correct chronology order. Mistakes in circuit design does not communicate any feedback (it works or it does not), which requires a lot of cognitive effort and previous knowledge to debug
LittleBits	Functional and Inherent feedback: Short delay from action to reaction to functionality feedback. Feedback information is communicated through inherent means. This kind of feedback especially appeals to perceptual motors skills of the user
Makey Makey	Augmented feedback: Medium time delay from connection crocodile wires to a conductive material to functionality feedback on the computer screen. The functionality is communicated through augmented information on a GUI. The user is only able to test whether the circuit is connected correctly by receiving augmented feedback. However, the time duration from action to receiving feedback is shorter than the Arduino, since no coding or advanced circuit design is required

4.2.2. Location

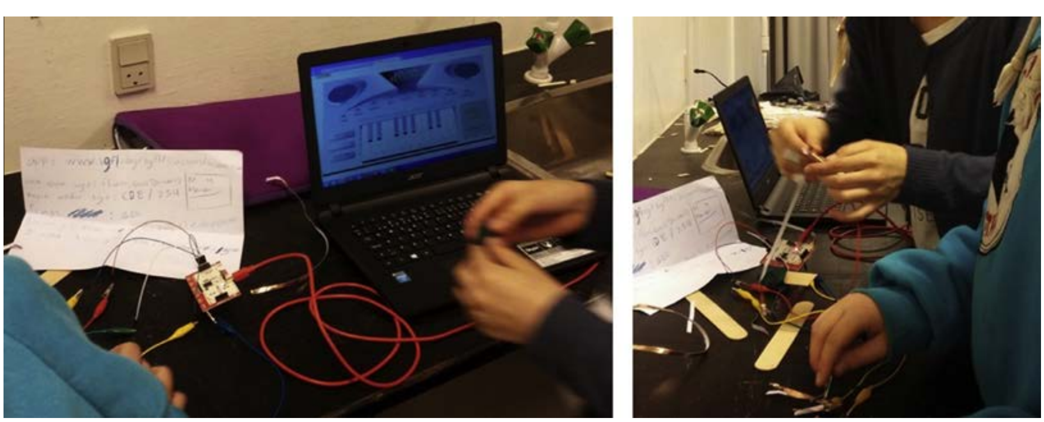
With location we want to emphasis *where* functionality feedback is communicated. Since we are talking about location in physical space, this aspect is primarily related to perceptual motor skills of the body (e.g. moving from a GUI to physical materials and back again). Location is closely related to time, since bodily movement can be an important factor in how much time various actions takes to complete. To exemplify we shall analyze Makey Makey and LittleBits.

With Makey Makey, action and reaction of the used conductive materials (e.g. copper tape or tin foil) happens at the same location; the student jumps on a pad made of tin foil, and the foil reacts by deformation. However, the actual functionality feedback is communicated through augmented information on a computer screen. Without a screen, the coupling between the action and the desired functionality is lost. What we found in our field studies is that this kind of feedback often resulted in students dividing their groups, so that one part would test the connections from the Makey Makey to the conductive material, while the other would be on the computer and make sure that the coupling between the physical and virtual was as desired. We also observed that it was possible for all members of the individual workgroups to simultaneously tinker with the physical materials, since the location of these materials were easy to physically spread out. Thus, it became possible for the children to both work on the floor and tables, which made it possible for them to collaboratively design bigger installations (see Picture 12).

With LittleBits action and feedback happens at the same location. Since the individual bits are autonomous, and does not

Table 5
Action and functionality feedback in relation to location.

Technology	Location
Arduino Uno	Augmented feedback: Action and reaction happens on different locations. Functionality feedback happens at different locations from the physical space (making circuits) to the digital space (coding a program on the computer). Suitable for one pair of hands, that requires precision work
LittleBits	Functional and Inherent feedback: Action and functionality feedback happens at the same location as the hand in action. There is a direct coupling in the location of action and communication of functionality feedback. Suitable for two-three pairs of hands, and is not depended on precise circuit design
Makey Makey	Augmented feedback: Action and reaction happens on different locations. The reaction of the bodily interaction with conductive materials is seen on a computer screen, where functionality feedback is communicated. Suitable for many pairs of hands, can be spread out in a large physical space, and is very forgiving when designing circuits



Picture 12. Division of group, working with different materials and switching between the physical and the virtual.

Table 6
Summing up our framework.

Maker technology	Artifact properties	Action-function couplings
Arduino Uno	*Size*: small-to-big *Artifact:* (———————*——————) *Components:* (-*—————————*——)	*Time* Augmented feedback: Long delay from action of making circuits, to program and upload code, to functionality feedback. The bridge from action to function is realized through augmented information, using text, icon, etc., on a GUI. Acting on a physical input device like a keyboard, is only coupled to augmented information provided by a GUI. The user only receives functional feedback if actions are done in a correct chronology order. Mistakes in circuit design does not communicate any feedback (it works or it does not), which requires a lot of cognitive effort and previous knowledge to debug
	Robustness: fragile-to-sturdy *Connectors:* (——————*———————) *Artifact:* (—————————————*–)	*Location* Augmented feedback: Action and reaction happens on different locations. Functionality feedback happens at different locations from the physical space (making circuits) to the digital space (coding a program on the computer). Suitable for one pair of hands, that requires precision work
	Connectability: low-to-high (—————————————*–)	
LittleBits	*Size:* small-to-big *Artifact:* (–*—————————————) *Components:* (———————*——————)	*Time* Functional feedback and Inherent feedback: Short delay from action to reaction to functionality feedback. Feedback information is communicated through inherent means. This kind of feedback especially appeals to perceptual motors skills of the user
	Robustness: fragile-to-sturdy *Connectors:* (—*————————————) *Artifact:* (—*————————————)	*Location* Functional and Inherent feedback: Action and functionality feedback happens at the same location as the hand in action. There is a direct coupling in the location of action and communication of functionality feedback. Suitable for two-three pairs of hands, and is not depended on precise circuit design
	Connectability: low-to-high (—*————————————)	
Makey Makey	*Size:* small-to-big *Artifact:* (————————————*—) *Components:* (-*—————————————*-)	*Time* Augmented feedback: Medium time delay from connection crocodile wires to a conductive material to functionality feedback on the computer screen. The functionality is communicated through augmented information on a GUI. The user is only able to test whether the circuit is connected correctly by receiving augmented feedback. However, the time duration from action to receiving feedback is shorter than the Arduino, since no coding or advanced circuit design is required
	Robustness: fragile-to-sturdy *Connectors:* (—————*————————) *Artifact:* (————*—————————)	*Location* Augmented feedback: Action and reaction happens on different locations. The reaction of the bodily interaction with conductive materials is seen on a computer screen, where functionality feedback is communicated. Suitable for many pairs of hands, can be spread out in a large physical space, and is very forgiving when designing circuits
	Connectability: low-to-high (—————————*———)	

depend on a tethered connection a computer, it makes for a system that is only "programmable" through bodily interaction. When a "power bit" is connected to a "LED bit" the LED immediately lights up, disconnecting the bit turns of the light. Thus, action and functionality feedback is located where the "hands are". This allows for what Sadler [33] describes as *feedback first*, which he argues to be very important. We agree with Sadler in that initial functionality discovery, is a critical when experimenting with new maker technologies. We hope that our articulations can help to reflect upon how to design for feedback first (Table 5).

4.3. Summing up – a compiled framework

Finally, we sum up our analysis by compiling them into a comprehensive framework so that readers may have a better overview of the articulated form properties and action-function couplings (Table 6).

5. Discussion

As shown in Table 6, the various form properties and action-function couplings makes for different kinds of interactions when making. These different possibilities also make for considerations about where in the design process a particular technology works best. In future work we plan to use our framework to fit the individual technologies into Fig. 1, in order to help teachers, choose what technology to use in a particular situation. To exemplify, the action-function couplings of time can help us better understand whether a particular maker technology allows for fast iterations times. Location can help us understand where the interaction happens in the physical space, and how it works when collaborating simultaneously. Arduino Uno and Makey Makey both utilize augmented feedback to communicate meaning and knowledge, while LittleBits relies on inherent feedback in terms of communicating functionality. LitteBits clearly have a more unified coupling between action, reaction and functionality, which might be one of the reasons why we have experienced a lot of positive comments on LittleBits from teachers and children. On the other hand, LittleBits are very expensive and fragile compared to the other technologies. The magnet-connector technology is also closed and proprietary, making it hard to design new forks, and potentially increase connectability. However, LittleBit does allow for fast iteration times, whereas the Arduino Uno might be more suitable for creating more sophisticated prototypes with slower iterations. In the future we hope to design connectors similar to projects like The Free Universal Construction Kit [64], but for the electronic connectors on maker technologies, in order to heighten the connectability between the different maker technologies.

Our framework is limited by not being exhaustive in terms of the amount of maker technologies that we have included in our analysis. We would have liked to include more, but this was beyond what was possible at the time of our intervention. Moreover, not every technology was used equally by the children. The most used technologies were Makey Makey and LitteBits. This makes sense as the children were very inexperienced with the technologies. Makey Makey and LittleBits both focus on feedback first, as the time between action and functionality feedback is very short. It is clear that there are more form properties and action-function aspects to be discovered. We therefore look forward to future school interventions, as the children might have become more competent with other technologies like Arduino or Raspberry Pi. The lack of more maker technologies in our framework also makes its use limited. As the analysis is relational, the framework would change as more technologies are introduced. This does not make the framework useless, but it should not be thought of as something finalized or generalizable for all contexts.

Through our analysis we also encountered methodological issues. Firstly, the context in which we have studied the maker technologies did not focus exclusively on using the presented technologies to make whatever the children felt like, or follow a rigid "how-to" guide that would result in predesigned artifacts. Instead, the maker technologies were used as part of a design process, which are inherently complex and requires children to not only work with the technologies, but also do field studies, generate ideas and reflect on they decisions. Thus, the framework presented in this paper could also change depending the context. Even though the 'Fabrication phase' (c.f. pp. 9–10) mainly focused on building an interactive prototype, many children primarily focused on constructing the surrounding context mock-up with various analogue design materials such as cardboard, wood, paint, felt, and glue, rather than working with the maker technologies. Working within such an open-ended context influenced how well we could attend and observe the children's engagement with the technologies throughout the process. Children would move between many different locations: grab new materials, discus ideas with other groups and ask teachers for help. Consequently, it was impossible to isolate and contain the activities in which the children engaged with the technologies. Furthermore, the main author of this paper took the role of facilitating the process and were the main go-to guy when the children or teachers needed technical support. While the two supporting anthropologists were skilled with at least five years of experience, they also had an interest in documenting other aspects of the design process [12]. Thus, the presented work might lack details that could become visible in more rigid and constrained contexts. E.g. size might not be an important factor if the educational goal is to teach a predetermined set of math skills within rigid curricula based courses, were there is no need to integrate the technologies with other artifacts. The information provided in this paper is therefore designated to a specific place rather than the other field settings. The second limitation was the children's lack of competences in terms of working with maker technologies. Very few children had much experience with programming or designing simple electronic circuits. This constraint was both good and bad. Since feedback is extremely important to get a first expression of how a technology works, it made our observations on these factors more reliable as we were able to see how novices would appropriate the technologies without any prior experiences. Conversely, it might have been harder to analyze aspects of feedback, as the children would already know how to deal with unexpected outcomes of their actions.

The issue of generalizability of qualitative studies have also been discussed by Yin [65]. Yin argue that qualitative case study results can be generalized to some broader theory. The generalization occurs when qualitative researchers study additional cases and generalize findings to the new cases. This approach manifested itself as we have used empirical data from different schools, while trying to replicate the general framing of themes and processes of the courses. However, to repeat a case study's findings in a new case setting requires good documentation of qualitative procedures, such as a protocol for documenting the problem in detail and the development of a thorough case study database. Such protocols were difficult to design as we did not know exactly what materials and technologies would be present at each particular school, nor know which technologies the children would be most engaged with. In terms of qualitative generalization, we don't seek to generalize our findings to places outside of the context that we have studied. Instead, the value of our research lies in the particular description developed in the context of a course that introduced a focus on learning design, and using maker technologies as an means to address complex societal challenges.

We envision three future activities for further developing our framework. First we invite other researchers to expand on our early suggestions. An expansion of the framework would also mean new ratings on artifact form properties, as these are all analyzed in relation to one another. We also limited ourselves to only two aspects of action-functionality coupling, but other aspects such as *direction* or *modularity* could provide new useful insights. Second, we want to introduce the framework into schools, and investigate whether our framework can scaffold teachers in decision making when using maker technologies in their lessons. As Zimmerman et al. [66] argues, evaluating the quality of interaction design research must be judged in terms of its relevance to a larger community of practitioners (not only academics), and how findings can instantiate change that change current situations and turn them into preferred ones. This is currently one of the main goal of our FabLab@school.dk project, and much effort goes into helping teachers become better at planning and facilitating design activities in maker settings. We also hope that designers and researchers can find our framework useful in articulating factors on form properties and action-function couplings and its effect on interaction.

One major objection that readers might find in our analysis is the idea of intuitive use. As previously mentioned [42,44], argue that intuitive use of an interactive artifact is determined by how well the direct and natural mapping of appearance, action, reaction and functional feedback is unified on various aspects such as time and location. However, it can be argued that the idea of intuitive use is vague in terms of how it gets defined. What was once considered to be intuitive use from a semantic perspective, have been challenged by the movement towards embodied and tangible interaction. From our experience, intuitive use is highly dependent on the child's repertoire of previous experiences, examples, knowledge, etc. E.g. a child who have used a computer all his life, might find that augmented information to be intuitive to comprehend. However, a longer discussion on this issue is beyond the scope of this paper.

6. Conclusion

In this paper we have presented a tentative framework that focus on two interrelated aspects of three maker technologies; artifact form properties and the coupling between user action and functionality feedback. We argue that our framework can be beneficial for designers, researchers and teachers involved in work with maker technologies in children's education. First the framework highlights the importance of reflecting on form properties of the individual maker technologies, as these have important impact on how, what and when the technology can be used. Our framework helps improve the language used to describe and analyze maker technologies, so that we may be able to better articulate key form factors of their design, and how it relates to the use in context. Second we provide an analysis of how the coupling between user action and functionality feedback is expressed and communicated through three types of feedback; functional, inherent and augmented. The aim of our analysis has been to expand on the design language of maker technologies, so designers can improve existing or future designs by reflecting upon the coupling between action and function in order to strengthen feedback information on aspects such as time and location. Furthermore, the framework can be used by teachers when deciding on what maker technologies to use in different situation ns.

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Understanding design literacy in middle-school education: assessing students' stances towards inquiry

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Abstract We present a comparative, quantitative assessment, focused on measuring 'stances towards inquiry' among middle-school students who have received design education. Our assessments are based on results of a written survey questionnaire and a statistical analysis using 'The Design Literacy assessment tool'. Our analysis suggest that participating students have internalized basic knowledge about design, but lack adaptive aspects of design literacy, specifically the capability to take a designerly stance towards inquiry when confronted with 'wicked problems'. We suggest that, due to societal developments, students are becoming more 'design literate', but that they generally develop routine expertise in these first practical encounters with design processes, whereas the more complex adaptive capabilities demand more education of both students and teachers.

Keywords Design education · Design research · Reflective practices · Evaluation

Introduction

This paper highlights the promise and challenges of teaching design to middle-school students. The idea of integrating 'design thinking' as a subject in general education has been suggested (Baynes 1974; Cross 1980, 1984; Pacione 2010), and contemporary design studies literature argues that design thinking and practice offer opportunities

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to support new literacies needed for the 21st century (Balsamo 2009; Burdick and Willis 2011; Smith et al. 2015; Christensen et al. 2016). Similar claims are made by authors of frameworks [e.g. OECD; (Ananiadou and Claro 2009)] for identifying 21st century skills, most of which define the capability to take on complex problems as an important 21st century skill (e.g. Voogt and Roblin 2012). As expressed by Dorst, taking on wicked problems is at the very core of design thinking, and therefore we propose that design may provide middle-school students, with knowledge and practices that help address and solve what are known as 'wicked problems' (Rittel and Webber 1973; Buchanan 1992; Coyne 2005). Following these thoughts, we present design as a basic literacy akin to reading and writing. This implies that students should develop basic design abilities such as designerly inquiry, ideation, navigating a design process, and skills for materializing ideas as externalizations. In this study, we are particularly interested in students' 'stances towards inquiry' into wicked problems, which is an important part of becoming a design thinker (Löwgren and Stolterman 2004; Nelson and Stolterman 2012).

Field observations have shown that the middle-school students' design processes "(…) often resulted in simplistic solutions and finalization" (Smith et al. 2015). However, there is a lack of literature that addresses middle-school students' stances towards inquiry, and the possibility of them acquiring a more designerly stance towards inquiry. To fill this gap, we did a baseline survey and developed 'The Design Literacy (DeL) assessment tool' to assess students' stances towards inquiry when asked to solve a wicked problem (Christensen et al. 2016). Our initial results from using the tool showed that fewer than 3% of the participating students took a designerly stance towards inquiry (Hjorth et al. 2015; Christensen et al. 2016).

In this paper, we use the DeL Tool to gauge whether or not there has been a significant change in a group of 246 middle-school students' (aged 11–15) stances towards inquiry after a two-year period of design education. We did this by testing the following two hypotheses with regard to the group of 246 students, named the FabLab group (the experimental group):

(1) FabLab group students take a designerly stance towards inquiry to a greater extent than the control group students;
(2) FabLab group students take a designerly stance towards inquiry to a greater extent than students from the 2014 baseline study.

We will be referring to the experimental group as the FabLab group throughout the rest of this paper, as students were taught design in the context of the FabLab@School.dk project, and because the participating schools generally referred to the design course as the 'FabLab subject'.

The paper is laid out as follows. First, we review literature on design thinking in children's education, and present an argument for why a well-developed stance towards inquiry is an important fundamental for design literacy. Second, we describe maker settings (e.g. FabLabs) as a context for introducing design thinking. Third, we describe our methodology and how we applied The Design Literacy (DeL) assessment tool to assess aspects of design literacies. Fourth, we present our findings, execution, data analysis, and interpretation of the survey data. Finally, we discuss the validity of these findings, their implications, research contributions, and limitations.

Design thinking in middle-school education

Svihla et al. (2009), Nelson and Stolterman (2012) and Keirl (2006) have argued that design was relevant for all, and that design therefore should be "put back in the hands of everyone" (Pacione 2010). In line with this, introducing design as a literacy in middle-school has previously been suggested by authors such as Baynes (1974), Cross (1980, 1984), Smith et al. (2015) and Razzouk and Shute (2012). At the same time, digital technologies are becoming ubiquitous as e.g. internet of things, deep learning computing or smart cities (Greenfield 2006). These technologies have the potential to radically change our lives and our societies, and therefore future technologies have significant roles to play in 21st century citizenship education and democracy (Kolodner 2002; Kolodner et al. 1998). Design thinking offers ways to understand what choices are made in design processes, how to reflect on design judgements and how design practitioners handle and design around and within complex and "messy" reality. In the FabLab@School.dk project, students have engaged in design processes with digital technologies in order for them to develop design literacy as part of education for citizenship and democracyD.esignerly ways of engaging with the complex problems enable individuals to act as agents of change and creators of preferred futures, capabilities that are echoed in OECD's descriptions of 21st century skills, for example. It is argued that, 'design for the people', as a form of basic literacy, can serve us in our daily lives. This 'design for the people' argument, motivates our work on assessing design literacy through quantitative measurements.

Educational philosophy, such as Dewey's progressive education (1916) or Freire's pedagogy of the oppressed (1970), often criticize the so-called 'banking model of education,' which entails teaching with the goal of internalizing facts in order to prepare for standardized tests. Such approaches to education are also criticized in more recent works, such as Biesta's works on the 'learnification' (2008) and risk-aversion of the modern educational systems (2010). In line with this, Lin et al. (2007) note the difference between routine expertise and adaptive expertise, and argue that most of today's formal education is designed to produce routine expertise. Lin, Schwartz, and Bransford use Hatano and Inagakib's demarcation between routine and adaptive expertise, and their educationally relevant question concerning how "(…) novices become adaptive experts – performing procedural skills efficiently, but also understanding the meaning and nature of their object" (Hatano and Inagaki 1984, 262–623). Adaptive experts are also more prepared to learn from new situations and avoid the over-application of previously efficient schemas learnt through 'banking knowledge' (Hatano and Oura 2003). As noted by Nelson and Stolterman (2012), adaptive expertise is fundamental to designers. According to their hierarchy of design-learning outcomes, 'becoming designers' move through 'routine expertise' to 'adaptive expertise', on their way to 'design and value expertise' (Fig. 1). E.g. students need the confidence to switch between different problem solving processes, rather than relying on 'tried-and-tested' methods that might have worked in other situations, but which do not take the ultimate particulars of the problematic situation as a given.

We build on Nelson and Stolterman's hierarchy, and regard design literacy as including many aspects of adaptive expertise, and thus as an important part of education. However, Nelson and Stolterman's hierarchy of learning outcomes was not created with middle-school in mind. Instead, the hierarchy represents development towards becoming an expert designer. Being literate does not imply the need to become an expert. We do not propose that all middle-school students should become expert designers.

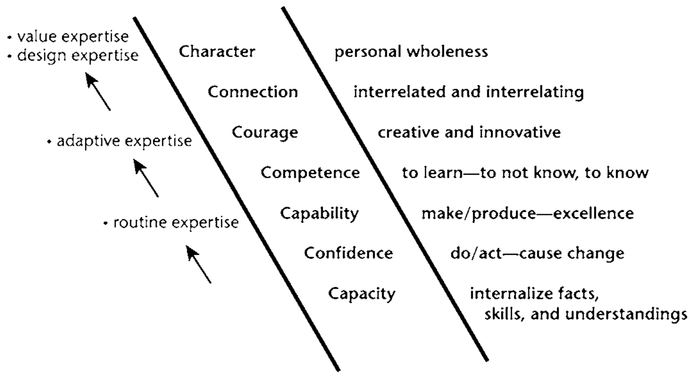


Fig. 1 Hierarchy of design-learning outcomes, Nelson and Stolterman (2012)

Stance towards inquiry

Design has been described as a particular form of engagement with complex and "messy" world (Cross 2011; Nelson and Stolterman 2012; Razzouk and Shute 2012; Dalsgaard 2014). Designers approach problematic situations by engaging with these situations through reflective conversations with the design situation, and its parts, such as stakeholders and artifacts (Schön 1984). They frame problems, and create new understandings by making inquiries into phenomena of the situation. Thereby, in the early stages of design processes the designer is often driven to understand phenomena not well understood, in order to gain a more holistic understanding of the problematic situation (Löwgren and Stolterman 2004; Kelley and Littman 2005; Kembel 2009; Nelson and Stolterman 2012). Designers use a variety of ethnographic and/or anthropological techniques to gain these insights into the existing situation, before deciding on the next step in their design process (Randall, Harper, and Rouncefield 2007; Hanington and Martin 2012; Gunn et al. 2013; Sanders and Stappers 2013). This designerly way of working presupposes that the designer is open to new understandings rather than preoccupied by his own prejudices and ideas of how to synthesize these into a solution. Similarly, Donald A. Schön argued that designers take a distinct stance towards inquiry (Schön 1984, 1992), which he contrasted with a stance of 'technical rationality'. Schön argued that it is crucial for the designer to develop such a designerly stance towards inquiry, which based on Schön's pragmatic understanding of design, entails personal reflection on the first intentions that set the designer on a specific path of inquiry and leads towards action (Schön 1984). Similar claims concerning the importance of the nature of inquiry into wicked problems have been made by other scholars (Löwgren and Stolterman 2004; Krippendorff 2006; Lawson 2006; Cross 2011; Nelson and Stolterman 2012).

Students who do not recognize a problem as wicked, perform poorly in design education (Simmonds 1980; Portillo and Dohr 1989). They often seek single, 'correct' solutions to problems that they erroneously perceive as well-defined and tame (Schön 1984; Portillo and Dohr 1989; Cross 2011, 48–60; Nelson and Stolterman 2012, 105–117), and therefore do not recognize the importance of a designerly stance towards inquiry. Real-world challenges are, per definition, wicked. Since middle-school students will in time become adults and thus be engaged in the design of futures for themselves and others, they will be better equipped for their future if they develop the capability to recognize problems as wicked, and to approach wicked problems with a designerly stance towards inquiry. As we have previously shown, in 2014 there was a significant lack of middle-school students who took a designerly stance towards inquiry (Christensen et al. 2016). In Schönian terminology, schools that train students to become routine experts direct the students to adopt a stance of technical rationality, from which wicked problems are seen as tame, by focusing on answers that are readily at hand, easily accessible, or based on a set of finalized solutions. Our view is that in risk-averse school systems that are driven by national and international testing regiments (Biesta 2010, 20), this move towards tame problems and stances of technical rationality is strengthened rather than challenged.

We wish to promote design literacy and therefore also a designerly stance towards inquiry as an important part of middle-school education, and since an important part of the logic of today's educational systems is quantitative measurement, we developed a survey questionnaire that combined quantitative and qualitative questions on design and technology. The tool we used to gauge students' stances towards inquiry, which we named the DeL Tool (Christensen et al. 2016), focuses on the stances towards inquiry taken by students when presented with a survey embodying five wicked aspects: (1) societal challenge; (2) dilemmas; (3), ethical concerns; (4) multiple stakeholders; (5) unfamiliar domains. Assessing the extent of the impact of design education in middle-school helps to develop arguments for use in political discussions about education, and to better understand how we, as researchers and educators, may make future design education better.

In the following section, we present how design literacy may be positioned within the emerging field of new literacies.

Design literacy in an age of measurement

Literature that discusses design in relation to education addresses professional subjects such as engineering, industrial, computational, or architectural design in higher education almost exclusively (Eastman and McCracken 1997; Lewis and Bonollo 2002; Oxman 2004; Curry 2014), and is devoted to the comparison of expert and novice designers (Ho 2001; Cross 2004, 2010; Lawson and Dorst 2009). We look towards mid-level design capabilities – capabilities which are not adequate for expert designers, but which may be of great use to laypersons. We have chosen to frame this as design literacy. In our definition of design literacy, we draw on sociocultural literacy theory (Lankshear and Knobel 2008; Coiro et al. 2014), and argue with Gee (2015) that the literacy has to be understood "(…) in its full range of cognitive, social, interactional, cultural, political, institutional, economic, moral and historical contexts". By doing this, we position design literacy under what Coiro et al. (2014) has termed "a new literacies umbrella" (ibid., p. 10).

According to Biesta, we live in an age of measurement in which the educational systems give value to that which is measurable (Biesta 2010), and we need to quantitatively measure the development of literacies, skills, abilities, and so on, which we deem important in education. Thus, if we value design as educationally desirable, then design and educational scholars should also work towards new ways to quantitatively assess design literacy (Cross 1980). Following this line of thinking, we report on the FabLab@School.dk project. This project was devised to make an educational environment to can support and prepare students to deal with wicked problems in the 21st century, by leveraging design thinking and practice combined with physical-interaction and digital fabrication technologies. In order to quantitatively assess the students, we administered two large-scale surveys to measure aspects of design literacy over a two-year span (Fig. 2).

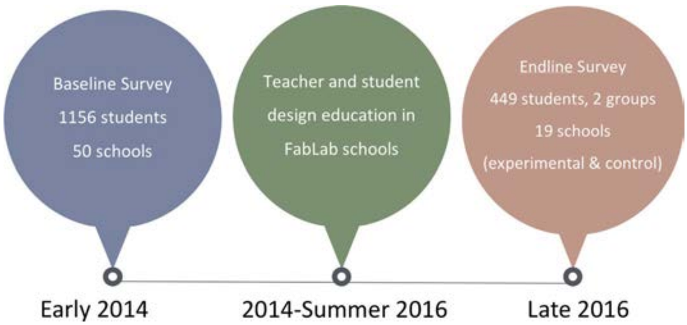
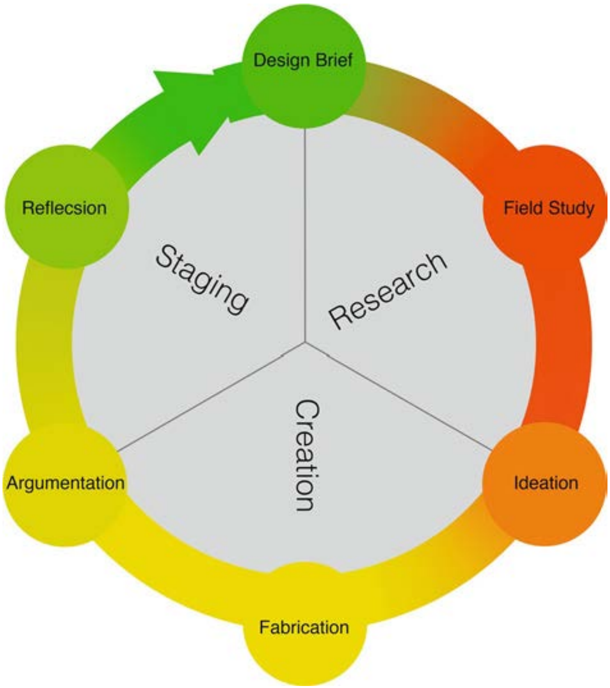


Fig. 2 Survey administration timeline

Fig. 3 The 'Design in Making Model' for scaffolding design activities in schools, also referred to as the design process model



As reported by Hjorth et al. (2017), according to the students themselves, the three-year FabLab@School.dk project did have an effect on students' understanding and practice of design. This was expressed in students' responses related to knowledge about a generic design process model (Fig. 3, made to scaffold the educators' teachings) that they had worked through. To simplify the complexity of the design processes, we made a sequenced model. The intention was to introduce the basic ideas of working through design processes, but as teachers and student gain more experience with design, they will be free to navigate back-and-forth, iteratively and crossing across the different phases. Thus, the model is preliminary, and will be further developed to reflect contemporary understandings of design processes, as teachers and students gains the necessary education.

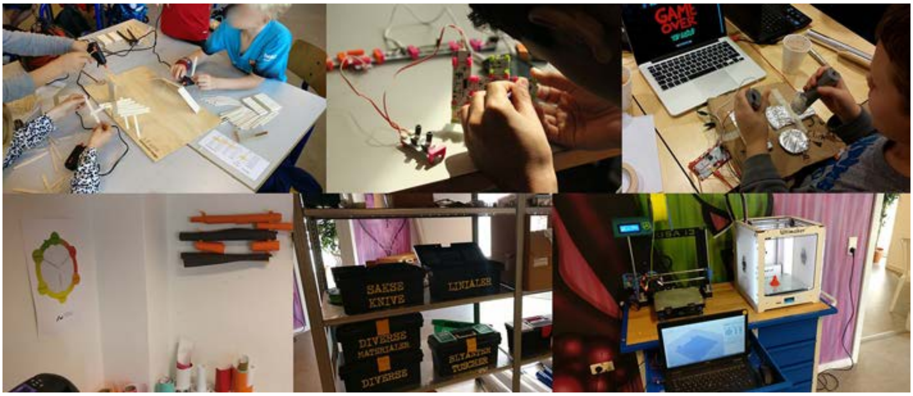


Fig. 4 Middle-school maker settings

Students e.g. responded that, to some degree,[1] they had acquired knowledge of the design process model and its constituent parts (problem framing, field studies, idea generation, fabrication, argumentation, and reflection). In Hjorth et al. (2017), we concluded that design education may have had an effect on students' understanding of design. Since these were self-reported measures and since they measured "knowledge", however, what we effectively measured was how much knowledge the students "had banked" throughout the two-year period. Changing one's stance towards inquiry is, on the other hand, an entirely different accomplishment. In section four, we will argue that maker settings may provide schools with spaces for 'learning by doing', which may be roughly described as the Schönian idea of a 'reflective design practicum' (Schön 1987). In turn, this allowed us to study students' design processes in real educational contexts.

Maker settings: a space for design in middle-school education

We are currently witnessing an emerging field of research into FabLabs, Makerspaces, and Hackerspaces in curriculum-based education (Fig. 4) (Halverson and Sheridan 2014). These settings present new opportunities for students to acquire skills in subjects such as STEM,[2] design, and art. Maker settings also provide researchers with new opportunities to study the potential benefits of teaching design thinking to middle-school students (Katterfeldt and Schelhowe 2008; El-Zanfaly 2015; Smith et al. 2015).

The turn towards design thinking and practice in schools' maker settings builds on the new possibilities made by technological developments in digital fabrication tools, programming languages and physical computing platforms designed specifically for children (Blikstein and Krannich 2013; Iversen et al. 2015; Smith et al. 2015; Peppler et al. 2016; Christensen and Iversen 2017), and the desire to accommodate educational theories such as constructionism (Papert 1993), critical education (Freire 1970), and progressive education (Dewey 1916). Terms such as 'hacking,' 'making,' and 'tinkering' are central for

[1] Likert scale from 1 to 6.

[2] Science, technology, engineering, and mathematics.

this cultural phenomena (Martin 2015). Such terms denote some kind of creation or design with physical and virtual materials. Historically, maker- and hackerspaces have been community-driven by people with common interests in technology, creating a space for socialization, and project collaboration (e.g. *Chaos Computer Club*, founded 1981)[3] The academic turn towards research into the possibilities of maker settings in middle-school education may also be seen in the emergence of new conferences (e.g. *FabLearn*[4]), and special journal issues on the subject (e.g. *Entertainment Computing: Special Issue on Maker Technologies to Foster Engagement and Creativity in Learning*[5] and *International Journal of Child-Computer Education: Special Issue on Digital Fabrication in Education*[6]). The topics of the field range from STEM education (Blikstein 2013; Johnson et al. 2016) to crafting skills with physical- and digital-materials (Buechley 2006; Lo and Paulos 2014). However, we focus on the arguments for the possible benefits of introducing design education as part of the formalized middle-school curriculum (Baynes 1974; Burdick and Willis 2011; Iversen et al. 2015; Smith et al. 2015, 2016a). Our initial work with the DeL Tool and this follow-up study builds on the notion that maker settings provide an opportunity for teaching and investigating design as a new literacy among middle-school students.

Studying students' design literacy in the FabLab@School.dk project

The study of students' design literacy was initiated by the Child-Computer Interaction Group[7] at Aarhus University as part of the three-year research project, FabLab@School.dk,[8] in collaboration with thirty-nine Danish public schools. FabLab@School is a worldwide network of educational FabLabs, created by Transformative Learning Technologies Lab (TLTL) at Stanford University.[9] Our research was central in developing the FabLab@School project for a Danish context, focusing on how to combine FabLab activities with design education. Thus, we define the FabLab@School.dk settings as hybrid learning laboratories that combine digital fabrication, design thinking, collaborative idea generation, and developing solutions to wicked problems. Central to our research project was an assessment of students' competences in such areas and their development over time. 1156 students, who had not yet received training in design, were surveyed in 2014. Our 2016 follow-up study was carried out among two groups of 449 students, containing 169-questions, asking students to self-assess their relationship to digital technology and design thinking [a thorough account of the entire survey can be found in Hjorth et al. (2017)]. The first group consisted of middle-school students who had been educated in as part of the Danish FabLab initiatives in education, whereas the second group had not (*control schools*). Students in the FabLab group did not received the exact same training in design, as it was up to the locale design trained teachers to

[3] On a side note, hackerspaces have been around for over 20 years, whereas makerspaces are a rather new concept. The concept is primarily defined by Make magazine (ISSN 1556-2336).

[4] http://www.fablearn.org (accessed 28-11-2017).

[5] http://www.sciencedirect.com/science/journal/18759521/18/supp/C (accessed 28-11-2017).

[6] https://www.sciencedirect.com/journal/international-journal-of-child-computer-interaction/vol/5 (accessed 28-11-2017).

[7] http://www.ccid.dk (accessed 28-11-2017).

[8] http://fablabatschool.dk (accessed 28-11-2017).

[9] https://tltl.stanford.edu/project/fablabschool (accessed 28-11-2017).

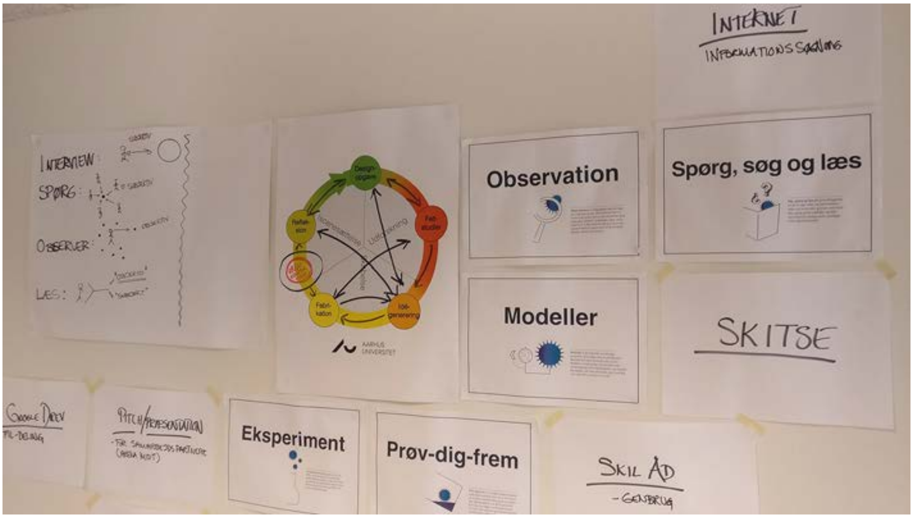


Fig. 5 Design in Making Model in a classroom wall display. Arrows indicating that the process is not linear step-by-step guide, but also iterative and retrospective

plan and facilitate lessons, thus creating a broad variety of courses and assignments. In this paper, we will focus on two parts of the survey; (1) students' knowledge of the design processes and (2) the students' stances towards inquiry.

In order to support students in designing, and to get a snapshot of the current state of students' design literacy, we used our Design in Making Model (Fig. 5). The model helped them navigate back and forth between the six phases: (1) *Design Problem*; (2) *Field Studies*; (3) *Ideation*; (4) *Fabrication*; (5) *Argumentation*; (6) *Reflection*. Only students who reported that they had used the model to scaffold their design processes (69% of the FabLab group) were asked how familiar they were with each of the six phases. We did this to discuss students' self-perception of their knowledge of the design processes, in comparison with their stance towards inquiry.

To assess students' stances towards inquiry, we applied the DeL tool (Christensen et al. 2016). In short, the DeL Tool consists of the following three elements:

- An open-ended, qualitative survey that presents a problem with wicked aspects, tailored to our investigative context;
- A scheme for coding aspects of a designerly stance towards inquiry;
- Statistical analysis and validation of quantitative data based on the coded categories.

The DeL Tool questionnaire was designed to assess the students' stances towards inquiry, by utilizing an open-ended survey item. To assess their stances towards inquiry, students were asked to write how they would approach a wicked problem concerning elderly peoples' welfare, which most of the students could be expected to relate to. We based our question on a much-talked-about problem discussed in the Danish media, which was that elderly residents suffering from senile dementia would disappear from their nursing homes, get lost, and sometimes die before they were found. The question translates from Danish as follows:

> At the beginning of 2014, nine grandparents disappeared from their nursing homes because of loss of memory (owing to dementia). The problem for the nursing homes is to create a secure environment for the elderly without taking away their freedom. If you were asked to solve this problem, what would you do?

In order to do a comparative follow-up study, we used the same question in our 2016 follow-up survey as in our 2014 survey. In the next section, we give a short description of the DeL Tool coding scheme and its method, used to assess the participating middle-school students.

Method: categorizing students using the DeL Tool Coding Scheme

The DeL Tool applies a coding scheme that makes it possible to reliably distinguish among categories of written responses (for a detailed description of the DeL Tool methods, see (Christensen et al. 2016). The DeL Tool involved three phases: (1) pull response data on the wicked problem in the survey; (2) read and openly code each response; (3) assign codes into one of the three categories, in order to assign students to one of three categories (*no interpretable answer/don't know*; *technical rationality*; *designerly stance towards inquiry*). Finally, (4) the DeL Tool requires the researcher to do a statistical analysis, in order to determine whether there is a significant difference in the number of students who display a designerly stance towards inquiry, compared with those who do not. The three categories listed below were derived from theoretical considerations, whereas the responses were coded according to the specific content of particular responses:

0. No interpretable answer/"I don't know"
This category included blanks, random characters, and responses such as "I don't know" or "I don't care."

1. Technical rationality
Students who took a stance of technical rationality assumed they had sufficient knowledge of a domain that was more or less unknown to most of them. Students showed no concern for the wicked aspects of the question we posed, nor did they suggest an inquiry into the problem. Instead, responses assigned to this category suggested complete solutions that were readily at hand, easily accessible, or finalized solutions, and they wrote about the problems as though these were tame (please see example responses in Table 1). This suggest that the students in this category accepted their own beliefs and assumptions without reflection and suggested routine solutions. We interpreted such responses as approaching the wicked question with a stance of technical rationality.

2. Designerly stance towards inquiry
All responses that indicated some form of reflective inquiry into the problem space were included in this category. The responses explicitly or implicitly recognized wicked aspects of the question posed, and sometimes presented additional wicked aspects that were not explicitly part of our question. If a student suggested inquiring into any of the five wicked aspects of the question posed, this was considered as taking a designerly stance towards inquiry, rather than technical rationality. This means that students did not have to recognize all aspects of the wicked problem to be assigned to the category of 'stance towards inquiry.'

In order to make our analysis transparent, we have included examples of how we assessed the students' responses in accordance with the DeL Tool (Fig. 5). Our coding

Table 1 Examples of students' responses, translated from Danish by authors

(1) Response example	(2) Our codes	(3) Stance Category
Implant small GPS device under their skin	No consideration of ethical dilemmas (associated with tracking and implantation) Makes assumptions (e.g. GPS will prevent the elderly from getting lost)	1. Technical rationality
Mount sensors in the street doors that monitor when the elderly go in and out. The elderly should carry a map in their pockets or attached to their clothes, and carry a note giving their name, etc. In this way, you could see who was missing[a]	Suggests that the initial idea is a final solution Simplifies relationship between problem and solution No consideration of ethical dilemmas (associated with the sensors) Makes assumptions (that the elderly are able to use a map to get home) Assumes that there is enough personnel to check alarms	1. Technical rationality
Take care of them and make sure they have a good life before they die, and get visits from their family[b]	No concrete reflections of what it means to have "a good life" Assumes that family visits will somehow fix the problem	1. Technical rationality
First, I would examine the possibilities available in the nursing home. Then I would brainstorm for ideas on how the problem could be solved	Inquiry into the domain (field studies of nursing home) Consideration of possibilities and constraints Initiates an ideation process	2. Stance towards inquiry
It can be complicated to be both safe and secure, without losing one's freedom or privacy (…) I would first focus on the public's wishes and assessment of safety and security [Writes about privacy and online tracking]. Therefore, I'm interested in creating a sense of security among the people by asking for their opinion of how much of their privacy they would give up for security. Since we also have a human rights framework in Denmark, the elderly sitting in the nursing home would of course be asked. This may lead to some bad ideas or criticism, but since we are all human, we need to accept that some people may be weaker at judging today's technologies and concerns, but we must take them into account too. (…) I would ask about their assessment (…) of safety as the cost of their privacy. I would then bring amnesia into the discussion, and secure that the perimeter, the nursing home staff cannot control. It would not only establish a good balance between privacy/freedom as the cost of safety, but also great respect for the elderly, who have a really difficult time. (…) Addressing such questions is a great responsibility as everyone looks at things differently. The one thing that I would most of all try to assess would be human life. We certainly know that not everyone will agree (…)[c]	Inquiry through iterative processes of idea development Uses methods of participatory design (assumes that problems are wicked) Considers various ethical aspects of the problem Accepts the wickedness of the problem and how this will elicit criticism from various stakeholders Relates to a wider context than is presented by the wicked question	2. Stance towards inquiry

[a] "Have en sensor der er i dørene når de ældre går ind og ud. De ældre skulle have et kort i lommen eller et til at sidde fast på deres tøj hvor de er registreret med navn m.m. På den måde ville man kunne se hvem der mangler"

[b] "Passe dem godt og få det godt det sidste i livet og få besøg af familie"

[c] We shortened this answer because of its original length of 2453 characters

process consisted of three iterations of qualitative reading and coding, using an incident-by-incident method, followed by testing for inter-rater reliability, after which we finally categorized the responses into one of the three above-mentioned categories. Coding was done by the first two authors of this article.

Students identified as taking a designerly stance towards inquiry generally suggested that they would initiate some kind of process, such as exploration (visiting the nursing home in question), further investigation of the problem (looking up information on the web), entering into a dialogue with stakeholders (talking with experts or nursing home staff, and presenting initial ideas to an audience), or engaging in ideation (e.g. brainstorm or six-thinking hats). In contrast, students who took a stance of technical rationality, generally suggested finalized solutions, such as establishing more surveillance (GPS tracking, video cameras on-site, alarms, and digital GPS fetters), confinement (fences and locks), hiring additional personnel (police, guards, and personal assistants), more family visits (e.g. taking their loved ones for several walks a week), or teaching the elderly sufferers of senile dementia to not leave their nursing homes on their own.

Inter-rater agreement and reliability

To ensure reliability of the assessment process, two researchers openly coded the students' responses. Next, each assigned the open codes into one of the stance categories presented in section seven. Responses were then compared and discussed. For testing inter-rater agreement and reliability, the ratings, which were established prior to the discussion, were used. The inter-rater agreement between the two first authors on the combined experimental and control group students of the 2016 endline survey (447 students) was 97%. The resulting inter-rater agreement and reliability (Tinsley and Weiss 2000), using Cohen's Kappa (Cohen 1960), was $k=0.92$. In the literature on inter-rater agreement and reliability, a Kappa value above 0.80 is commonly interpreted as 'very good' (Altman 1999) or 'almost perfect' (Zegers et al. 2010). However, as pointed out by Kottner et al. (2011), this should depend on the intended use of the rating system. Since we did not propose to use the DeL Tool on individuals, we are confident that a Kappa value of 0.92 testifies to good inter-rater agreement and reliability.

Data analysis

In the next two sections, we present the participating students, and our analysis of the data collected from the follow-up survey. We analyzed our data in several steps. First, the DeL Tool question was given to a group of middle-school students who had already received design education in their school (FabLab group), and a group of students who had not (*control* group). This was done in order to find out whether there would be a statistically significant difference between the two groups. For our calculations, we used *R Project for Statistical Computing*.[10]

Participating schools and the selection of the FabLab and control groups

In the fall of 2016, the follow-up survey was administered by the four authors and researchers, with two groups comprised of 449 students (aged 11–15) at seventeen schools in

[10] http://www.r-project.org (accessed 28-11-2017).

Fig. 6 Students taking the survey

Eastern Jutland, Denmark (Fig. 6). The schools of the FabLab group participating in the FabLab@School.dk project were selected with help from the three collaborating municipalities in the project. The control group had participated in the 2014 baseline survey, but were not officially part of the FabLab@School.dk project, and here we contacted individual control group schools directly (Hjorth et al. 2017).

The criteria for the selection of the FabLab group schools was to have a diverse set of participating schools with regard to student age, school size and location and student socioeconomic status, and to include only schools and classes that had either worked with design or digital fabrication in education. The FabLab@School.dk coordinators in each of the municipalities informed the associated teachers about the survey, whom we then contacted by e-mail and telephone. The teachers then appointed the class that they deemed best-equipped to participate in the survey.

With regard to the control group, selection criteria were based on whether the school had participated in the 2014 baseline survey, and matched a school from the FabLab group with regard to student age, school size and location, student socioeconomic status (SES) and average grades received by the students, based on national results. Contact with the control schools was established through a letter to the school principals, in which we asked if they could help us find classes and teachers who would conduct a 45-min survey. We followed up with telephone calls with the teachers who were able to participate to explain the survey and organize the event. In this way a control group/class was found for each FabLab group spread across 17 schools. However, as evidenced in Table 2, one school was not matched, since the two possible/targeted schools declined to participate.

In the classrooms, we introduced ourselves, the research project, and the survey to the students. We were present during the entire survey session, in order to provide help with questions and technical problems. To increase reliability, the introduction was based on a document that included the most important points to communicate. Students filled out the survey through a website, accessible on computers, tablets, and phones.

Comparison of FabLab-group students and control-group students

In order to test our hypotheses, we applied a generalized linear mixed model fitted by maximum likelihood. As we were interested in the proportion of students with a design stance towards inquiry, we recoded the data so that it became binomial. Either the students had a design stance towards inquiry, or they did not. Thus, the students assigned the code 0 (*No interpretable answer*/"*I Don't know*") were pooled with the students whom we had assigned the code 1 (*Technical rational stance*). The generalized linear mixed model was fitted to these binomial data. Furthermore, the model included the schools as a random

Table 2 Participating schools. Control group schools are listed with corresponding FabLab groups. Socioeconomic status (SES) is represented by the average grades received by the students graduating in 2014–2016. SES and students grade are calculated by the Danish Ministry of Education annually, and is publicly available

School	Group	Class/Grade	Students	SES	Area
1	Control	8	32	7.1	Suburban
2	FabLab	8	41	7.5	Suburban
3	Control	7	17	6.7	Urban
4	FabLab	7	24	6.2	Urban
5	Control	6	20	7.1	Suburban/rural
6	FabLab	6	20	7.8	Suburban/rural
7	Control	7	51	7.4	Suburban/rural
8	FabLab	7	17	7.8	Suburban/rural
9	Control	7	22	5.3	Urban
10	FabLab	7, 8	20	5.9	Urban
11	FabLab	8	41	7.6	Suburban
12	Control	8	22	7.4	Urban
13	FabLab	8	20	7.4	Urban
14	Control	9	20	6.6	Urban
15	FabLab	9	46	6.5	Rural
16	Control	7	19	6.9	Rural
17	FabLab	6, 7, 8, 9	17	6.4	Suburban/rural
			449 Total		

effect, in order to control for individual variance across the surveyed FabLab and control schools.

Having tested our first hypothesis using the DeL assessment tool, we found that the hypothesis, *FabLab group students take a designerly stance towards inquiry to a greater extent than the control group students*, could not be confirmed, since the difference between the FabLab students and the control group students was not significant ($p > 0.05$). Among the FabLab students, 5.69% of the students suggested taking a designerly stance towards inquiry (Fig. 7), whereas among the control students, this number was 2.46%. This difference was not statistically significant.

Comparison of 2014-study students and 2016-FabLab students

To test our second hypothesis, *FabLab group students take a designerly stance towards inquiry to a greater extent than the students from the 2014 baseline study*, we again used the method prescribed by the DeL assessment tool. In 2014, 2.87% of the student responses were categorized as suggesting a designerly stance towards inquiry (Christensen et al. 2016). However, similarly to our findings concerning our first hypothesis, we did not find a significant difference in stances on inquiry between the students surveyed in 2014, and FabLab students surveyed in 2016 ($p > 0.05$).

Designerly stance towards inquiry: high level of design literacy?

As mentioned earlier; however, FabLab students seemed to have gained design process knowledge. In the following, we focus on the four elements of the Design in Making Model (Fig. 6): design problem, field study, ideation, and fabrication. These four terms would

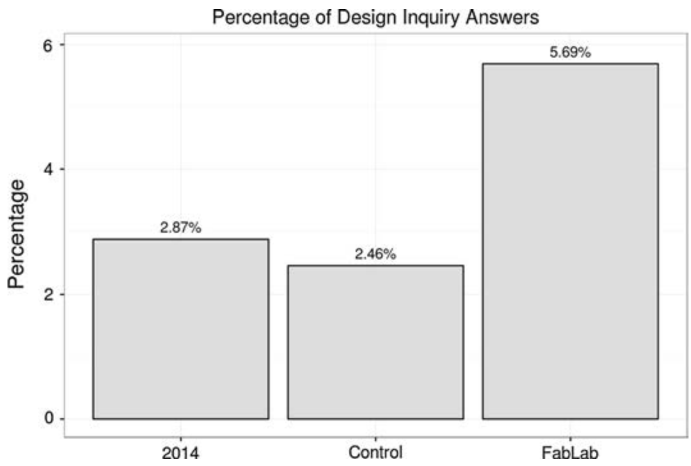


Fig. 7 Distribution of students with a designerly stance towards inquiry

have been new to most Danish middle-school students, whereas words such as 'reflection' and 'argumentation' are associated with all subjects and thus familiar to the students from other school contexts.

Our data indicate that students who participated in design education at the schools involved in the FabLab@School.dk project perceived themselves as knowledgeable of the various parts of the Design in Making Model (Fig. 8). Since we did not ask these questions in the 2014 baseline survey, we are not able to directly compare the two groups. Even so, our survey data indicates that almost half of the FabLab students assessed themselves

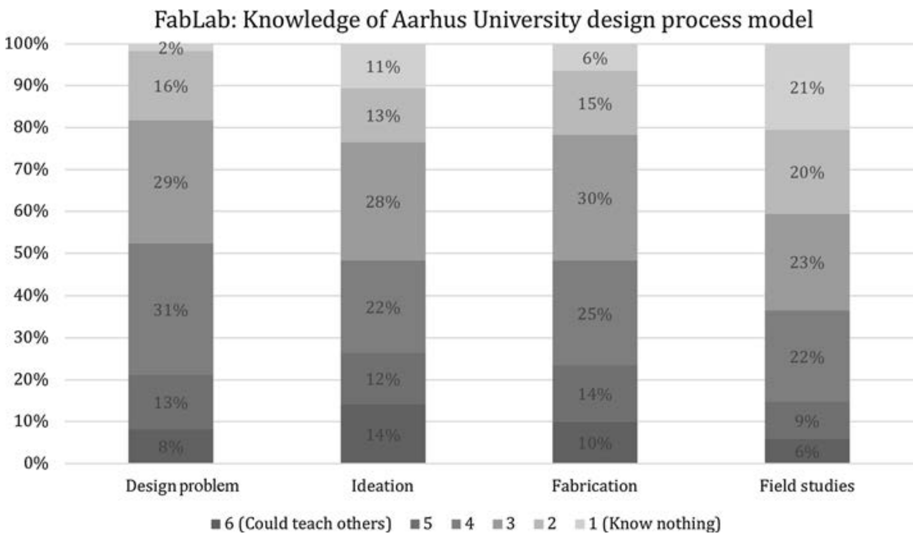


Fig. 8 Students from the FabLab group's self-perception of their knowledge of the various parts of the Design in Making Model. Students were asked to rate themselves on a scale of 1 ("I know nothing about it") to 6 ("I could teach others about it")

as above average with regard to their understanding of a design problem (52%), ideation (48%), fabrication (48%), and field studies (37%). This suggests that, to some extent, students have internalized facts, skills, and understandings about design thinking as expressed in the process model (Hjorth et al. 2017). However, when comparing these data to the results from our DeL Tool survey data, we find indications that, although students have subjectively learned elements of design knowledge, this knowledge is on the level of the development of routine expertise. The students are only beginning to proceed to levels of adaptive expertise and a designerly stance towards inquiry. Based on these data, we suspect that students' design knowledge and action are primarily bound to heuristics that they apply in a process of trial and error. That students did develop some degree of design process knowledge but not a designerly stance towards inquiry, which was measurable with the DeL tool, suggests that a designerly stance towards inquiry is difficult to develop to the point that it becomes students' default approach when they approach wicked problems. Thus, we suggest that a designerly stance towards inquiry becomes the default modus operandi only when one has developed the capability to be reflective of personal intentions, outlooks, and attitudes, and to know the nature of wicked problems, such as seeing the whole from multiple conflicting dialectical contradictions among stakeholders, including ethical, political, and even spiritual ones. Getting to this level of design literacy it seems/we suggest is best accomplished by developing a repertoire through the experience of working with multiple design processes over extended periods of time.

In general, the students seem to primarily be design literate on the lower levels of the design-learning outcomes hierarchy. To some extent, they have *knowledge of design*, which Nelson and Stolterman consider to be the level of routine expertise (Nelson and Stolterman 2012). Therefore, we suggest that these students have taken the first step towards developing adaptive design expertise.

Limitations of this study

In this section, we discuss a number of possible factors that may have affected our results. First, we discuss limitations of our measures and the factors that might have influenced our results. Second, we discuss impediments that may help explain the students' lack of a designerly stance.

Measurement limitations

As with other quantitative assessment tools, our analysis with the DeL Tool has limitations. First, the self-assessment procedure demands that the students demonstrate a designerly stance towards inquiry, which they were supposed to have developed through design processes carried out several months previously. We have yet to investigate the extent to which a designerly stance towards inquiry is situated in a specific time and context, and thus the extent to which this stance is transferable in the early stages of development. Second, the DeL Tool item demands that the students use more time and effort to engage with, and reflect on the question, in contrast to the Likert scale questions. This may lead students to act in such a way as to satisfy the minimum requirements for achieving a particular result or by the way of least effort. Third, our inability to produce statistically significant results also highlight problems of quantitative testing of the self-perceived effect of interventions in real-world settings in general (that is not to say that we *should* have found an effect).

When doing research in authentic classroom settings, there were many factors that we could not control. Furthermore, students were taught design by different teachers and not all students had received the same amount of design training, as it was decided by locally by the school. Some schools only had few courses, while others had design as an integrated part of their curriculum. Finally, the lack of a statistically significant development of a designerly stance towards inquiry among the FabLab students may also be attributed to the broad representation of different types of schools, and by extension, the great variance among the areas from which students were recruited (socio-economic status, urban/rural areas, etc.).

Impediments to teaching design in middle-school

Schools' implementation of design teaching varied for a number of practical reasons that may have influenced the extent to which students were taught design in the way we would conceptualize design. Furthermore, these variations may be the reason the difference among the three groups compared did not prove statistically significant when treating the schools as a random variable. First, there were no concrete specifications with regard to the implementation. The teaching done at this stage was as much explorative and research-driven and therefore without set evaluation measures etc. Second, although pre-specified learning goals are becoming more of a norm in Danish schools, teachers are accustomed to a high degree of freedom with regard to teaching approaches and methods (The Danish Ministry of Education 2016). Third, some schools were more restricted in terms of time, economy, and availability of teachers who were genuinely interested in teaching design.

Educators' lack of competencies for teaching design

In a previous study, we found that teachers experience significant challenges when teaching design in a formal school setting (Smith et al. 2016). One factor is the teachers' capability to teach students how to navigate and iteratively work through design processes that focus on wicked problems (Hjorth et al. 2016). In other words, we suspect that the teachers themselves in general may be considered no more than routine experts at best, as they lack adequate design experience. Another challenge might be that teachers experience design fixation when working with our design process model. McLellan and Nicholl notes, that while process models can provide useful guidance to non-specialist practitioners, they point out that in British Design and technology classes in secondary education "(…) practitioners tend to break down the design process structurally, forming a linear sequence of stage (…) rather than emphasize the holistic and iterative nature of the process…" (McLellan and Nicholl 2011). Without proper training and experience, teachers might unknowingly contribute towards students generating fixated responses, which might have influenced student responses. However, we were not able to further investigate this potential issue of our study.

Technology-focus bias in design processes

As researchers, we experienced a technological excitement among teachers and students, as new technologies promised to make the creation of digital products feasible in schools. Currently, most of the in-service teacher training happens through maker workshops at conferences, museums, or local hackerspaces. These introductory workshops tend to center on simple robotics or wearables, and be constrained to 30- to 120-min sessions, making them fast, scripted, and with predetermined outcomes (Peppler et al. 2016, 1:64–79) (e.g. see (“FabLearn Europe 2014, 2016 Workshops”; “FabLearn Stanford 2016 Workshops”). Although this may contribute to what Schön defines as a repertoire (Schön 1987), they do not provide the experience of a long, complex, and open-ended design processes. Although constructionist (Papert 1993) in their pedagogical approach, these workshops seem to primarily develop routine expertise. Thus, teachers may not be able to plan activities that enable students to experience design processes. Instead, many of these teachers may focus on small workshop activities focused on technological literacy rather than design literacy. Furthermore, teachers feel a need to educate students to become technology experts (Smith et al. 2016b). Instead, we suggest that teachers should think of technology as a material for reflective conversation and dialogue (Hjorth et al. 2016).

Design in formal education

The lack of middle-school students’ designerly stance towards inquiry may be attributed to the educational discourse of learnification, where students may have come to think that the teachers have either a ‘right or ‘wrong’ solution to (wicked) problems. Thus, they may fear that they make the wrong choices during the design process and that they reach the ‘wrong’ outcome, which does not ‘correctly’ solve the problem. Students may try to guess the teacher’s intentions, thinking that she has the correct solution to the problem at hand. In line with this, educators are often tasked with specific learning goals, which in turn underpins the idea of ‘right’ and ‘wrong’ solutions, and the need for routine expertise.

The limited time frames of curriculum-based education presented an additional problem. This limits the teachers’ capability to do longer and more intense design processes.

The settings in which students carried out the design processes varied significantly. Some schools used their traditional classrooms, whereas others had built entirely new FabLab classrooms for carrying out design activities. The schools also had varied access to materials such as Post-it® notes, crafts materials, or LEGO. Some had almost unlimited access to such materials, whereas other did not. Such availability of materials may have influenced the design processes, which teachers thought it possible to carry out.

Finally, our results may also be attributed to the fact, that students simply need more design education and experience working with wicked problems through design processes.

Conclusion

In this paper, we quantitatively assessed students’ stances towards inquiry, when asked how they would solve a wicked problem using the Design Literacy assessment tool (DeL Tool). We tested two hypotheses: (1) *FabLab group students take a designerly stance towards inquiry to a greater extent than the control group students*, and (2) *FabLab group students take a designerly stance towards inquiry to a greater extent than the students from the 2014 baseline study*. Both hypotheses proved false, as we were not able to find a statistically significant difference between students who had received some design education through middle-school maker settings, and students who had not. Instead, Danish middle-school students seemed to primarily approach wicked problems as tame problems, regardless of whether or not they had been taught about design in maker settings. If students are to successfully apply design processes in their education, they need to further develop an awareness of the complex and wicked nature of future problems such as climate change or e-waste, and through experience, learn how to apply design thinking to make designerly inquiries into these problems and to create potential solutions. The lack of significant results also highlights how difficult it is for teachers to teach this one aspect of design literacy, and to implement it in a middle-school context, especially while such subjects are not compulsory but in the process of being developed and tested. The participating teachers also show indications of being routine experts, as they lack adequate design education and experience.

Our survey study showed that despite the students' lack of a designerly stance towards inquiry, the middle-school students who received design education generally reported that they had acquired design knowledge and skills they could put into action. In our view this shows that students generally gained some form of routine expertise during these first engagements with design processes, whereas the more complex adaptive capabilities, such as developing a stance towards inquiry, demands more education for both teachers and students over a longer period of time.

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Abstract

Problems induced by the growth of online data tracking have reached a stage where serious concern must be given to the education of children regarding this continuing issue. We ask the question, What knowledge, understandings, concerns, and experiences do Danish middle-school students have regarding online data tracking, and how do they articulate themselves critically on the issue? We discuss the importance of developing critical digital literacies and give students the tools to explore and critique digital technologies. A pilot study of a three-hour lesson with 40 students suggests that students lack knowledge and understanding of online data tracking, have a limited vocabulary to engage in critical discussions, voice various concerns about online data tracking, and have improper conceptual models of the Internet. We discuss how Mozilla Lightbeam as an adversairal artifact, scaffolded the participating students in developing aspects of critical digital literacies.

Keywords: Critical literacies, Digital literacy, Middle-school context, Technology

“I Don’t Want to Know Who Is Tracking Me” - Critical Digital Literacy in Danish Middle-School Education

We present a study of middle-school students’ (aged 14-15) critical digital literacies, to gain insight into students’ knowledge, understandings, concerns, and capability to critique online data tracking practices. Our study is conducted to help researchers, policy makers, and educators gain insight into the current state of critical digital literacies among Danish middle-school students so that new curriculum and teaching methods can be designed to support students to develop a critical consciousness toward digital technology. We discuss how the Firefox “Lightbeam”[1] succusfully scaffoled students to develop critical digital literacies and recommendations for teaching strategies.

Online data tracking is of concern within various fields of research, from algorithmic cryptography design to philosophical discussions on ethics. As tracking of personal information is becoming more ubiquitous within industry and government (Schelter & Kunegis, 2016), heated debates have arisen regarding its impact on democracy, privacy, and freedom of speech on the Internet (Clement, 2014).[2] The personal information is often sold by data brokers to create user personas, used for various purposes such as personalized news feeds or filter bubbled search

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[1] https://www.mozilla.org/en-US/lightbeam/ (15-6-2015).

[2] https://www.washingtonpost.com/news/democracy-post/wp/2017/08/18/chinas-dystopian-push-to-revolutionize-surveillance/?tid=ss_tw&utm_term=.df73d813863e (16/1/18), https://www.theguardian.com/news/2018/mar/17/cambridge-analytica-facebook-influence-us-election (5/4/2018), https://privacylab.yale.edu/press/android-trackers (1/4/18).

results that create an online experience that confirms one's beliefs and perspectives (Christakis & Fowler, 2011, 2011; Pariser, 2011), which in its extreme, affects the democratic process and soft control modes of government (Hassine, 2016). Fuchs (2014) argues that we partake in activities that unwittingly enslave us into producing surplus value labor and profits for corporations, capitalist exploration, colonizing our "fun free time." Hence, tech industry manufactures a pedagogy of commercialization that prioritizes the acquisition and use of digital technologies for their own sake. Hinrichsen and Coombs (2014) warn of the dangers of naïve engagement with technology, emphasizing the need for critical digital literacies.

Although the Internet provides students with new creative, social, and scientific opportunities, the Internet has seen a move toward being more restricted and closed in walled gardens. This can be exemplified in Netflix's attempts to block Virtual Private Networks,[3] the threats posed to net-neutrality in the United States of America, and mass surveillance by government agencies such as the National Security Agency (NSA). This restricts citizens' options for securing their personal information and affect journalism and whistleblowing. Technologies that enable such practices are often proprietary and hidden from the user. This "black boxing," intentionally makes it difficult to know what data is collected and how it is used and shared (Latour, 1987, pp. 1–17). In such cases, critical thinking can be beneficial in developing a systematic, holistic, and reflective understanding of how the design of, for example, social media sites are closely related to political, economic, and sociocultural issues.

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[3] https://media.netflix.com/en/company-blog/evolving-proxy-detection-as-a-global-service (4/4/2018).

Based on these concerns, we argue that critical discussion of online data tracking and surveillance of citizens needs to be a topic within education. Critical digital literacies must be developed if future generations are to confront the complex problems surrounding online data tracking and surveillance (Pangrazio & Selwyn, 2017). Klafki argues that students should work with epochal key problems throughout their education, as they concern a large portion of humans today on a global scale (Klafki, 2011). It is essential to get a historically disseminated understanding of central issues in the present and in the foreseeable future to gain the insight that everyone shares the responsibility and a willingness to contribute to solving these problems. Online data tracking is one such epochal key problem.

Numerous researchers have discussed critical digital literacies (Frechette, 2014; Hinrichsen & Coombs, 2014; Keirl, 2009; Kellner, 2001; Pangrazio, 2016). A common denominator is the importance of engaging students in critical thinking in relation to technology, society, political, economy, and culture in order to accommodate technology-related problems in the 21st century (Fuchs, 2014; Hinrichsen & Coombs, 2014; Lankshear & Knobel, 2008, pp. 28–30, 55–68; Pangrazio, 2016; Pangrazio & Selwyn, 2017). This requires the capability to write as well as critically read digital texts. This concern is shared in the emergent fields of critical data studies, arguing that people need to adopt a critical stance toward what data is tracked, for what purpose, and how it is used—become vigilant data citizens (Kitchin & Lauriault, 2014; Selwyn, 2015).

We will not give an exhaustive definition of critical digital literacies; rather, we acknowledge the broadness of the concept. Our conception of critical digital literacies entails a critical consciousness toward epochal key problems related to digital technologies, encourages systematic understanding of how digital technologies are designed, and promotes a reflective way of using them to nourish democracy and empower people (Kinnula et al., 2017). This includes understanding technology design, production, and consumption processes, its democratizing potential, but also its dangers of undermining democracy and deprive people of privacy. Educating for critical digital literacies is a collective process, as it demands the individual to be empathic toward new ideas and perspectives that disconfirms held beliefs. To be critically digital literate, one must become self-determined, have a cultivated relationship with media consumption, and a spacious view of the world to avoid narrowmindedness, think relationally, and become equipped with the knowledge to critique digital technology from multiple perspectives. However, we must also acknowledge that children already have digital literacies, and what we want to do is supplement this knowledge; students know things about the technology that their teachers do not

In the context of our study, the attitude that we wish to promote is that digital data is not a neutral means of delivering information, and we wish also want to problematize this in terms of, for example, political and economic values and the interests and biases that underpin the design of such systems —that is, all discourse is ideological. Such a critique improves a person’s capability for discernment and the formation of informed judgment in the digital domain; to prepare for self-determination and empowerment to make informed decisions and design new solutions to epochal key problems. We return to this in section 2.

Based on these concerns, we ask the following questions.

- What knowledge and understandings do students have of online data tracking?
- How do students articulate themselves and experience issues of online data tracking?

- What concerns and critical reflections do students have regarding online data tracking?
- How do students conceptualize the design of the Internet and their part of this assemblage?

To probe these questions, we planned a three-hour in-class lesson in collaboration with locale school teachers from Kirkebakke Skolen in Vejle, Denmark. The lesson was a small part of a larger research and development project called FabLab@school.dk by the Child Computer Interaction Group at Aarhus University. The participating students were 14–15 years old and came from families with high socioeconomic status. Based on a previous survey study (Authors), we did not expect students to be advanced users of digital technologies, although they spent much time interacting with, for example, smartphones.

We used the Firefox extension Lightbeam to enable students to unravel the “black tracking box.” Lightbeam “*uses interactive visualizations to show you the first and third-party sites you interact with on the Web. As you browse, Lightbeam reveals the full depth of the Web today, including parts that are not transparent.”*

This paper presents insights into Danish middle-school student’s critical digital literacies, specifically knowledge, understandings, concerns, and critical articulations on online data tracking. We show that students lack knowledge and understandings about online data tracking, have not been taught critical digital literacies in school, and lack a proper conceptual model of how the Internet is designed. These insights can serve as conceptual scaffolding for developing critical digital literacies among middle-school students, which in turn has implications for how schools can bring forth issues of digitalization. Our objective is to develop a discussion into the discourse of child-computer interaction and education, specifically related to the importance of critical digital literacies. Without discussions on teaching critical digital literacies, education plays to the market and does not allow young people to develop a sophisticated understanding of their positions within wider socio-technical systems.

Critical Digital Literacies

Traditionally, literacy means being able to write and read print-based text. However, literacy has historically been an ambiguous concept as it includes a range of reading and writing capabilities (Kaestle, 1985), for example, phonology, orthography, and semantics. During the 1970s, this notion changed dramatically and has continued to do so (Colin & Michele, 2011, pp. 3–32). In 1996, the New London Group presented a new approach to literacy pedagogy, “ multiliteracies,” calling for a much broader view of literacy than portrayed by the read/write tradition. The emergence of a post-typographic literacy spurred a new interdisciplinary field of study, often referred to as New Literacy Studies (Gee, 2015). This field takes a sociocultural perspective to understand and formulate new literacies, rather than the traditional psycholinguistic paradigm. It is an approach to studying literacies as a constantly transforming and emerging social and cultural phenomenon (Colin & Michele, 2011, pp. 27–33; Gee, 2015) often associated with new digital technologies and their impact in the world. The shift from print-based texts to digital texts is described by Manovich through five characteristics that differentiate the two (Manovich, 2001). Digital objects are (1) Numerical (binary) representations, which can be algorithmically manipulated; (2) Modular, as all digital are collections of separate objects, from machine code and to the multimodal web; (3) Automation is the creation, manipulation, and accessing digital objects; (4) Variability means that digital objects are variable, not fixed, but can exist in different versions; (5) Transcoding refers to two levels of representation. First, the human cultural side, where people engage in aesthetic dialog with digital objects. Second, digital objects consist of pixels mapped to a Cartesian coordinate system. On this level, the numerical representation of the digital object is no longer in dialog with the human cultural side but with computer files and programs. The two sides use different languages to describe the qualities of digital objects. On the human cultural side, we might engage in a dialog on the meaning of the image or techniques used to create it. On the digital side, the image is described in the language of attitudes such as file size, modification date, filetype or permissions. The two sides influence each other to create a composite of a blend of human and computer language, where a process of conceptual transfer takes place from the computer world to the human cultural world based on the computer’s ontology, epistemology, and pragmatics. We shall later see how this transfer is present in the participating students’ experience of online data tracking.

Digital literacies have been explored within educational literature for at least 20 years (Pangrazio, 2016) through the use of several interrelated and overlapping concepts. Some concepts are used as synonyms, for example, digital competence and literacy, as is evident in both political and academic texts (Ilomäki, Kantosalo, & Lakkala, 2011; Krumsvik, 2008; Lankshear & Knobel, 2008). Defining *a* digital literacy has proven to be complicated, as knowledge and practice in the field is constantly changing and is no longer exclusively related to typographic reading and writing. It is a complex and contested field with many perspectives on what constitutes literacy and what technological developments mean for future conceptions of literacies. The field is characterized by different concepts such as digital, media or web combined variations of educational concepts such as literacy, competences, or capabilities.

In 2008, Coiro et al. developed a framework of multiple digital literacies to extend the notion of literacy beyond the capability to read and write texts. Literacy now implies a wider-form education about digitality that is not restricted to instrumental skills. Lankshear and Knobel argue that the highest level of digital literacies represents attitudes and perspectives (2008, pp. 28–30). These attitudes and perspectives constitute a moral and social framework that reflects the individual's capability to think independently and critically about digital technology, to help students learn what is necessary for living life within a digital environment. According to Buckingham, "*we need to equip students to understand and to critique these media: we cannot regard them simply as neutral means of delivering information"* (Lankshear & Knobel, 2008, pp. 73–91). Glister (1997) agrees with this line of thought, writing that we need to teach and learn how to critique the web. These arguments resemble how Hansen defines digital literacy: "*individual's abilities to adopt, adapt, invent, and evaluate technology to positively affect his or her life, community, and environment"* (Hansen, 2003). Eisenberg and Johnson (2002) also emphasize this shift from instrumental computering, to use them *"as a tool for organization, communication, research and problem solving."* Coinciding with this stands the German Bildung tradition, which we use to inform the Anglo-Saxon idea of digital literacies.

Schelhowe, Dittert, and Katterfeldt argue that education should develop students' insight into the relationship between digital technology and society (Katterfeldt, Dittert, & Schelhowe, 2015; Schelhowe, 2013). They utilize Bildung to denote the learning process in which students, through reflection and action, critically consider their conception of self and the world. Klafki describes Bildung as forming people so that they can improve society as does (Klafki, 2011). Students should not be educated for the present, but for a possible condition of humans in the future, based on humanistic virtues of free speech, democracy, emancipation from oppression, and freedom to live the life one wants (Tække & Paulsen, 2017). Students should not be educated merely to fit into an already existing world. Instead, students should acquire agency that enables them to become critical and empowered citizens who can relate different perspectives, practices, and knowledge to the “overall situation of the world.” This is a collective process, which can have real societal impact only if obtained by the general public (allgemein Bildung). Public education has reasonability to provide students with a form of Bildung that animates students to feel responsible for future socio-technical changes and to investigate topics from multiple perspectives. Proponents of Bildung argue that such responsibility makes for citizens who can think for themselves in future society. Accordingly, digital Bildung is concerned with emancipation, empowerment, and democratic citizenship in relation to digital technology. Thus, digital Bildung is as much about personality, character, and perspectives on life as it is about developing competences for future job markets. It is a process of both personal, collective, and sociocultural maturation in relation to digital technology that is holistic in scope rather than specific. Kellner (2001) draws on the American philosopher John Dewey to underscore the importance of nurturing a strong relationship between democracy and education, as technology can increase inequality and the divisions of cultural capital, power, and wealth.

Closely related to Bildung is Paulo Freire’s critical pedagogy (Freire, 1996, 2005). Freire argues from a Marxist tradition that critical literacy should be an integrated part of civic education, which makes social and moral obligations for educators and policy makers. As with Klafki, Friere argues that an epoch is characterized by a web of complex ideas, hopes, doubts, values, and challenges in dialectical interaction with their opposites striving toward their fulfillment. The representation of these constitutes the themes of the epoch. Critical consciousness develops through the identification of “generative themes,” creating a critical consciousness of one’s social reality through reflection and action. Applying these ideas to the digital realm means that the development of critical digital literacies requires practices that should aim to explore and expand the human interpretative process associated with digital technologies, revealing the design of digital technologies such as the Internet that manifests and maintains systems of power and privilege (Fuchs, 2014; Pangrazio, 2016).

The development of critical digital literacies should start from a personal position so that an individual’s beliefs and experiences can guide the exploration of ideologies that structure the digital environment (Pangrazio, 2016). Using Lightbeam, we let students explore their personal network of data trackers through network visualization. It collects and renders a complex dataset by applying simple visual cues such as different shapes or colors to assign significance to the dataset. Lightbeam enables students to manipulate variables to generate new visual representations.

Research Method

Our empirical evidence derives from a research through design experiment with online privacy as the theme for exploring and supporting students’ development of critical digital literacies. We combine design research theory with anthropological methods, giving us the opportunity to triangulate experiments (Mackay & Fayard, 1997; Smith et al., 2016). We present exemplary cases of students’ work (Binder & Redström, 2006), as they characterize the varied engagement and experiences among students.

Through a participatory design process with two local teachers, we produced a teaching program that touched upon three epochal key problems: online data tracking and privacy, remixing, and e-waste. The objective was to engage students in making inquiries into the theme of "Hacking Global Communication," and have students reflect on their relationship with digital technology when enmeshed with ethical, ecological, sociocultural issues, and so forth. The outcome was a 63-lesson teaching program integrating conventional classroom teaching, group discussions, and free exploration with digital technologies. We use empirical data from the lesson, titled "Privacy and Security on the Web."

Two teachers and two researchers were present throughout the lesson. The teachers did not have experience facilitating lessons that focus on students' critical digital literacies. One would facilitate the lesson, while the other would document the activities using written notes, photos, and AV recordings with both handheld and stationary cameras. We observed different groups of students work with Lightbeam and their concurrent discussions and conducted semi-structured interviews throughout, as well as post-lesson interviews with the teachers. Our empirical AV data was analyzed with a focus on groups and students who sought to engage actively in discussions and make critical inquiries. All material was transcribed and coded, to find patterns through exemplars. Finally, our empirical data has condensed into coherent patterns using affinity-diagramming techniques (Beyer & Holtzblatt, 1997).

Having introduced ourselves as researchers, we screened a video about online data tracking[4] to give the students an initial vocabulary, a sense of the issues of online data tracking, and its undesired consequences. Students were split into discussion groups to make to some initial reflections on online data tracking, accompanied by four guiding questions. This was followed up with a hands-on, visual exploration of the web using Lightbeam. Students were asked to browse the web as they pleased while encouraged to move between a critical mindset and their everyday online practices. Finally, we had a class discussion in plenum.

Consent for conducting the studies was provided by the principal, teachers, parents, and the students themselves. Students were informed that they could refrain from being observed, filmed, or interviewed at any time. To generate trustworthy knowledge, it is essential for this type of research to build rapport and trust with participants (Creswell, 2014). We had been visiting the school multiple times in Vejle, talking with teachers and students. The students and teachers already knew us by name, and vice versa. The students were not afraid to ask questions about the lesson activity and our research.

Lightbeam scaffolded student exploration of tracking networks through visualization (figure 1). Pangrazio and Manovich both argue that digital aesthetics and data visualization can be beneficial to contextualize or defamiliarize digital networks, tools, and practices in order to critique commonly held assumptions, ideas, and views (Manovich, 2013; Pangrazio, 2016). Design researcher DiSalvo uses the term adversarial design to label computational objects that

[4] Gary Kovacs, http://www.ted.com/talks/gary_kovacs_tracking_the_trackers (4/5/2018).

do the work of agonism (DiSalvo, 2012). Adversarial designed objects have the function of prompting recognition of political issues and relations, express dissensus, and enable contestational claims to reveal hegemony. Lightbeam works as an adversarial design that through agonistic tactics scaffold students in revealing the relations between a heterogeneous array of entities through interaction with visual representations, giving them the tools to reflect on their assumptions, knowledge, and understandings.

Our study revealed that that:

- Lightbeam gave students new insights into the design of the web. Gradually, the students engaged in the process of reflecting on their relationship with online data tracking, based on their personal online habits.
- Students generally lack knowledge and understandings of online data tracking, how it works, its extent, what data is tracked, and how is it used.
- Students lack a vocabulary to articulate themselves critically.
- Students lack a proper conceptual model of how the Internet is designed.
- Students had not previously engaged in critiquing digital technology such as online data tracking.
- Students were surprised and scared of the number of websites that track their everyday Internet interaction and felt powerless against tracking practices.
- Students expressed concerns but also mentioned benefits of online data tracking.

We present exemplary cases that highlight these findings (Binder & Redström, 2006), starting with the students’ lack of knowledge and a vocabulary for addressing issues related to online data tracking. Note that while students are numbered *n* in every exemplar, it does not refer to the same student across the exemplars. Researchers are denoted by their first name.

Students' Knowledge and Understanding of Online Data Tracking

The following exemplars showcase the students' lack of knowledge and understanding of online data tracking and a limited vocabulary, which made it difficult for students to articulate themselves in group discussions and semi-structured interviews.

Author: Does anyone know what a web browser is?

Student 1: [only one student raises his hand, the rest of the class looks confused] For example Chrome or Firefox.

Author: Ok, does anyone know what an add-on is?

Class: [mumbling and confused facial expressions].

Student 1: Yeah, it is an addition.

Author: That is correct; it is an additional with which I can extend the functionality of my web browser. For example, I use add-ons for blocking ads, IP addresses, and scripts on websites. Does anyone know what an IP address is?

Class: [Students are silent. None of the students tries to articulate an answer, except one student who answers "yes" but does not give any further explanation].

Only one of 40 students attempted to answer questions about basic web technologies. Whether this is due to a lack of knowledge or a reluctance to exhibit themselves in front of the class (and two visiting researchers) is hard to say. If nothing else, the exemplary student 1, presented only limited articulations in answering the researchers' questions. The lack of responses suggests either a lack of language to make precise articulations when having a dialog about everyday digital technologies or that students were too shy to respond.

Author: Have any of you heard the word tracking before?

Class: [in choir] Nooooo!

Author: It is a bit like following someone. Have you heard of being stalked before?

Class: [in choir] Yes!

Author: Okay, it’s a bit like that. There are people who follow you online without you knowing it. In other words, you are constantly being stalked and monitored on the web.

This example is indicative of students’ lack of knowledge and awareness of online data tracking. Tracking is not a new term but has long been an integral part of the web, like cookies. Students had an easier time relating themselves to the “stalking” metaphor, a concept that they had experienced or knew about. Our interpretation of this is that stalking is a term used on social media to describe people who use the Internet to stalk or harass individuals. However, there is a significant difference between the concept of tracking versus stalking. As we will see later, not possessing proper language and knowledge of how computers operate and their infrastructure, and by extension online data tracking, makes it difficult for students to articulate themselves critically.

Based on the introductory video, we hoped that students would frame the notion of tracking based on the idea that it is first and foremost an activity practiced by large data-driven corporations like Google, as an insidious way to create economic profit. Students lacked this understanding and initially understood tracking as stalking of individuals to harass or check other people’s social media profiles, to peak into their lives (McFarlane & Bocij, 2003). This was also how a student described stalking:

Student 4: Look, there is a stalker, stalking me on Facebook. It is something called Akaimihitme [pulls nodes around the screen making them swing around].

The student understands tracking from the viewpoint that Akamai is a human individual that stalks his online interactions, while it is a web service used to do automated real-time web monitoring to prevent cyber cracking. This lack of knowledge and technical vocabulary was also observed among another group of students.

Student 2: But can I find out who’s stalking me? [how other individuals could stalk his online interactions].

Author: Yes?

Student 2: But how? Is it another person?

Author: No, it is usually a company, like we discussed in the beginning.

Student 2: Oh.

Student 3: Can you demand them to not do surveillance?

Author: You could try to demand it, but then you would probably have to close your Facebook, Google, and similar accounts.

The two students seem to be unknowledgeable about what rights they are handing over when signing up for various web services and show signs of unfamiliarity with End User License Agreements. Student 3’s question suggests that he is not aware of how his personal data and privacy relates to tracking. We observed the same lack of knowledge in the final class discussion:

Student 4: I have investigated a site called Webtrends. It was just some fashion stuff.

Author: Do you know what they are doing?

Student 4: No, I did not explore that.

Author: Did you figure out where the site is located?

Student 4: No.

Teacher: But you did find out, that you thought it was about clothing?

Student 4: Yeah.

Teacher: We talked about what the words mean on the web? What did we find out?

Student 4: Internet fashion.

Teacher: Yeah fashion. So, trends on the Internet.

This exemplar illustrates how the students’ vocabulary is entangled with concept connotations from a different domain than the web. The students are uncertain about the various meanings and definitions at play. The lack of a nuanced technical language of online data tracking was confused with meanings from other domains. While the teacher pointed out that the student did indeed figure out what “trends” was on the web, she still relied on her vocabulary from another domain, rather than adapting the language that framed the lesson. However, the teacher also seems to lack a proper vocabulary, and the knowledge to assess what is meant by web trends, web analytics, and measurement for digital marketing optimization. The discussion among the two students did help them gain new understandings, but the teacher did not intervene and explain that fashion is not about clothing in this context of the Internet. Instead, she confirms the students use of “Internet fashion” and confuses this with trends. This suggests that the teacher lacks knowledge and experience with contemporary technology. This narrows the possible teaching approaches and creates constraints when incorporating teaching activities that focus on critical digital literacies, which both teachers experienced as extremely relevant (but without the competences to teach). A post-lesson interview with one of the teachers further highlights this:

Author: What is it like to work with these [themes]?

Teacher: I think it’s great. The things that you have prepared are so interesting, the thing about thinking critically and what their online behavior means, right? They are totally unaware. If you asked them questions like “did you know that so many websites tracked, you on the web?” Nobody knew. I find these activities to be extremely relevant to work with, and it’s very interesting.

The teacher calls for more critical digital literacies teaching, and that a critical perspective on digital technology is relevant for the students’ education. However, our observations show that it is challenging for the teachers to instruct students in thinking critically about what they uncovered with Lightbeam.

In summary, we found indications of students having limited knowledge and understanding of online data tracking. Our observations suggest that both students and teachers experience online data tracking in a general sense but do not have technical understandings of what online data tracking is, how it is done, who practices tracking, and for what purposes besides advertisement. Consequently, students lacked a proper vocabulary to articulate themselves critically in discussions on online data tracking, even students with a high degree of technical skills.

Students’ Conceptual Model of The Internet

The following discussion takes place between a teacher and two boys, exploring what happens when visiting a large number of websites. The two boys were very eager to browse through many websites.

Teacher: Is it a declared goal for you to get as many trackers to follow your whereabouts?

Student 1: Yes, I am aiming for at least a thousand.

Teacher: How do you behave to get that many followers?

Student 1: I will just do a search on Google… for example… what should I put into the search bar?

Student 2: IKEA?

Student 1: [types IKEA]. At the Google search site, I will click on every accessible link on the site. Accordingly, more tracking companies will follow my actions. And perhaps I will get more commercials.

Teacher: Okay, so why is this interesting to you?

Student 1: Now I can see that IKEA is following me and perhaps they can see what I am buying elsewhere.

Teacher: What can the company use this information for?

Student 1: Perhaps they can make statistics about my preferences when I visit their site. Or what I have bought. Perhaps they can offer me a special discount?

Teacher: What is the most interesting tracker you have found?

Student 1: I don’t know. It is surprising that Jyllandsposten [Danish newspaper covering the region of Jutland] is so big. How can they get so many things to track me? They have so many trackers, and they automatically track me. That is something that really surprises me. Right after Google, Jyllandsposten is the biggest [tracker].

Teacher: Perhaps that would be an interesting question to pose to the researchers?

Student 1: Yes.

Teacher: Can anyone of you explain why Jyllandsposten is tracking that much?

Student 2: Maybe because Jyllandsposten as a newspaper covers the entire country?

Student 1 can explain some important aspects of how the Internet is designed, and he does make relevant hypotheses as to how online data tracking works. However, the teachers told us that student 1 was a “computer geek,” meaning that his knowledge and capabilities were well beyond the other students. In contrast, student 2 is lacking a proper conceptual model of the Internet. Student 2 assumes that Jyllandposten.dk connects to a big network of trackers, because of its popularity in Denmark. The student seems to interpret and understand the tracking network in terms of the physical geographical location of the company in question, rather than thinking about how digital networks come together from many different countries. The students understand tracking by representing the Internet as a collection of objects that are directly analogous to objects in the real world.

The following case exemplifies two students’ understanding of how online data tracking works and its purpose. They often visit a website where Fifa (football videogame) players can trade, buy, and sell virtual cards to create teams. The students explored the trackers on the Fifa website.

Researcher: Why do you think that Fifa is so big?

Student 3: Because there are a lot of people trying to hack it, so a lot of people are looking at it, so you do not get hacked yourself.

Researcher: Are there other computer games that you play?

Student 3: I do not play that often, but if it is a football game that everyone plays, then you are at the risk of getting hacked. That is why there is a lot of people are looking [referring to the tracking sites represented in Lightbeam].

Student 3 conceptualizes his network of online trackers as a form of protection of his personal data and his in-game trading cards in Fifa. According to the student's statements, the game developers' intention with the tracking was not to collect personal data but to prevent hacking. The students understand the circle of trackers as a protective safety measure, rather than a modular network that is privacy invasive. They are unable to “read” the visualized network, like someone who can pronounce words but does not understand their meaning. In continuation, we observed how the two students were confused as to why a website about buying illegal drugs from Silk Road was not connected to a big network of trackers. Their findings did not correlate to their previous hypotheses that the trackers protected them from hacking.

Student 3: We are visiting a hash page!

Researcher: Try and check out your network.

Student 4: There will probably be a lot of trackers

Researcher: Is it the big one? [big central website connected to a 20+ trackers].

Student 4: Hmm, no, it is TV2 (Danish TV channel). Try and click on it.

Researcher: Yeah, it is quite big. Did the drug site come up?

Student 3: No, not really [the drug site outside the network of trackers].

The two students think that websites containing information on illegal activities such as buying drugs off the Tor network would be surrounded by trackers to surveil the people visiting these types of websites. This confused them, as they found out that the TV channel TV2[5] had a large number of trackers connected. They perceived TV2 as a business that would not need tracking of its users and did not understand that it is common practice for businesses to keep a close eye on peoples' interactions when using their service, for example, viewing habits. They seem to understand tracking primarily as a practice performed by the state to prevent crime such as selling illegal drugs or as protection from black hat hacking.

The two exemplars suggest that students do not conceptualize the Internet as being constructed as a globalized modular network infrastructure of computers, of hidden scripts and algorithms, and the state is only a part of the equation. We found that students' knowledge of the design and infrastructure of the Internet is lacking and that they misinterpret the meaning of the tracking network represented in Lightbeam.

In summary, the lack of knowledge in understanding how the Internet is designed and the limited awareness of online data tracking among the teachers and the students, affect the students' capability to engage more deeply in making critical inquiries and reflections. Without proper knowledge and understanding of how the Internet is designed, it becomes difficult to make critical articulations. This is aggravated as the teachers are not trained to scaffold activities

[5] Danish television channel.

that focus on developing critical digital literacies, and that they seem to be lacking critical digital literacies.

Students’ Concerns on Tracking

From our observational studies in the classroom, we saw how several students had genuine concerns about online tracking. One student even experienced discomfort in knowing how much tracking happens on the web and expressed that she would rather not have the knowledge presented in the lesson.

Student 1: It really sucks to learn who tracks you.

Researcher: It does?!

Student 1: Yes, it is a real bummer.

Researcher: So, you would prefer to not know that this happens when you are online, who tracks you?

Student 1: Yes.

Researcher: But you would know that someone is watching you?

Student 1: Yes, but I would rather not know who they are. You see… [talking directly into the camera held by the researcher] Before [today], I didn’t really know that this tracking thing really occurred. I thought that there was this *hacking* thing, which I know is different, but I thought [humming a happy go easy tune]. But now I just realized “THAT IS LIFE”. That is annoying – to have this insight, I mean.

Researcher: So how many would you guess are tracking your whereabouts?

Student 1: Five thousand [laughs]. I am famous!

The exemplar is indicative of the student feeling uncomfortable knowing about the commonality of online data tracking. She shows restraint from engaging in critical reflection on digital technology occurred as an attempt to avoid facing some of the negative consequences of living with digital technology. Her newly gained insights, challenged her habits with digital technology, thus subverting her everyday practices and prompting her to consider alternatives and make critical inquiries—which she would rather not. It was not unusual that students considered changing practice troublesome and expressed that new practices would potentially cause a feeling of “missing out,” by not having accounts on privacy invasive social media.

Three students did make deeper inquiries into their tracking network and experienced some of the issues that arise when digital technologies become opaque and black boxed.

Student 2: All those websites that are tracking us, or whatever it is called... If you search for them on the web, I just get like, this site is not available. Do they block me or what? Why can I not see it?

Author: My guess is as good as yours. If I had a company that did online data tracking, without the user knowing, then I would make it so that you could not easily find out who am I as a company.

Teacher: Student 3?

Student 3: We tried to visit a site called Newsrelics, and then a lot of new ones popped up?

Author: Like, there were more trackers popping up?

Student 3: Yeah, it was like they were tracking us, and then we tried to visit their site, and then a lot of new trackers popped up.

Author: Did you figure out, what Newsrelics is doing?

Student 3: No, not really.

Student 4: We visited a site called Uservoice or something like that. And it was a website that helped with tracking their consumers, so, yeah.

Student 5: I find it a bit scary that you have no idea, who it is.

Teacher: They are kind of anonymous?

Student 5: Yeah.

Based on their exploration with Lightbeam, the three students decided to dig deeper and research the tracking services that they had never heard of before. While the students did not get a complete understanding of what the different tracking services do and how they function, they did initiate critical inquiries that led them to understand that the companies running tracking services make efforts to remain anonymous to the average user.

We finished the lesson with a class discussion revolving around four questions that the students had discussed throughout their wor. We asked them what surprised them, what concerns they had, what positive sides there is to online data tracking, and what their newly gained knowledge meant for their future web interactions. The discussion was facilitated by one of the researchers and one of the teachers. Having the discussion as a dialog between the teacher, researcher, and students meant that students were more comfortable about speaking up. The first exemplar is a group of boys explaining their concerns.

Teacher: Before today, did you know that you hand over a lot of your privacy rights?

Student 6: No, I did not. I just read, like, that there is something, I want something, and then I just press yes and accept, because I want Facebook and stuff like that.

Teacher: Then there is something that you can do about it yourself in relation to privacy.

Student 7: But if you do not press yes, then you cannot get Facebook.

Teacher: That is correct, but, so what?

Student 8: It is extortion!

Student 7: It is boring!

The two boys also express feeling uncomfortable knowing that online data tracking is so ubiquitous on the web. The boys are challenged by a dilemma which remained unresolved; either they keep their privacy, or they quit popular privacy invasive services and potentially experience social exclusion and boredom. The following dialog between a teacher and a student also illustrates how students felt surprised, uncomfortable, and worried by their newly obtained knowledge, but it did not pave the way for concerns.

Student 9: It doesn’t concern us that much, but it’s a bit unpleasant to know, that they can go in here and get your personal data. For ads or whatever. It’s unpleasant, but it’s not something that really concerns us, and we don’t think too much about it.

Teacher: What about you, what did you talk about? [points toward a group].

Student 10: We are a bit surprised, or worried, about what they use our data for. We did not really know about it. So, they can use them [data] for advertisement and stuff like that, but we do not even get money for it?!

Most students understood data tracking to personalize advertisements or as hacking but had not reflected upon what issues other than data tracking might entail. The exemplars suggest that some students have started to raise concerns about online data tracking, whereas others are not concerned about online data tracking, and again, lack knowledge and understanding of the subject. However, whatever their opinion, none of the students was willing to change their online interactions, for example, deleting their Facebook account or extend their web browser with anti-tracking addons. It indicates that students feel trapped into social media like Facebook, and fear that they might become socially excluded. The exemplars showcase what has been termed a “privacy paradox,” they feel social pressure to participate in privacy-invasive services while having concerns about privacy (Barnes, 2006, p. 200). They feel ambiguous and unsure of how to relate themselves to the new information.

While the students had different (non)concerns, the majority agreed that they had learned something new and that this new knowledge was surprising but useful to them. Students were especially surprised by the amount of tracking that happens online and their inability to do much about it. Thus, students’ investigative work with Lightbeam cultivated a new relationship and nuanced understanding of the Internet, as a conceptual model and in terms of how to understand and make critical articulations on the issue of online data tracking.

Teacher: You have worked for 3 hours with a topic that most of you did not know about? So, what did you learn today?

Student 11: I did not really think that it existed. I just thought that some people were hacking others or something.

Teacher: No, it does not need to be a hacker. Yes? [pointing toward student]

Student 12: It’s crazy that you do not know what you agree to, but you just accept and press yes, and then they can use it. It came as a surprise to me.

Teacher: Yes, Student 13?

Student 13: I did not know that I give up so much of my private life online.

Teacher: Great. What did you learn today, student 14?

Student 14: That so many people are stalking me.

Teacher: OK. Is there anything that surprised you today?

Student 15: Yeah, it surprised us that there are so many [trackers].

Student 16: And that there are so many [trackers] in such a short time span.

Teacher: OK, it seems that that is a recurring theme among all of you.

In summary, we found that students were surprised by the large number of websites that tracked their data and how it is hidden from users. Some students worried about corporations’ and government institutions’ collection of private and intimate details of their life, whereas others were primarily surprised but did not show many concerns. Most students also found the opacity of online data tracking troublesome, but only a few engaged in making critical inquiries based on their tracking network. One student claimed that it seems impossible to have any privacy online and browse the web without being tracked and surveilled. However, some students also pointed out that there are positive sides to online data tracking, such as personalized advertisements or movie recommendations, based on what you have previously watched, or to prevent crime.

Discussion

Research through design experiment findings

We found that students generally lacked knowledge and understanding of online data tracking and lacked a proper conceptual model of how the Internet is designed. The video screening made it clear that the students generally were unaware of the scale and detailed collection of personal information. Students did not possess the knowledge to understand how the futurist promise of technology giants bases itself on a new world of “smart cities,” fully linking people and objects enabled by digital advancements, creating a panoptic view of people’s lives and behaviors (Lyon, 1993). We see our task as researchers and teachers to give students the opportunities to develop this understanding. As a consequence of this limited knowledge, the participating students relied on language from other knowledge domains to articulate themselves.

Most of the participating students had not previously engaged in critical thinking and discussion on online data tracking. Instead, we found that students were unaware, surprised, some even scared, by the number of websites that track their data. They felt powerless against tracking practices, as so much of their world happens through online services, to a point where life can be confused with its digital persona modeling. Students feared to be left behind and be socially excluded by giving up on services that intentionally track their behavior, and because so much of the students’ identities is formed on social media services, which allow the negation of a positive self-image by attaching “cool” values to their identity, for example, stories on Instagram. However, this also has effects for those who refuse to use these services. It limits information access, fosters social exclusion, and alienated them from then on as potential suspects. As with most young people, they are immersed in cultures of digital consumption that help shape their identity (Hill, 2011). Not by a buy-and-consume modality, but a prosumer modality facilitated by surveillance capitalism that monetizes acquired data (Fuchs, 2010). As prosumers, students do not pay with money for consuming digital media content, for example, YouTube videos. Instead, the line between consumer and producer is blurred, and the prosumer works without payment by generating data for the corporate market (ibid.). The students in our study were unaware of this political economy, which might not be surprising as critical digital literacies seem to be lacking in schools and are backgrounded in favor of instrumental technology usage, thus leaving behind the critical pedagogical commitment of exposing the relations of sociocultural domination and ideological hegemony in surveillance capitalism. In summary, the participating students had not been taught to reflect critically on the political, cultural, historical, economic, and social ramifications of online data tracking. As Willingham (2007) points out, critical thinking is not possible without proper domain knowledge and practice. This leaves the students in a situation where they are unable to take on new perspectives, as critical thinking is not a capability that can be applied regardless of context and knowledge. Instead, students interpret the issue of online tracking on prior knowledge, for example, the idea of cyber stalking as showcased in section 3.1 or the student finding it unfair that they do not get paid for the use of personal data in section 3.3. Students have transcoded their language from a human cultural side, and thus, their vocabulary seems to be more influenced by their everyday life, rather than using the "language of new media" (Manovich, 2001). They do a conceptual transfer from the human cultural world to the digital world. This transfer might also be understood in terms of the digital environment and products that are advertised toward students with and which they interact the most. This might be a consequence of what Lialina contends is the denial of the *user* in favor of *people* who experience digital technology, as Interface Design is renaming itself to Experience Design—"*whose primary goal is to make users forget that computers and interfaces exist"* (Lialina, 2012). One attempt at this is the WIMP paradigm to bridge the human-computer cap by transcoding the material world to digital objects to the world of the computer. This obscures the vocabulary used to depict qualities of digital technology, by attempting to hide the underlying principles of how the computer operates. Being a *user* reminds us that we use a programmed system. I want to extend this thought by saying that designing for "invisible" technology intentionally makes us forget that we are using programmed systems and moves the user further and further away from “the metal.” This is reinforced by Service as a Software Substitute (Stallman, 2010), meaning that a third party does the job of running software, rather than the user, producing yet another black boxed computational layer, invisible and never controlled by the user. Thus, it is impossible for users to ascertain how the software manipulates their data and making it impossible to change it. Design is ideological, and thus, the programmed systems with which we interact are based on a set of values. However, these values are often backgrounded, as such reflections would break the experience in which the user “does not see” the system.

Even though the participating students had not previously been taught aspects of critical digital literacies, their work with Lightbeam gave them a more comprehensive and nuanced understanding of what online data tracking and surveillance are, how it is practiced and how it relates to their personal lives. Students got new knowledge and perspectives which challenged their current ideas of how the Internet is designed. Students generally gained understandings of digital technology through hands-on inquiry with Lightbeam as an adversarial tool to think with. It supported students in developing the knowledge and language to bring forth discussions of ethical, moral, and social issues in relation to online data tracking. Our studies also indicated that teachers do not necessarily possess the competences for facilitating teaching that focuses on critical aspects of how digital technologies impact the world, as they too, lack critical digital literacies, and seem unaware of the possibilities of using visualization technologies to scaffold critical digital literacy activities. This suggests that teacher training involving digital technologies should include elements of critical thinking. By creating new classroom experiences that scaffold critical thinking toward digital technology, we can promote increased participation in discussing how digital technologies shape and constitute our world.

The Lightbeam strategy

Hinrichsen and Coombs (2014) and Pragrazio (2016) ask the question of how critical digital literacies might be taught. Our strategy of using Lightbeam proved to be successful as an adversarial design and helped expose the political value dimensions in technology. It successfully enabled students to have an agonist engagement with their network of data trackers, that evoked reflection and provided access to the hegemonic conditions, making them visible and knowable, which in turn developed the students’ knowledge and understanding of online data tracking. Students were socially engaged and discussed their experience with Lightbeam among their peers. Although some students misinterpreted what the network visualizations represented, the students found Lightbeam easy to use and fun, and it allowed them to explore and investigate their online habits—some were interested in shopping fashion, others in sports and so forth. Representing tracking networks through visualization successfully gave opportunities for students to do investigate work. Our findings are in alignment with those of Pangrazio and Selwyn, who recommend that demystifying the data processes and making these transparent can raise students understandings (Pangrazio & Selwyn, 2017). We encourage other researchers and teachers to experiment with adversarial designs as a strategy to scaffold the development of students’ critical digital literacies.

Limitations and future work

Doing an interventionist study in a scheduled class meant that we had limited time to do interviews with students. As soon as the bell rang, the students left the classroom to go on their lunch break. The limited amount of time also meant that most students did not get to answer a set of written questions, and those who did, wrote very short sentences. We also would have liked to have fewer participants, but the number of students was decided by the school. Another limitation was the two researchers' lack of experience in teaching primary school students, particularly a class of 40 teenagers. This was obvious in the first and last part of the class, where the facilitating researcher spoke too much, for example, explaining different concepts, rather than letting the students talk. However, this was also a consequence of the students' lack of a language with which to articulate themselves. In future studies, we want to do more detailed interviews with students in relation to online data tracking and do follow-up lessons that focus on privacy protection practices so that students can overcome their "inability to do much about it."

Another critique of our study is that the teachers and we think that we have the "correct" ideological readings of the "text," which is less important than how they connect with students' lives. Analysis of our own involvement in the workshop showed that we, the researchers and the teachers, thought the students to be "victims of media manipulation."

Our finding cannot be generalized to all Danish students, only to this group of students. However, we speculate that this is a general issue in public middle-school education and a possibility at higher levels of education.

Conclusion

We have investigated how middle-school students experience online data tracking in their daily interaction on the Internet and how little critical awareness they have of the issue. Based on qualitative analysis of case exemplars, we found that students generally did not have a sufficient knowledge or understanding of the subject of online data tracking and surveillance. This meant that students did not possess a language with which to articulate themselves on the subject, thus making critical inquiry and discussions difficult. Despite being heavy prosumers of digital technology and services, students tended to have improper conceptual models of the Internet. Their online interactions are often limited to media consumption, and they rarely engage in processes of digital design or critical reflections on their relations with digital technology. We speculate that it is difficult for students to develop critical digital literacies because they are mostly prosumers and are not exposed to hidden "black box" layers of the Internet. Likewise, social media services such as Facebook have no interest in exposing these layers for their users. Furthermore, our results indicate that most students do not possess advanced technical abilities like hacking, but rather, think of themselves as masters of "office" software. Rather than thinking critically about digital technology, they use Internet services that provide easily digestible media for consumption and allure its users to keep presuming content unquestionably, keeping them inside "the filter bubble." Having attended the workshop, some students expressed concerns over the issues of online data tracking and how it affects their lives, initiating the development of a critical stance toward digital technologies. Other impediments for developing critical digital literacies can be found in narrow approaches to learning encouraged by curriculum constraints and the teachers' lack of experience with critiquing, understanding, and utilizing contemporary technologies.

Our findings indicate that students lack important aspects of critical digital literacies and that teachers are too constrained by a pre-defined curriculum, and they lack knowledge and experience with the issues of online data tracking and digital technology in general. Our study suggests that Danish public schools emphasize a very limited instrumental and instructional use of technology, whereas teaching related to critical reflections on epochal key problems are less apparent. We suggest that future curriculum should focus on developing students’ conceptual models and knowledge of the Internet through properly articulated discussions based on students’ personal experiences. Such activities should be scaffolded by new digital technologies that let students explore, reveal the black box, and relate critical issues of future technological developments to their own lived experiences. Our study suggests that using adversarial designed technologies such as Lightbeam can help scaffold teaching of critical digital literacies.

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Digital Technology and design processes: Report on a FabLab@School survey among Danish youth

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Report

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Digital Technology and design processes:

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Report on the FabLab@school.dk survey

This report contains findings from a survey on Danish adolescents aged 11-15 years conducted in the fall of 2014 among 1236 students. It is a part of the FabLab@School.dk research program, which investigates the use of digital fabrication technologies in Danish schools.

We would like to thank all the participating schools as well as the collaborating municipalities of Aarhus, Silkeborg, Vejle and Favrskov. We would further like to thank Rikke Toft Nørgaard for contributing to the survey.

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1 The FabLab@School.dk survey

FabLab@School.dk is a Danish research project at the Department of Aesthetics and Communications at Aarhus University supported with a grant from The Danish Industry Foundation. It is part of the global FabLab@School initiative, founded by Dr. Paulo Blikstein at the Transformative Learning Technologies Lab at Stanford University. The Danish research project focuses on Fablabs as a hybrid learning laboratory, which combines digital fabrication, design thinking, collaborative idea generation and creating in solutions to complex societal challenges. Based on this definition of FabLab@School, an emphasis is put on the entire creative process from early ideation, sketching and mockup creation to the initial presentation of a prototype.

The survey reported here has been conducted in collaboration with Stanford University, and parts of the survey are run in various countries around the world in order to establish foundations for comparison on a global scale. Aarhus University is cooperating with Aarhus, Vejle and Silkeborg municipalities in the FabLab@School.dk project.

The survey is in part based on questions used by TLTL at Stanford University. These questions have been translated into Danish language and some have been modified to better fit the Danish context. The questions reported here are translations of the Danish questions. Some of the instruments used, are tentative measures, which are guiding our further investigations, but which are not yet established as valid measures of the concerned traits. This report is mainly descriptive in its approach to the collected data, and it serves the purpose of presenting these data in a way, that lends itself to further exploration. Apart from the survey reported here, the research project consists of ethnograhic observations and interviews with teachers and students and on design interventions in and with the collaborating schools.

1.1 Content and limitations of this report

This report describes the frequency of answers on questions, and the report further tentatively explores composite measures, correlations and underlying factors.

The findings in this report are divided into themes, which are explored from different perspectives with different types of questions. In chapter two of this report, participating schools are compared with the population of schools in general and in chapter 3, the group of respondents is analyzed. Chapter 4 concerns the students' abilities to use, master and understand digital technologies, while chapter 5 is an analysis of what the students claim to learn about IT in schools. Chapter 6 is a comparison of the students self-perceived creativity compared to their experiences with working with ideas and relating to complex societal challenges. Chapter 7 is the conclusion, which is followed by a list of references and an appendix containing the original questionnaire, translations into English of all the questions, charts showing the number of responses for every quantitative question asked on the report, and details with regards to statistical tests, which have been run on the data.

1.2 Research question

The main research question guiding the Danish FabLab@School research project, is:

How can design thinking and digital fabrication in Danish public schools contribute to adolescents' abilities to understand and create with digital technologies?

1.3 The Danish FabLab@School project

This survey is (as stated above) part of an ongoing research project on digital fabrication in education. In 2014 the educational landscape in Denmark changed due to a new reform of standards in the Danish public school (primary and lower secondary). Part of the initiative was to introduce a stronger focus on competencies related to "21 century skills"(Ananiadou and Claro 2009). On this basis, The Danish FabLab@School project was initiated by the Child-Computer Interaction group at Aarhus University together with Aarhus, Vejle and Silkeborg to study how digital fabrication could promote 21st century skills in educational contexts. The aim of the FabLab@School project is to develop a sustained digital fabrication in education initiative within the existing framework of the Danish school system among children aged 11-15 (Smith et al. fc.).

Among 21st century skills, which were considered relevant to the above-mentioned combination of digital fabrication, design thinking, collaborative idea generation and creating in solutions to complex societal challenges, were:

- Abilities to use, master and understand digital technologies
- Abilities to actively engage in heterogeneous communities of practice
- Abilities to think and act innovatively (with technology) on societal challenges

It is a central hypothesis of the research project that adolescents aged 11-15 years through hands-on education with digital fabrication technologies can improve these abilities significantly compared to existing offers in the Danish school system.

1.4 Research design

As stated, our hypothesis is investigated through observations, interviews, interventions as well as the survey reported here. The survey is a baseline study of children's use, knowledge of and skills with regards to digtal technology, design and attitudes towards hacking, open data and privacy issues. The baseline survey will be followed up by an endline survey after three years, at the end of the project (2016) to assess improvements among the target group. The research design resembles a quasi-experimental design where a test group and a control group are followed in order to look for differences in their development. In our case however, it is not possible to follow the same students throughout the project period. In order to be able to use the same schools in the endline survey however, we included two target groups in the survey: One group consisting of students from schools that are formally part of the FabLab@school.dk project (FabLab schools). The other group consists of students from schools not within the project (non-FabLab schools). When the endline survey is run at the end of the three-year project, we will test different classes within the same schools. Since we will be surveying the same age group next time, we will not be able to use the same students, many of whom will have graduated lower secondary school by the time of the next survey. On schools, which are part of the project, we will specifically ask for students, which have been a part of the FabLab@school.dk project activities in order to compare these to students from the non-FabLab schools.

1.5 The questionnaire

The survey was conducted as an online questionnaire with 227 questions under the following six themes:

1. Personal information
2. School and leisure
3. Media and technology in everyday use
4. Technology in school
5. Design and creativity
6. Hacking and repair of technology

Table 1 gives an overview on how the six themes were used for investigating the initial three areas of interest above. The personal background of the students was investigated through questions relating to their background, leisure time and interests in and outside of school. The abilities to use, master and understand digital technologies was gauged through 127 questions regarding media and technology in everyday use, use of technology and learning about technology in school and repair of technology in the "hacking and repair of technology" part of the questionnaire. Finally, abilities to actively engage in heterogeneous communities of practice and to think and act innovatively (with technology) on societal challenges were measured through questions regarding design and creativity, and through attitudes towards hacking etc. in the "hacking and repair of technology part of the questionnaire.

Areas of interest	Themes	Number of questions
Personal background and interests	• Personal information • School and leisure	34
Abilities to use, master and understand digital technologies	• Media and technology in everyday use • Technology in school • Hacking and repair of technology	127
Abilities to actively engage in heterogeneous communities of practice Abilities to think and act innovatively (with technology) on societal challenges	• Design and creativity • Hacking and repair of technology	66
3 areas of interest	**6 main themes**	**227 questions**

Table 1: The relationship between areas of interest, themes and the number of questions.

1.5.1 Types of questions

In the survey, four types of questions were used to investigate the different themes. Likert-type scale questions with a scale from 1 (strongly disagree) to 6 (strongly agree) were used to gain insight into the students' views and perspectives on technology and issues related to various kinds of stakeholders and activities within a concrete design process. In order to gauge self-perceived abilities within the areas of interest, another Likert-type scale was used with values ranging from 1 (I know nothing about it) to 6 (I could teach others about it). Time used on leisure activities and different types of IT-use was measured through multiple-choice questions with different ranges. Finally, open-ended questions and tasks were used in order to evaluate students' abilities and mindsets with regards to the aforementioned areas of interest. The latter method involves a coding of the responses with regards to different categories of answers. These types of questions afford opportunities for comparing self-perceived abilities with scores or categories on a specific type of performance. For example the students where asked to rate their own creative skills in terms of coming up with new ideas, having a good imagination, etc. Such questions were used to prompt a range of responses about the students' self-views, which could be compared to other types of responses where the students were asked for ways to solve a concrete societal challenge.

It is important to note, that in many questions, we asked the students to evaluate themselves. This method is prone to different types of biases. For one, students are often uncertain of their own level of competence, and especially male students tend to score their own IT skills higher than their female counterparts (Bundsgaard et al 2014). Another problem is the so-called demand characteristics: Students' answers are often influenced by their wish to find the "right" answer, that is, to answer what they think, the researchers or teachers want to hear. Students will often experience a survey as a test, and make attempts to do well in the given task.

As stated, we have used Likert-type scales with six possible values. When using Likert-type scales, it is common to recommend using an uneven number of response possibilities. The reason for this, is that respondents whose views are genuinely in the middle of the scale are otherwise forced to answer to one of the sides and are thus misrepresented in the data (Marsden and Wright 2010). On the other hand by taking away the middle category, even those respondents who are prone to satisficing (by choosing the option in the middle) in order to finish quickly will at least have an extra incentive to reflect on if they are on one side of the middle or the other.

1.5.2 Ordering of questionnaire themes

The six themes in the survey were ordered in the abovementioned sequence of:

1. Personal information
2. School and leisure
3. Media and technology in everyday use
4. Technology in school
5. Design and creativity
6. Hacking and repair of technology

As can be seen, the survey started with questions of background and demographic characteristics. It is common to recommend having this type of questions at the end of a questionnaire (Marsden and Wright 2010). This is recommended, because respondents may feel intimidated or otherwise put off by questions about their background. We chose to begin with background questions for two reasons: Firstly, we did not know if all students would finalize the questionnaire (and the data would be useless without correct background information). Secondly, for motivational reasons we communicated to the students that we had an interest in their genuine experiences and responses, and thus that the questionnaire was indeed not a test.

Each section of questions were grouped by content in order to facilitate respondents' cognitive processing (Marsden and Wright 2010). The ordering of questions and themes had two main aims: 1. To create a sense of a common thread running throughout the questionnaire, and thus to make the questions make sense to the respondents, 2. To make the students respond with their own uses and views on technology and design before revealing too much about our understandings. The last aim was important in order to minimize demand characteristics, which could potentially lead students to try to give us what they thought might be the correct answer

1.5.3 Translations and wording of questions

Large parts of the survey were translated from survey questions used in the FabLab@School project at Stanford University. While some questions were directly translatable, others posed problems in terms of interpretation in a Danish context. For example, concepts such as creativity and imagination can be interpreted differently in the two different contexts. The wording of the questionnaire was carefully selected with a goal of reducing the complexity of the language and having as little text as possible. This was done in order to speed up the reading process. At the same time, our aim was to be as precise and easy to understand as possible in order to secure valid data and minimize fatigue and satisficing resulting from this fatigue.

The questions and the questionnaire were tested on small groups of adolescents within the age group on four occasions. During the testing, students were asked to read the questions aloud, in order to reveal which words and wordings were difficult to understand. Furthermore, in 2 cases the students were asked to discuss their answers in pairs, in order to reveal how the students interpreted the questions. After completing the survey, the students where interviewed about their experiences of answering the questionnaire.

2 Survey administration and data treatment

The survey was carried out among 11-15 year old students in 39 schools (upper primary and lower secondary) in 4 municipalities in Eastern Jutland, Denmark (Vejle, Silkeborg, Aarhus and Favrskov). A team of six researchers from Aarhus University administered the survey to the schools in the period of August 25th – September 12th 2014.

In the classrooms, the survey was administered by two researchers (although in a few instances towards the end of the administration period only one researcher was present). The researchers introduced the research project and survey to the students and were present in the classroom during the entire test in order to help with questions and technical problems. Studies suggest, that researchers assistance increases reliability because fatigue-effects are slower to set in (Marsden and Wright 2010). To increase reliability, the introduction was done based on a document including the most important points to communicate to all involved students. The response time varied from approximately 30 minutes and up to one hour. The teachers and the students were generally very flexible with the students' time, which allowed for most students to complete the questionnaire (see below).

The survey was administered as an online survey through SurveyXact. During the introduction, the students were asked to enter the webpage www.fremtid.eu, on which there was a "pop-in" link to the survey. In most cases, this worked reliably, but we did experience technical problems in the schools with Internet connections and servers. The survey was accessed on computers, tablets and phones, and therefore letting the students use their own phones/devices on the mobile network solved some technical issues. Tricking school computers to enter other networks than the faulty one, which they had been locked to, solved other issues. Because of technical problems, some students, who had started answering the survey before the problems arose, had to start over again. A few classes even had to reschedule the survey to a different day.

2.1 Recruitment of schools

As stated earlier, both FabLab and non-FabLab schools were to participate in the survey. With help from the municipalities, we identified 21 schools, which were already or which would in future be part of the FabLab@School project. The research team had already established contact with many of these schools, as they had been objects of our initial observations and interviews. Thus, these schools were very accommodating in terms of assigning participants to the survey.

We asked the municipalities to help us find corresponding groups of schools, which were not part of the FabLab@School.dk project, and for which did not have any plans of becoming part of the project. Ideally we wanted these schools to match the first group in terms of average socioeconomic status of the students, school size, average grades of the students, etc. In most cases, the suggested schools from this group accepted the invitation to be part of the survey, whereas in the one municipality, only 2 out of 10 suggested schools were willing to participate. In the end some schools in this municipality were chosen mainly on a basis of their willingness to participate. In total, the survey was carried out on 18 schools, which were not part of the FabLab@School.dk project.

As is clear, our aim was not to create a random sampling amongst the schools. In order to later be able to estimate the generalizability of the results, it was made sure however, that the group of schools was as diverse as possible. Thus the group included rural and urban, low-achieve and high-achieve, low- and high socioeconomic status schools in order to be able to screen for effects from school type. Since we did not have the possibility of creating a representative sample of schools, we do not claim to be able to conclude on Danish adolescents as such. Thus, all claims made in this report, are made with regards to our sample of respondents only.

2.2 Data collection

On most schools we tested one class or group (on a few schools, we tested 2-3 classes). We wanted to get responses from as many different schools as possible in order to make sure, that we a wide range of background factors, such as e.g. socio-economic status, were represented.

Contact to the schools was made through a letter to the principals asking them for 45 minutes with a grade 6, 7 or 8 class of their choice. With most of the schools, it was necessary to call several times in order to make an arrangement. In the beginning, most principals chose to go with grade 7, and when this became apparent, we did our best to get 6th and 8th graders on board.

It was important for our data analysis, that we would get at least 200 respondents in each group consisting of a specific grade of students. In the analysis of the data, we do not distinguish between schools within the FabLab@School project and schools outside the project, which means, that we needed at least 600 respondents. In the endline survey, however, the plan is to compare project schools to non-project schools, and thus a sample of 1200 respondents is needed. In order to match the total number of respondents in the endline survey, the aim was for 1200 respondents in the baseline survey as well. After removing the responses, which did not fit the criteria for being part of the data, we had 1156 responses (see Data treatment below).

2.3 Data treatment

The data was downloaded from SurveyXact as a Microsoft Excel® file. In order to facilitate easy data calls from SAS and R, which were both used, the variable names were changed to s1-s227. In the original data file, there were 1433 entries. Responses which did not fit the criteria mentioned below, were deleted, and the final number of responses in the dataset ended up being 1156.

2.3.1 Blanks

When a person creates a questionnaire without filling in anything at all, it is counted as a blank. 112 Blanks were deleted from the dataset, which means, that there were 1321 responses to the survey.

2.3.2 Duplicate entries

Due to technical problems, several students needed to start over on the survey – thus creating duplicate entries. In each case, the entry with the most answers was kept in the data set, and the others were deleted. There were 163 records of multiple entries. Of these, 5 persons had three entries, and 74 had duplicates. A total of 84 entries were deleted from the 163, which left 1237.

2.3.3 Age range

In this survey, we are researching 11-15 year olds, and therefore any entries out of this range were deleted. 6 entries had put something un-age related in the age field, and they were deleted (1231 left), whereas 10 entries had stated an age above 15 and were deleted as well (1221 left).

2.3.4 Completion

It was decided to keep all responses that were either completed or were only missing the last task of answering what was inside a key fob. This decision was made, because the task was not of central importance with regards to the research question and the hypothesis' in question here. Of the remaining 1221, 65 had not answered the last question before the key fob task (s199). Since respondents were prompted to answer all questions, it was not possible to be missing this item, if the subsequent items were answered. It was also not possible to have answered this item without answering the items before it (except for open ended items). Thus, if there was an answer to item s199, there would also be answers on the items before it. If item s199 was not answered, neither would the subsequent items be. For this reason, the responses, which were blank with regards to item s199, were deleted (and the rest were kept), which meant that the total number of respondents ended up being 1156.

3 Participating schools and respondents

The 1156 respondents come from 39 primary schools in the municipalities of Vejle, Silkeborg, Aarhus and Favrskov. The sample includes a wide range of schools, though all except one are public schools.[1] The schools are positioned in both rural and urban locations in or around the towns of Aarhus (approx. pop: 260,000), Vejle (approx. pop: 53,000) and Silkeborg (approx. pop: 43,000). These schools recruit from a wide range of socioeconomic groups. However, the difference between socioeconomic groups in Denmark is low compared to most other countries, which is e.g. demonstrated by Denmark having one of the lowest Gini coefficients in the world.[2]

As a simple comparison of our sample of schools to the population of Danish public schools in general, the average score for grade 9 students from these schools on the national examinations in the years 2011/2014 has been calculated (see Table 2). Three numbers are publicly available from each school: The average score, the expected average score (based on socioeconomic status of the students), and the difference between the first two, indicating the performance of the school. The table below shows both the averages of these numbers based on the schools in our sample and the weighted average, in which the average is calculated based on the number of respondents from each school.

39 schools	1156 resp.		
Average	Weighted Average	Expected Average	Weighted Exp. Average
6.95	6.98	6.84	6.87

Table 2: Average marks of participating schools and their expected average marks. Both un-weighted and weighted average scores are shown.

The national average on grade 9 exams in these same three years among all school types is 6.6.[3] As can be seen, the schools we visited, were on average placed higher than this mean, both when considering actual scores and when looking at expected scores, which can be seen as a measure of average

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[1] Only public schools are a part of the FabLab@School.dk project, but N. Kochs skole was included in the survey. Public schools is the most common school type in Denmark. As of October 1st, 2014, 78% of all pupils of grade 0-10 in Denmark attended public schools. According to the Statistics Denmark: http://dst.dk/da/Statistik/emner/fuldtidsuddannelser/grundskole.aspx (retrieved April 14., 2015)

[2] http://data.worldbank.org/indicator/SI.POV.GINI (retrieved May 6th, 2015)

[3] The average score of all students in Denmark is evaluated in different ways. First of all, it can be split into different school types such as public schools, private schools etc. With one exception (N. Kochs skole with 17 respondents) our sample consisted solely of public schools. Removing N. Kochs skole gives the averages 6.93, 6.97, 6.81 and 6.85 respectively. This does not change the conclusion, that our sample is above the national average with regards to expected average scores and realized average scores.

socioeconomic status of pupils in the given schools. The same goes for the weighted averages.

FabLab-average	Respondents	Weighted	Non-FabLab average	Respondents	Weighted
7.06	595	7.01	6.81	527	6.95

Table 3: Comparison of the average exam scores between FabLab schools and non-FabLab schools

Comparing the average score between the FabLab and the non-FabLab groups, the schools designated as potential FabLab schools on average have higher average grades than the other schools. This difference is however not statistically significant[4] and thus we cannot conclude that the two groups differ with regards to average score on examinations in the 9th grade.

In conclusion, our sample schools in general have higher grades and socioeconomic status than the Danish average, and this difference is statistically significant.

3.1 Age and grade of the respondents

The age of the 1156 respondents ranged from 11-15 years old, with the majority between 12 and 14, as can be seen in Figure 1:

[4] See appendix I. The t-test was done on un-weighted scores for which the difference between the two groups is largest.

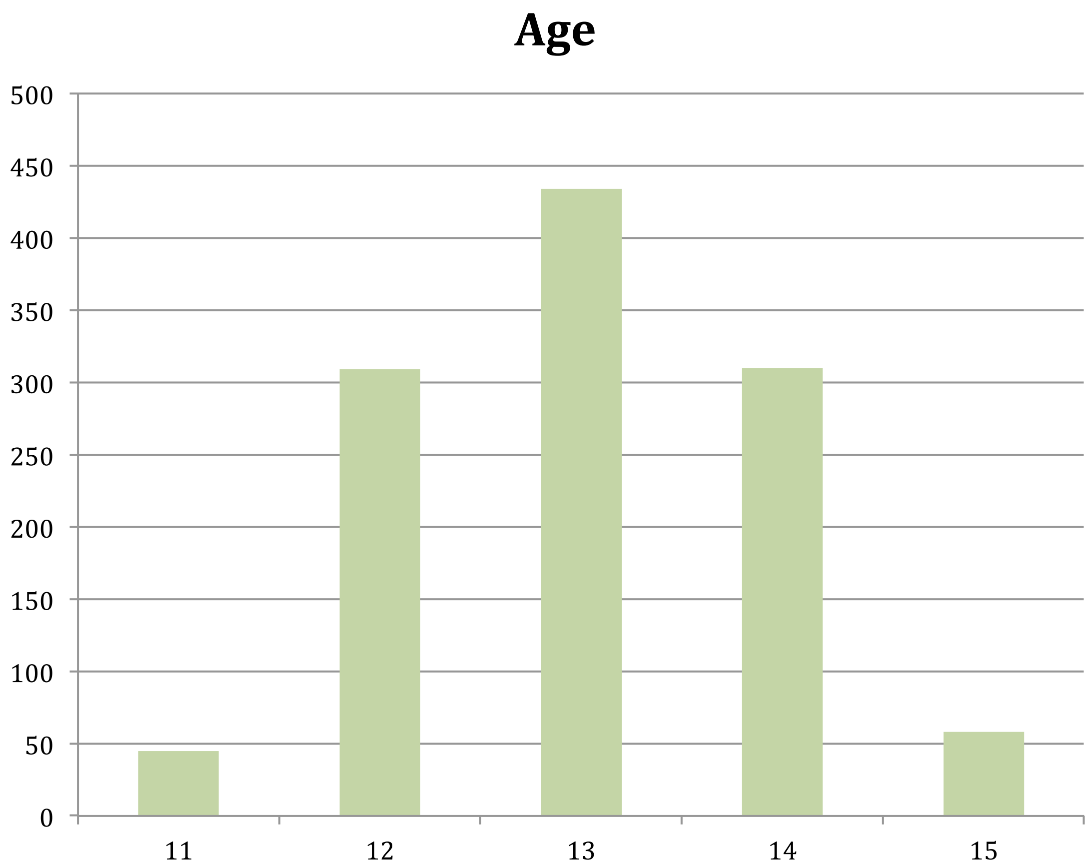

Figure 1: Respondents. Listed by age.

These students all attended grade 6, 7, 8 or 9, with the majority in grades 6 through 8 as seen in Figure 2.

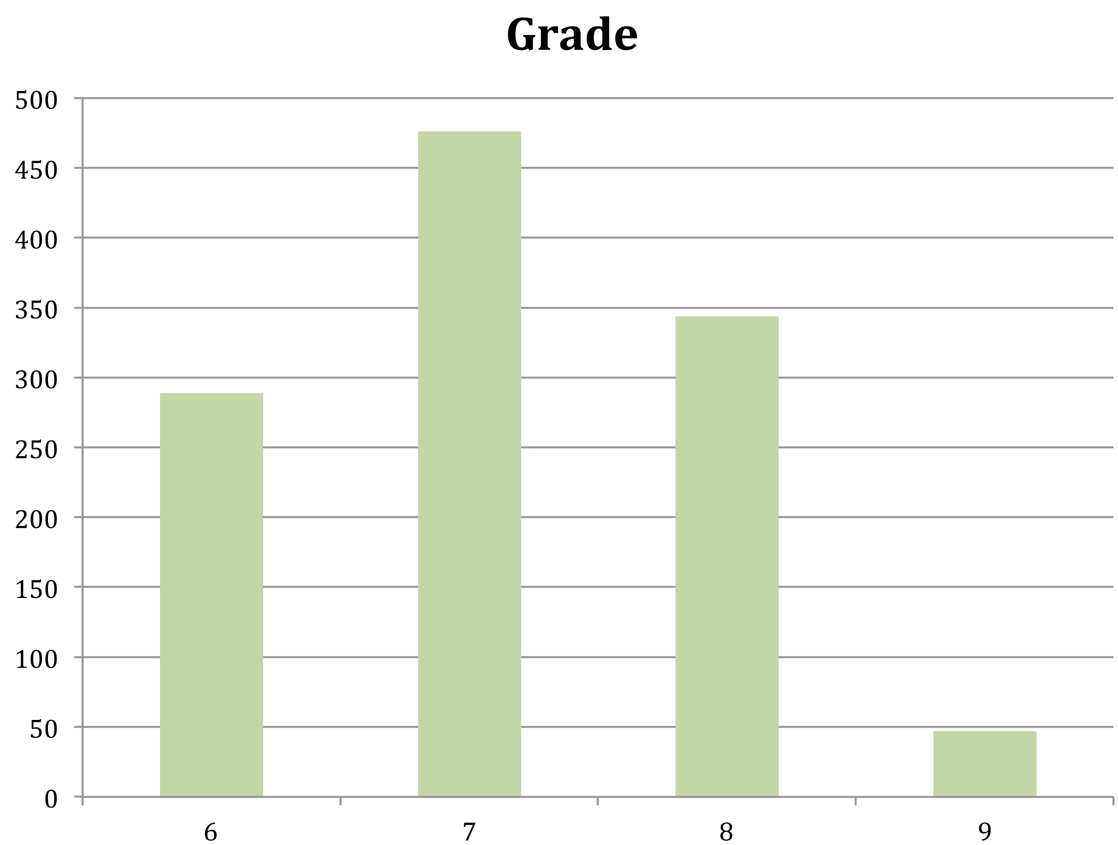

Figure 2: Respondents. Listed by grade.

3.1.1 FabLab and non-FabLab schools

The distribution of designated FabLab and non-FabLab schools with regards to the age of the students shows the difficulties we had in securing an even spreading out of the different groups of students:

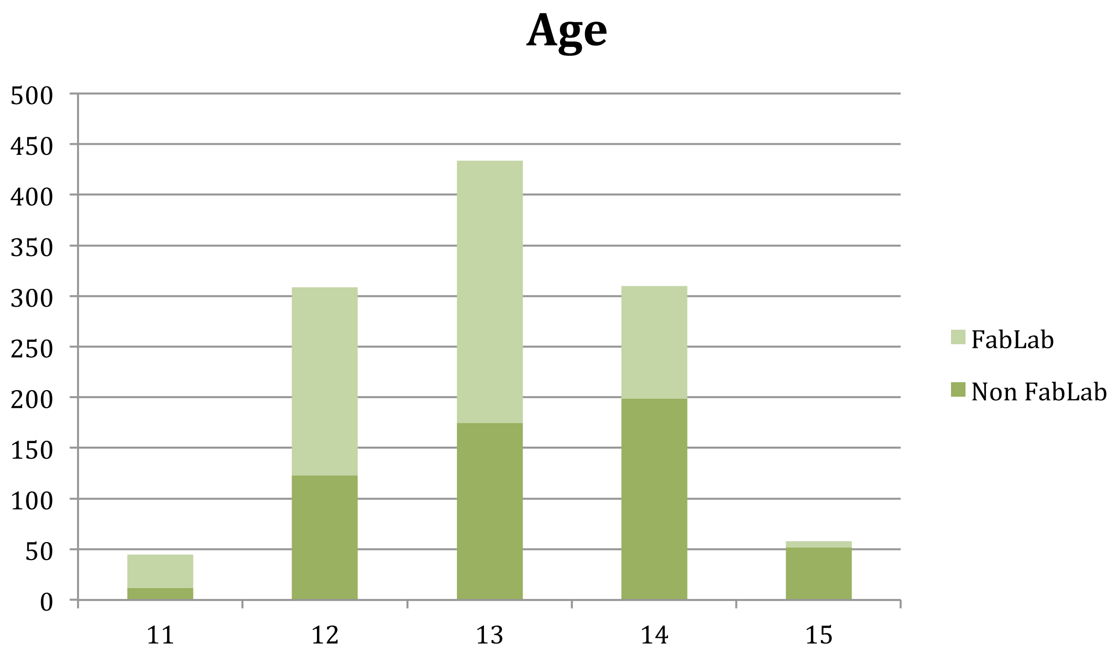

Figure 3: Respondents in the sample. Divided by FabLab-participation of school. Listed by age.

It is clear from Figure 3 (and Figure 4) that the students in the sample are not spread out evenly with regards to age and grade attended. Ideally, we wanted the 6 groups of grade 6, 7 and 8 in both FabLab and reference group to be of equal size, but this turned out to be difficult in practice as many schools selected grade 7 for the survey. At many of the FabLab schools, FabLab-activities had been planned for 7th grade, and thus these schools often chose to let 7th grade participate in the survey.

The survey was done in the early phases of the FabLab@School.dk project, and thus the participation in the project on some schools was unclear: Were they going to be a part of the FabLab@School project or not? Other schools had already created designated FabLab-facilities and were using these with select classes. In the schools, which were already using FabLabs, the schools were specifically asked to assign classes, which had not yet been a part of FabLab@School activities to the survey.[5] Thus, the schools' selection of classes means, that there should be no difference between the two groups respondents (FabLab and non-FabLab) with regards to FabLab background. Unless otherwise noted we have chosen to treat the FabLab and non-FabLab groups as one throughout this report (though they will be treated separately in the endline survey). This in turn leads to adequate numbers of respondents in each of the groups of 6th, 7th and 8th graders when testing for the effect of grade.

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[5] As mentioned earlier, we wished to be able to investigate effects of participation in the FabLab@School project in an endline survey after three years.

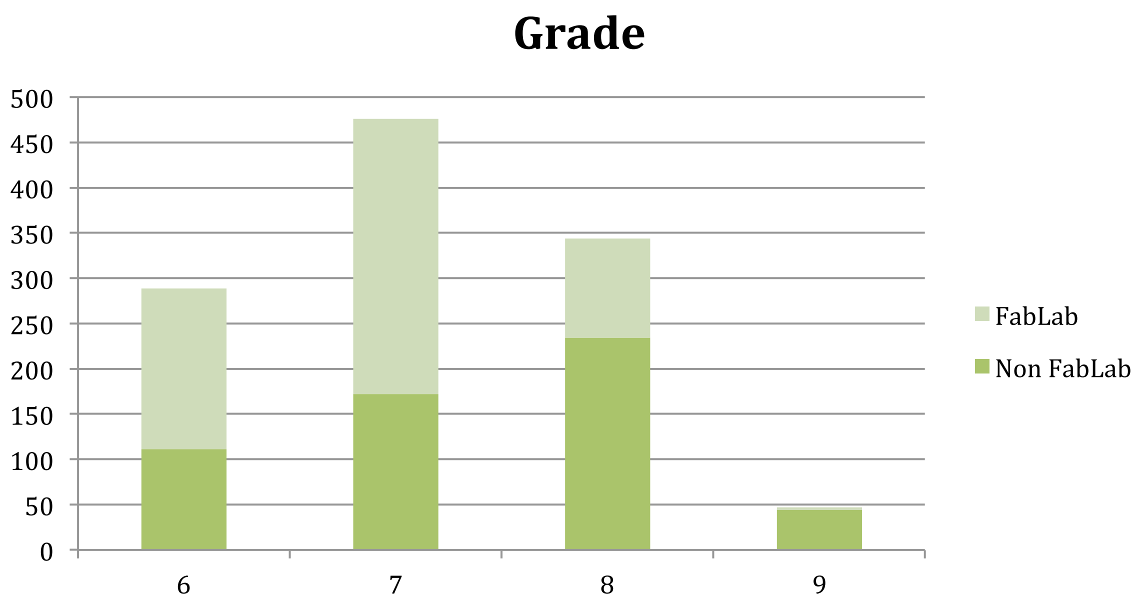

Figure 4: Respondents in our sample. Listed by grade.

4 Use and knowledge of digital technology

A central part of the survey was to investigate students' *abilities to use, master and understand digital technologies*. In order to investigate these abilities, this chapter concerns findings with regards to use of digital technologies outside of school and students' self-perceived knowledge of digital technologies. The following chapter focuses on which digital technologies students reported to have learned in school, and which technologies, the students reported to have learned outside of school.

In the current chapter, our main finding is, that while the students spend a lot of time with digital technologies, they mainly use these for consuming digital media and content rather than producing these.

4.1.1 Leisure time

In order to better understand our respondents, we asked them, what they spent their spare time on. The respondents were asked to report time spent on given activities during the past week. To ensure, that the students were able to respond rapidly we had given the students as little as four possible answers to choose from. As fig. 5 below indicates 69% of the students reported, that they had used a phone, TV or computer at least five hours during the last week. 57% of the respondents reported having been with friends at least five hours per week, while the students also spent a great deal of time on sports (39% spent at least 5 hours during the last week). Fewer students reported, that they spent more than 5 hours per week in nature (15%), performing household chores (12%), and studying (8%). Very few students reported to have spent at least 5 hours per week on working at a job that pays an income (7%), creating things (4%), singing or playing in a band (6%), home improvement (4%), and volunteering (2%).

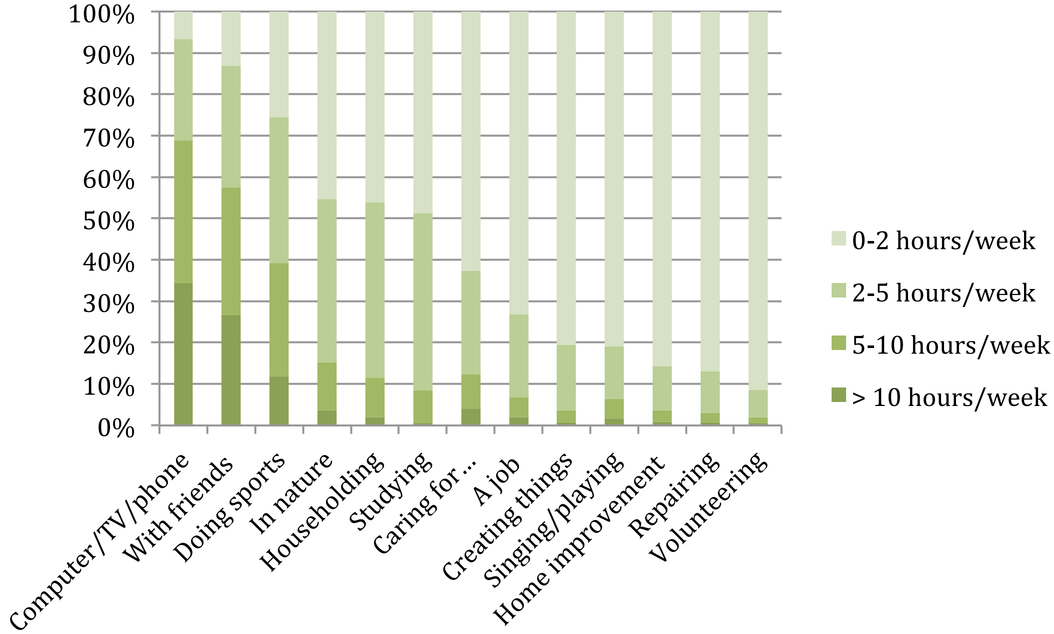

Figure 5: "During the last week, how many hours did you spend...?" The chart is ordered with regards to the 0-2 hours/week category.

4.1.2 Use of digital technologies

As mentioned in the last section (4.1.1), the students in our sample reported that they spent more of their leisure time (during the last week) on computers and phones than on any other of the given choices. The following questions probe further into which activities with digital technologies, the students reported to be engaged in most frequently.

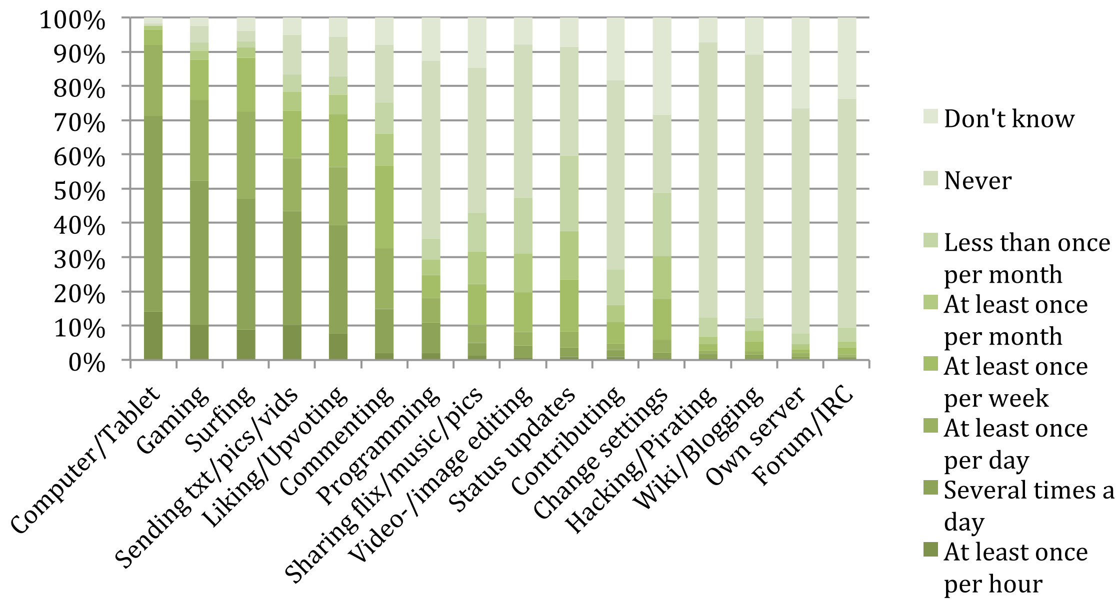

Figure 6: It use outside of school. Ordered by the sum of "at least once per day" and "Several times per day"

In Figure 7 and Figure 8, the six categories from Figure 6 have been collapsed into three possible answers, which were "several times a day", "at least once per week" and "less than once per week or don't know". This provides a more interpretable visualization of the data. To create more readable charts, the original chart has been split into two charts: Figure 7 contains the activities, which more than 50% of the respondents reported to do at least once per week, while Figure 8 shows remaining activities.

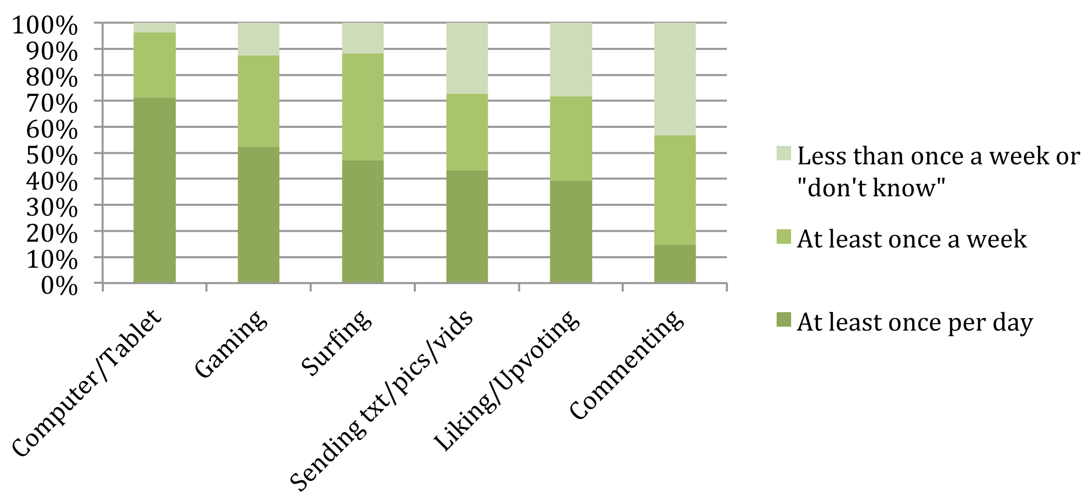

Figure 7: Time spent on computers/tablets, and on activities with digital technologies. Ordered by "at least once per day".

As can be seen in Figure 7, 71% of the students reported, that they used computers or tablets at least once per day. The data further show, that many of the students use computers, tablets and phones at least once per day for gaming (52%), surfing on the internet (47%), chatting (43%), liking/upvoting what others have posted (39%) and commenting on the updates and posts of others (15%). These activities all involve consumption of media and content as opposed to e.g. producing digital content.

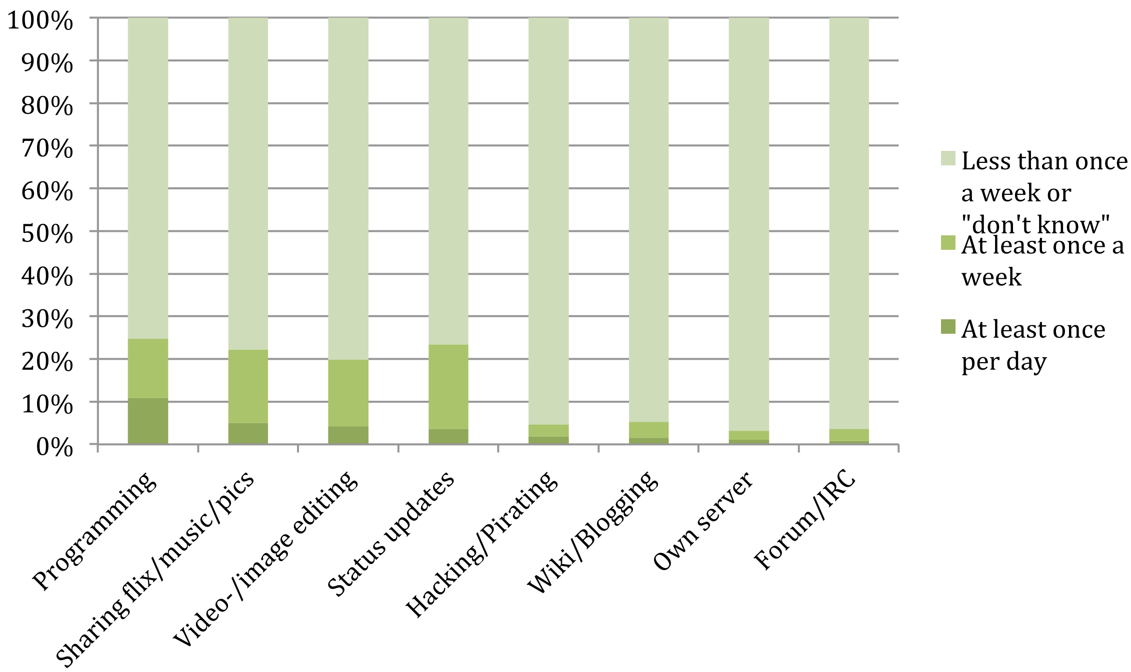

Figure 8: Time spent on computers/tablets, and on activities with digital technologies. Ordered by "at least once per day"

As Figure 8 shows, no more than 25% of the students reported to engage in any one of the included activities at least once per week. 25% of the students claimed to be programming at least once per week, but we have not had the chance to probe, what the respondents mean by programming.

Around 20% of the students reported to be engaged in sharing video, music and images on the Internet, using video-/image editing software (20%), writing status updates (23%), contributing to e.g. a Minecraft server or a blog (11%), or changing settings (18%) *at least once per week*.

Hacking and pirating was something, which very few students (5%) claimed to be involved in more often than once per week. Writing on wikis or blogs (5%) is also something, which most students do more seldom than once per. week. The same applies to setting up and running a server (3%) and communicating on forums or using IRCs (4%).

To conclude, it seems from the data, that rather than producing and sharing, the students spend a lot of time consuming digital media and content.

4.2 Self-perceived knowledge of IT

In the survey, we investigated the technological and digital literacy of the students through different instruments. One such instrument was a list of technologies towards which the students were asked to evaluate themselves on a scale from 1 to 6 (1 being “I know nothing about it” and 6 being “I could teach others about it”). The list of technologies included 22 types, and therefore it has been split into two charts. Figure 9 consists of purely digital technologies, whereas Figure 10 consists mainly of FabLab-technologies. The scale has been collapsed into three categories in order to better facilitate interpretation.

4.2.1 Computers, tablets and phones

The data shows that the most of the students in our sample reported, that they had some knowledge or good knowledge about using smartphones (93%), tablets (90%) and computers (92%). In other words approximately 90% of the students claim to be knowledgeable to some degree, when it comes to phones, tablets and computers. As shown in Figure 5, 69% of the students reported, that they use computers, TVs and phones at least 5 hours pr. week outside of school and 34% that they use computers, TVs and phones at least 10 hours pr. week outside of school. As shown Figure 7, more than 70% of the students reported, that they use computers or tablets every day. In conclusion, the students spent a lot of time on computers, tablets or phones, and they feel quite confident using these technologies.

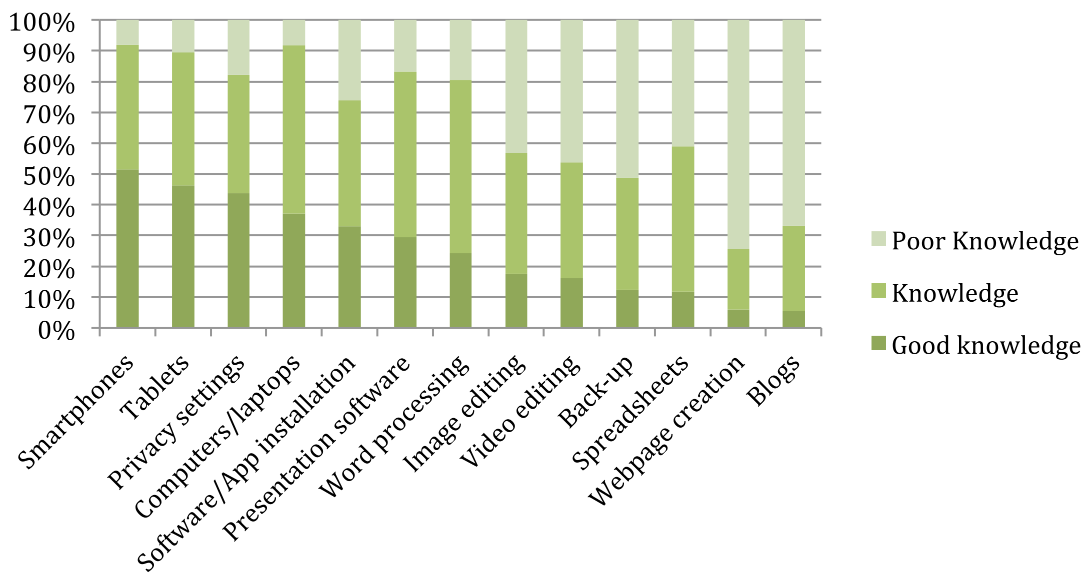

Figure 9: Self-perceived knowledge of technologies. Scale collapsed from 6 to 3 categories (1+2, 3+4, 5+6). Ordered by "Good knowledge" (5+6).

4.2.2 Privacy settings and installation of apps

The data shows that the students are relatively confident in changing privacy settings (83% claim some or good knowledge) and installing apps/software (75% report to have some or good knowledge). Both of these can be said to be important skills in an age of social media. As seen in Figure 7 most of the respondents reported that they play games (88%), surf the internet (88%), use social media for communicating (73%), liking/upvoting (72%) and commenting (57%) at least once per week. All of these are activities for which installing apps and changing settings is important.

4.2.3 Presentation-, spreadsheet and word processing software

Most respondents claimed to have some or good knowledge of presentation (84%) and word processing (81%) software. On the other hand, only 60% claimed the same with regards to spreadsheet software. These abilities will be treated under the name of *Office Literacy* later in this text.

4.2.4 Image- and video editing

When it comes to tools for creating other kinds of digital content than texts and presentations, the data show, that the students are not as confident in their knowledge: Less than 20% of the students claimed good knowledge and more than 40% claimed poor knowledge of image and video editing. As shown in Figure 6, 80% (of the students) responded that they use image- and video editing tools less than once per week (53% never use or don't know). Thus the respondents claimed to use image- and video editing software less than tools for consuming online media and content.

4.2.5 Back-ups, webpages, wikis and blogs

49% of the respondents claimed to have some or good knowledge of doing back-ups, while creating webpages (26%) and blogs (33%) also score low with regards to self-reported knowledge (some or good knowledge). In line with this, contributing to wikis and blogs is also something, which only 5% of the students claimed to do weekly (see Figure 8). A possible reason for this is, that perhaps the technology has shifted away from webpages, wikis and blogs (towards easily accessible social media platforms such as Instragram™, Tumblr™ or Facebook™. There is no longer a need for setting up a homepage or even what used to be called a blog.

4.2.6 Summing up

The data in this section suggests that, the students we surveyed were heavy users of computers, tablets and phones. They felt confident using these technologies. However, the respondents reported, that they mainly use computers, tablets and phones for consuming digital media and content by e.g. playing games, surfing the net, chatting, liking, and commenting posts and updates from others. Rather than producing content, the students reported to be consuming media and content. In line with this, many of the students in our survey reported, that they had relatively poor knowledge of tools for producing images, videos and webpages and thus move beyond consumption of digital content. The students reported to have some or good knowledge about using tools such as word processing and presentation software. We have not inquired into for what purposes they used these office programs and how advanced functions, the students were able to use.

4.3 Fabrication technologies

In the questions about self-perceived technological and digital literacy, the students were asked to evaluate themselves on a range of technologies associated with FabLabs and digital fabrication. They were asked to do this using the scale of 1 ("I know nothing about it") to 6 ("I could teach others about it"). Again, the categories have been collapsed for better visualization of the data.

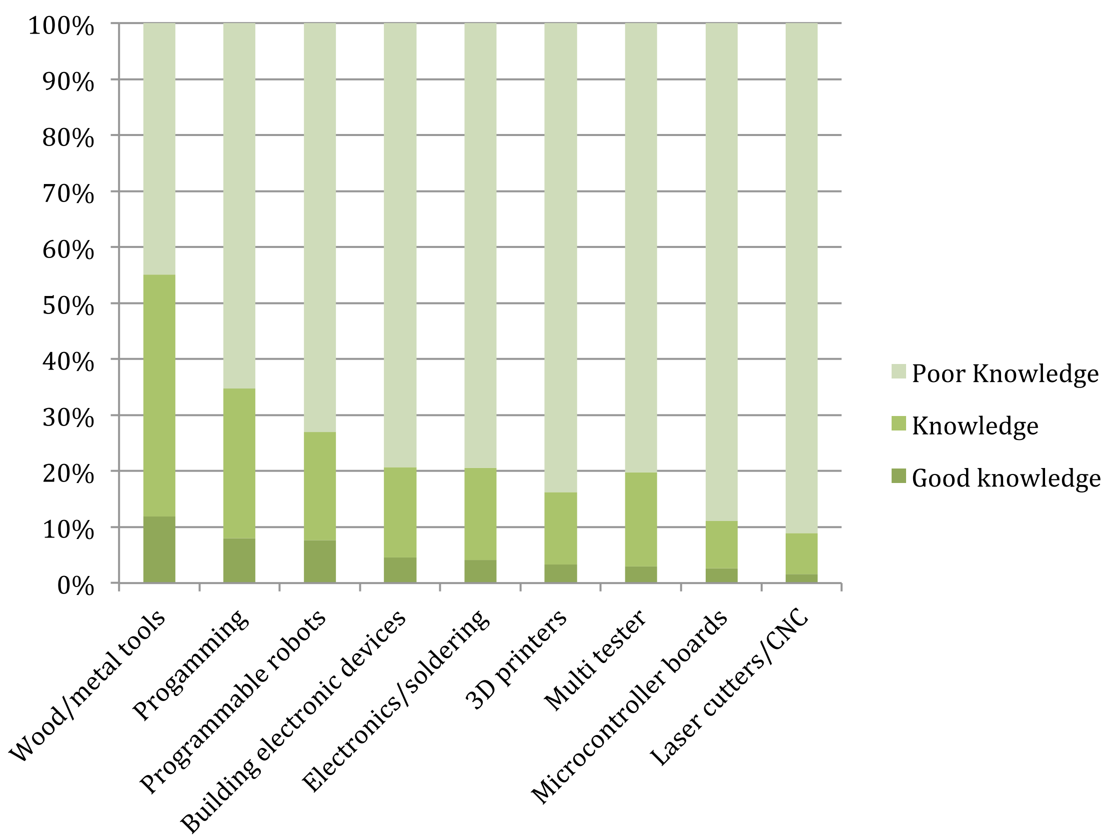

Figure 10: Self-perceived knowledge of technologies. Scale collapsed from 6 to 3 categories (1+2, 3+4, 5+6). Ordered by "Good knowledge" (5+6).

Very few students claimed to have good knowledge of any of these technologies. Tools for woodworking and metalwork stand out however as the most familiar (56% claim some or good knowledge). Except for wood/metal tools and multi-tester, the technologies in Figure 10 are all digital fabrication technologies. More students claim to have some or good knowledge about programming (35%) and programmable robots (27%) than building electronic devices from scratch (21%), electronics and soldering (21%), multi-testers (20%), 3D printers (16%), microcontroller boards (11%), and laser cutters (9%). As the category of programming is not self-explanatory it would be interesting to investigate, what the students mean by programming, how they do it, and what they use programming for.

Overall, it is clear, that few students reported to have knowledge of digital fabrication tools. This was to be expected, since digital fabrication technologies are not widely available, and since the respondents (as requested) had not yet taken part in FabLab@School activities.

4.4 Conclusion

This chapter concerns students' knowledge and use of digital media and technologies.

To conclude, it seems from the data, that rather than producing, the students spend a lot of time consuming digital media and content on computers, tablets and phones - e.g. by playing games, surfing the net, chatting, liking, and commenting posts and updates from others. Most students reported to have some or even good knowledge of using computers, tablets and phones for consumption purposes. On the other hand, many of the students in our survey reported, that they had relatively poor knowledge of tools for producing images, videos and webpages and thus move beyond consumption of digital content. The students reported to have some or good knowledge about using tools such as word processing and presentation software. We have not inquired into for what purposes they used these office programs and how advanced functions, the students were able to use.

In the recent International Computer and Information Literacy Study (ICILS) report it is concluded, that Danish adolescents are heavy users of IT but that their use is not very advanced (Bundsgaard et al. 2014). The ICILS based the conclusions on tests of advanced functions within software programs, as opposed to the present survey, which focuses more on use of different types of technologies, including social media and digital fabrication. The ICILS report is thus able to conclude, that the functions, which Danish adolescents are able to use within known types of programs, is not very advanced. In the present report, we are however able to conclude, that the students in our sample are in general not very familiar with technologies for producing digital content, and that very few of them are familiar with digital fabrication technologies.

When spending time with computers, TVs and phones is the most popular leisure activity, it is tempting to talk about the students in our sample as digital natives: Adolescents who were born in a digital world and to whom all things digital are easy and comes naturally (Prensky 2001). As seen in both this report and in the ICIL study, the school system cannot take this for granted.

5 IT in schools

The previous chapter concerns students' use and knowledge of digital media and technologies. This chapter on the other hand, concerns questions investigating which knowledge of digital technologies the students had acquired inside and outside of school. The students were asked, whether they had gained knowledge of the given technologies either "primarily in school", "primarily at home" or whether they had not yet learnt to use the technology in question ("I haven't learned it"). Our main concern was to identify which technologies are primarily being obtained as part of the Danish school system. Figure 11 below displays the results from the first section of questions, whereas the last part will be treated later in the chapter.

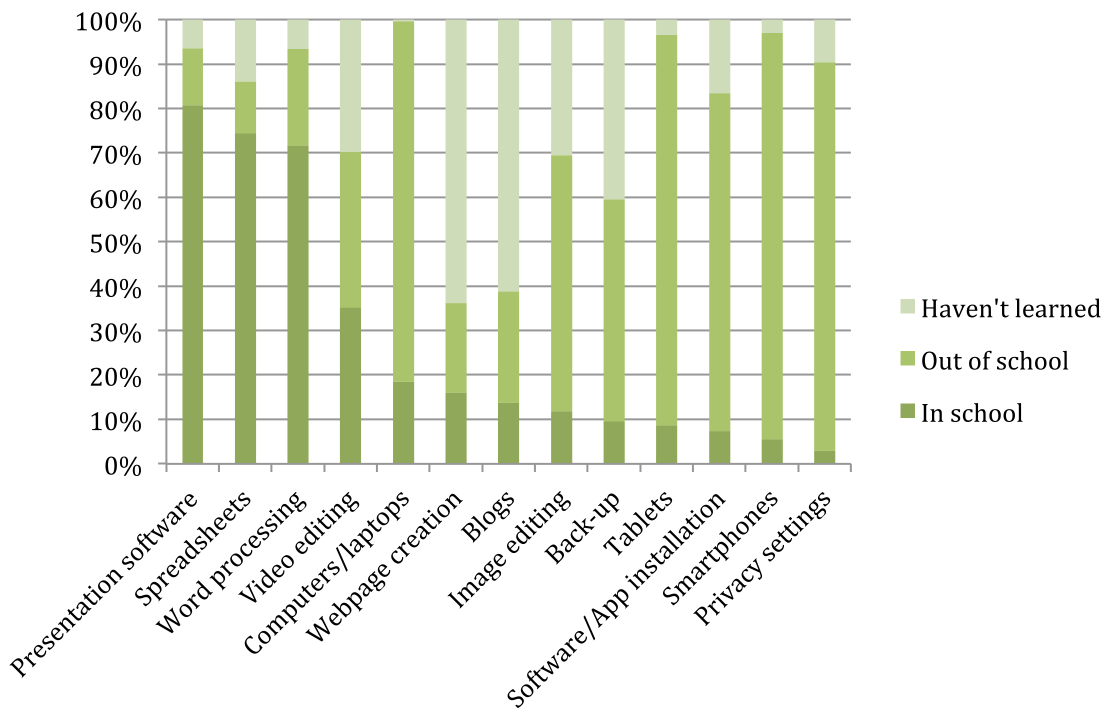

Figure 11: Where have the students primarily learned their digital skills? Ordered by "in school"

As Figure 11 shows, most students report, that they have learned to use presentation software (81%), spreadsheets (74%) and word processing software (72%) in school. While 35% of the respondents claim to have learned video editing in school, for the remaining technologies, this is true for less than 20% of respondents. Thus, few respondents claim to have learned webpage creation (16%), blogging (14%), image editing (12%), backing up (10%), installing apps (7%), and changing privacy settings (3%) in school. In line with this, few students report that they have learned how to use computers/laptops (18%), tablets (9%), and smartphones (5%) in school. Thus the vast majority of the participating students claimed, that they had learned how to use computers at home (81%), but there is a group of 18% of the respondents, who seemed to have learned this primarily in school. This group of students could potentially be a very important group to focus on when teaching the use of computers in schools.

5.1.1 Office literacy

As reported in the last paragraph, Figure 11 shows that a large majority of students report having learned to use presentation software, spreadsheets and word processing software in schools. Since these three types of software make up the core of any office-package of software, we have chosen to call the ability to use these programs *Office Literacy*. To investigate this finding further, we have run a factor analysis[6] on the data of self-reported knowledge with regards digital technologies (see section 4.2). A factor analysis is a statistical method, which searches for common factors underlying answers on several questions. Especially one factor stands out, when this analysis is run. Three variables all draw heavily on this factor, and that is presentation-, spreadsheet- and word processing software. Another way to put this is, that if one respondent has e.g. a high score on one of the items, that respondent is likely to also have a high score on the other items drawing on the same factor. The analysis shows, that there seems to be an underlying factor, which is explanatory with regards to self-perceived abilities with regards to presentation-, spreadsheet- and word processing software.[7]

In conclusion, students report having learned office software in schools, and knowledge of different types of office software draw on the same underlying factor. The data suggest that schools have an important impact on the digital literacy of the students in our sample.

In order to investigate the Office Literacy further, we have developed an index variable, which consists of the students' self-perceived knowledge with regards to word processing-, spreadsheet- and presentation software averaged and rounded off to nearest whole number. This gives the following chart:

[6] Principal Components on a polychoric correlation matrix with an orthogonal rotation. The group stands out with nfactors=3 as well as 4.

[7] The Danish findings do not match findings from identical questions used by the TLTL group at Stanford University in California, which makes them even more interesting.

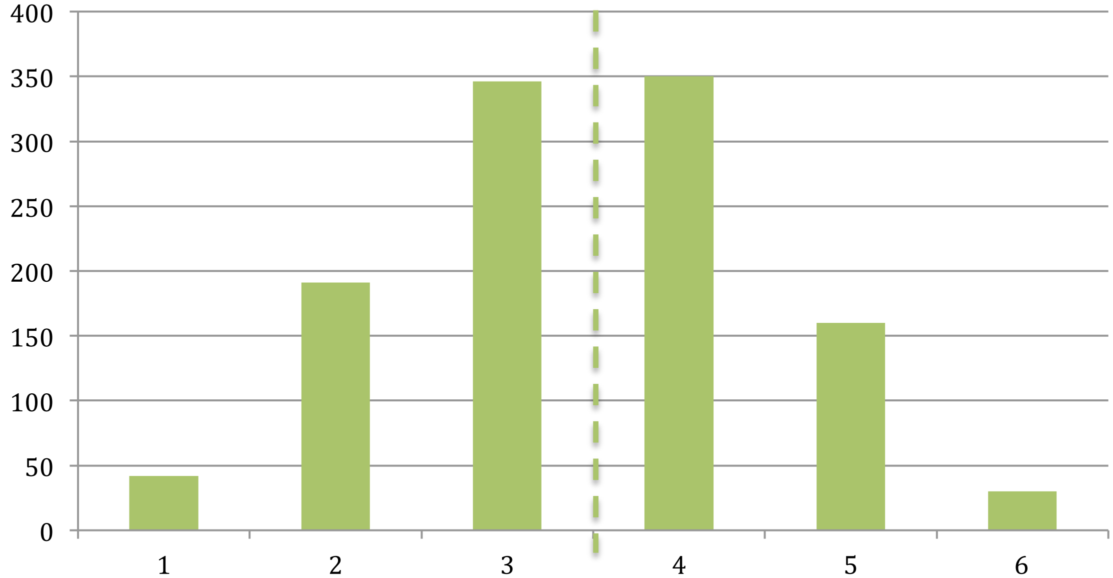

Figure 12: Average of students' responses on self-perceived knowledge about office software on a scale of 1 ("I know nothing about it) to 6 ("I could teach others about it).

The mean value of the scale is 3,5, and as can be seen, this coincides with the mean value of the Office Literacy score of the students.

As seen in Figure 12, the middle categories of the index variable are very populated. This indicates that office programs are familiar to most students, while at the same time it is something, that fewer students claim to be able to teach others about than e.g. phones, computers and tablets (see Figure 9). This could suggest, that teaching Office Literacy in schools has the aim of getting as many students as possible to reach a certain level of literacy in the office programs and thus not on teaching the more advanced skills, which only few of the students are ready for.

5.1.2 Image and video editing

The data shows that fewer students claim to have learned image- (12%) and video (35%) editing skills. This suggests, that these skills are not in the same way the focus of the schools. With regards to both types of software, there is a group of about 30% claiming not to know how to use them (see Figure 11). In Figure 9, which concerns self-perceived knowledge of given technologies, more than 40% of the respondents claim poor knowledge of these two skills. The scope of this report is not to claim, that video- and image editing are important skills (for content creation in a time of social media), but it is clear from the data, that if they are indeed deemed important, there seems to be an opportunity for schools to make an impact with regards to image- and video editing software.

5.2 Digital fabrication in schools

Figure 11 above displayed the first part of results regarding whether or not the students reported to have learned use of given technologies in- or outside of school. The last part of these results is displayed below in Figure 13. As before, the possible three answers included: "primarily in school", "primarily at home", and "I haven't learned it". The questions in this section focus specifically on fabrication technologies but include items from metal-/woodwork and a multi-tester as these technologies are often used in connection with digital fabrication.

Of the technologies mentioned in Figure 13, most students report to have learned wood- and metalworking in school (52%). Woodworking is taught as a subject in Danish schools, and metalwork is often offered as an elective course. In this perspective, it is not surprising, that more than half of the students think, they have primarily learned wood- and metalwork in school. 25% of the students report, that they have learned using the multi-tester in school. Since the some of the students have been introduced to the multi-tester in the subject Nature&Technology[8] (grade 1-6) and everyone should be introduced to it in the subject Physics&Chemistry[9] (grade 7-9), it is surprising, that 65% of the students in our sample do not think they have learned to use it.

According to the respondents, 22% of them have learned to use programmable robots (such as LEGO™ Mindstorms) in school. Less than 15% of the students report to have learned to use the remaining digital fabrication technologies and skills in school. These are building electronic devices from scratch (14%), electronics and soldering (14%), microcontroller boards (e.g. Arduino) (10%), 3D printers (8%), Programming (8%) and Laser cutters and CNC routers (5%). Students in our sample have not had much exposure to digital fabrication technologies in school, since we had specifically asked for school classes, which had not been part of the FabLab@School project yet for our survey.

[8] Natur/Teknik
[9] Fysik/Kemi

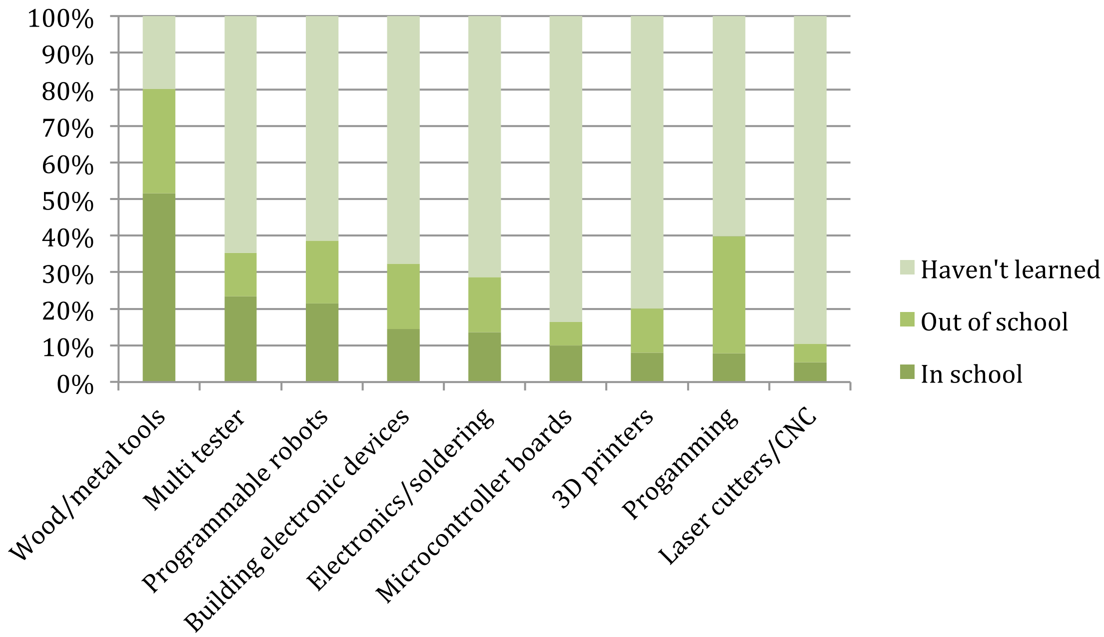

Figure 13: Where have the students primarily acquired their fabrication skills? Ordered by "in school"

5.3 Conclusion

In conclusion, it seems that most students are taught to use office programs in school, and that they acquire some form of Office Literacy. It also seems, that there is not the same amount of focus on teaching how to use image/video editing software, and that very few students have worked with digital fabrication technologies in school (below 15% except programmable robots, which 22% claimed to have learned to use in school). A large group of students report, that they have not learned how to use image-/video editing software (31% and 30% respectively) and digital fabrication technologies (60%-90%).

Overall it seems plausible, that the schools have focused on Office Literacy, and that this focus had the effect of reaching some level of literacy with regards to presentation software, spreadsheets and word processing. Further, it seems very plausible, that a focus on image-/video editing software and digital fabrication technologies would have the effect of raising the amount of students, who learn to use these technologies in school, raise the average level of knowledge about these technologies and thus expand the range of digital literacies among Danish students.

6 Design processes

The Organization for Economic Co-operation and Development (OECD) has through a series of reports on the topic referenced and defined a set of 21st century skills (Ananiadou and Claro 2009). The abilities to actively engage in heterogeneous communities of practice and to think and act innovatively on societal challenges are parts of what these 21st century skills. These same skills are also argued to be an important part of design thinking in academic literature (Cross 2011). Such skills are difficult to expose or measure in the timespan and limitations of a survey format. However, we have made attempts to probe into these aspects through a range of questions.

Firstly, we asked the students how they perceive their own abilities to work in groups, as well as their own creative, imaginative and idea generating abilities. (on a scale of 1 to 6). Further, the students were asked about their experiences with creating ideas for products or inventions and acting on these ideas.

After probing the self-views and experiences, the students were asked an open-ended question on a societal challenge. To follow up, the students were asked to rate different types of stakeholders, such as personnel, relatives, and police, in relation to their potential importance for solving the problem. They were further asked to rate the importance of different parts of the problem-solving (design-) process, such as planning, testing, involving stakeholders and building cardboard models.

The questions on design process thus combine measures of self-perceptions, experiences, approaches to real-world problems and valuations of process parts and stakeholders.

6.1 Creativity, imagination and collaboration

The students' were asked to self-assess their creative, imaginative and collaborative abilities by rating to which degree, they agreed with a range of statements. This was done on a scale of 1 (strongly disagree) to 6 (strongly agree). The students were furthermore asked, if they thought of creativity as fixed human capacity, whether they were interested in the creative (crafts) subjects in school, and whether inventing things were important to them. The data (see Figure 14) showed that most of the students rate themselves high in terms of their creative (73%), imaginative (80%) and collaborative (84%) abilities, and they find creative subjects interesting (74%), but inventing stuff is not important to most of them (42%). Apparently this is not a part of being a "creative person" according to many of the students.

For the sake of writing this report, the survey questions have been translated into English.. It is important to note that concepts such as imagination, creativity, ideas etc. are difficult to translate directly into Danish and can take on different meanings depending on the context in which they are used. For example, in the minds of the respondents, the Danish word for imagination (fantasi) might have more to do with imagining "weird stuff" than with imagining solutions to real-world challenges. The data is shown in Figure 14, but since the questions are abbreviated for the sake of formatting the chart, the full (translated) wordings of questions are included in Table 4.

1. **I am good at coming up with new ideas together with peers**
2. **I am good at collaborating in heterogeneous groups**
3. **I have a good imagination**
4. **I am good at generating new ideas**
5. **Creative subjects are interesting**
6. **I have lots of good ideas**
7. **I am a creative person**
8. **Some people are born creative, while others will never learn**
9. **I am good at building on the ideas of others**
10. **Inventing things is important to me**

Table 4: Translated questions from the multiple-choice creativity instrument

In Figure 14, the six categories of strongly disagree to strongly agree have been collapsed into two categories of either disagree or agree.

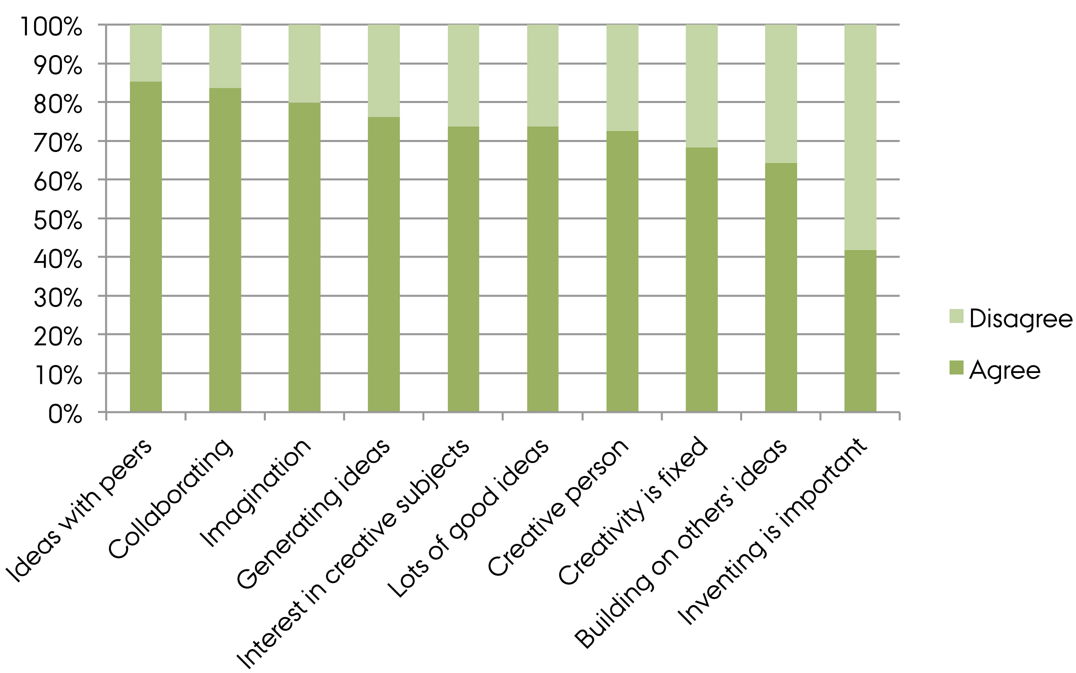

Figure 14: Attitudes and self-evaluation with regards to creativity, imagination, cooperation and creative subjects. Values collapsed from 6 to 2 categories. Ordered by "Agree".

Overall the data show a high self-rating in terms of the questions asked, with all except for the last one, at positive scores above 60%. More than 70% of the students report that they view themselves to be creative persons (73%), that they are good at generating new ideas (76%), have a good imagination (80%), and are skillful in terms of engaging in heterogeneous collaboration (84%). This was a surprising result to us, especially since the responses did not match our observations of students in this age group. There can be several reasons for this surprising result: Perhaps the students had unrealistic self-perceptions, perhaps they had other interpretations of the involved concepts and perhaps the answers are in part due to demand characteristics. As explained in section1.5.1 (Types of questions), demand characteristics cause students to answer what they believe the researchers want to hear. Another interesting result was that only 42% of the students considered inventing as important to them. Perhaps this has to do with the wording of the question. To invent (Danish: Opfinde) in the Danish context is equivalent to creating truly novel products. One could argue, that a question about whether or not producing or creating own products was important to the students could have aligned closer with their answers on the creativity items. Ultimately, the data indicate that according to the students, being creative, imaginative and generating new ideas is not necessarily linked to inventing things.

6.2 Realizing ideas for products or inventions

Following the questions concerning their own creative and imaginative abilities, the students were asked if they had ever had an idea for a product or an invention. If they responded positively to this question they were asked to describe the idea in an open question. As shown in Figure 15, 47% of the students responded positively that they had had an idea for a product or an invention

The students who responded positively to having had an idea for a product or an invention, were asked to describe this. The answers ranged from a bedside cup holder to new types of motherboards for computers, while others did not remember or did not wish to share their ideas for fear of us/others patenting or stealing them. Of the students, who answered that they had had an idea for a product or invention, only 26% had created their product, while 74% had not (see Figure 16 below).

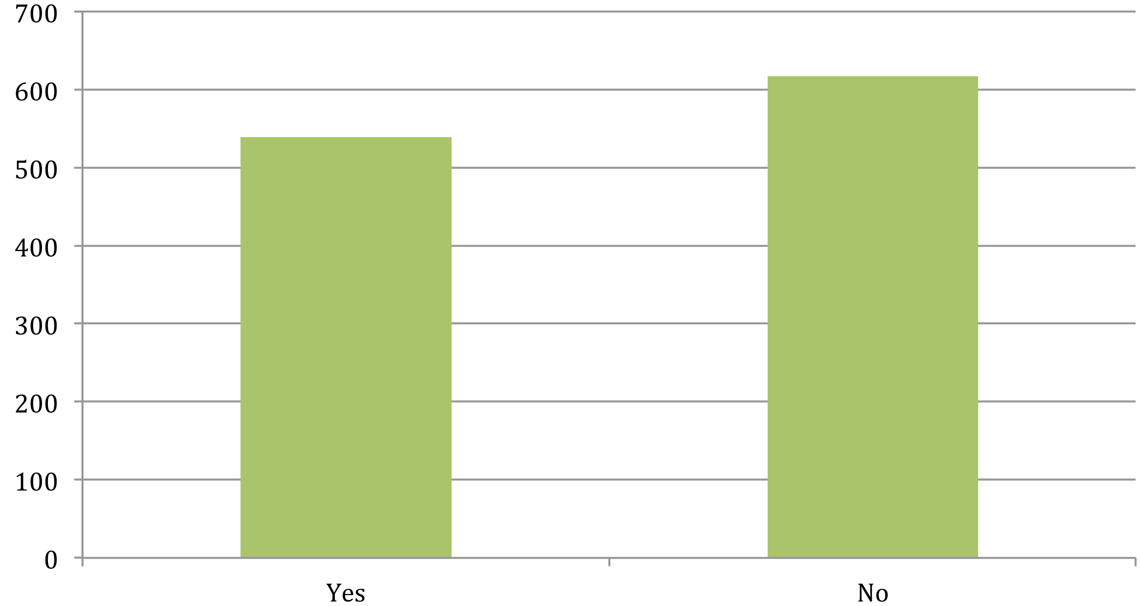

Figure 15: Have you ever had an idea for a product or an invention?

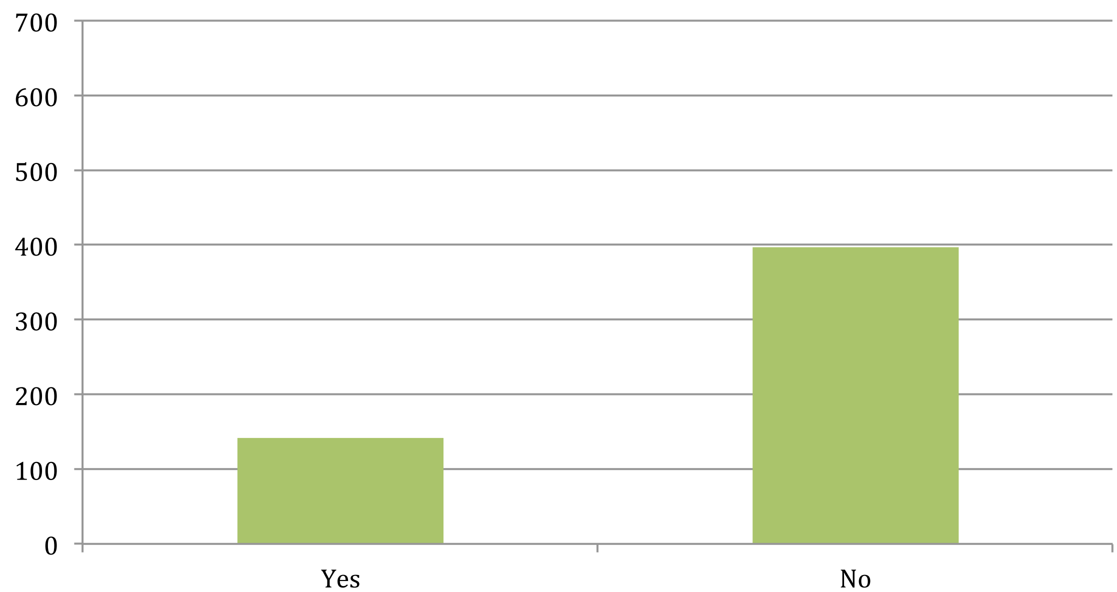

Figure 16: Did you create or build this product or invention?

When looking at the total number of responding students only 12% had built or created their idea or product. 34% of the students had an idea that they did not create or build while 53% claimed never to have had an idea for a product or an invention. This can be taken as an indication that most students are not used to thinking about objects in their everyday lives, which they can improve, and that very few are used to actually acting on ideas for improving their everyday lives. Another way of putting this is that the students in general approach the world as consumers rather than approaching it as something to which one can imagine preferred futures and create intentional change. That is, the students do not approach the world with a designerly mindset (Nelson and Stolterman 2012).

While this seems very plausible and fits well with our observations (Smith and Iversen Forthcoming), such a conclusion would require further investigation into how the students perceive the question: What is a product or an invention in their interpretation? What does it mean to create a product or invention?

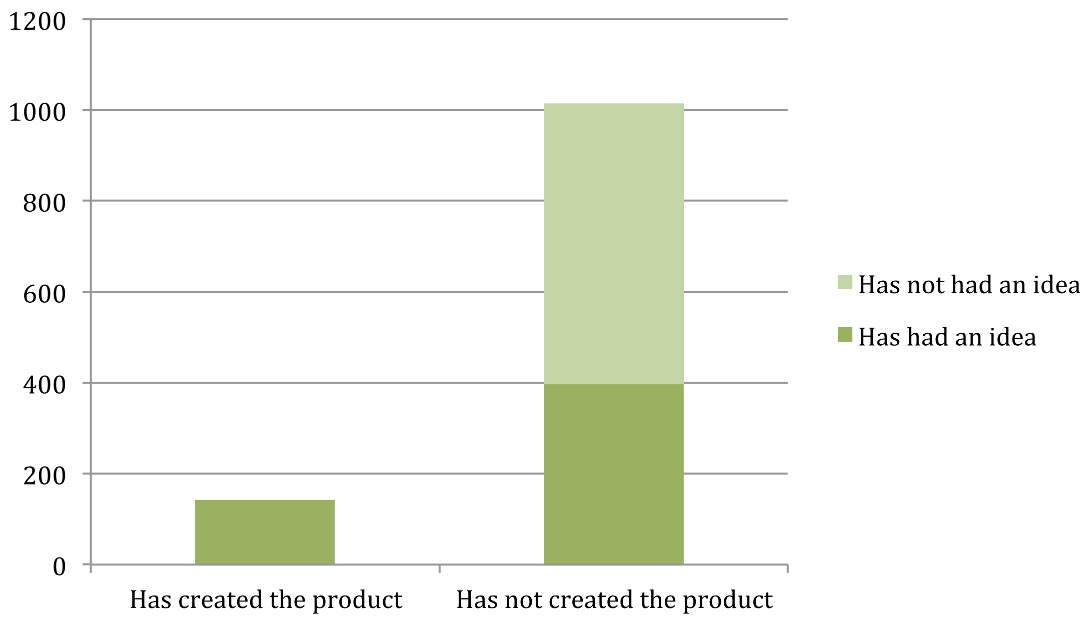

Figure 17: Have you had an idea and created the product or invention?

In conclusion the students generally perceive of themselves as good at imagining, generating ideas, being creative and collaborating in heterogeneous groups. They do not however seem to link these skills to inventing or producing things – neither in an abstract ("inventing is important to me") or a practical ("I have created the product or invention") sense.

Since one objective of the Danish FabLab@School research project is to investigate students' "abilities to think and act innovatively on societal challenges", the link between thinking and acting innovatively is of great interest. While we as researchers may define innovative thinking as linked to generating ideas, having a good imagination and being creative, we cannot conclude, that (an instrument consisting of) students answers on items relating to their self-perceived abilities within these areas is necessarily a measure of the students' abilities for innovative thinking. At the same time, it could be argued, that acting innovatively is not necessarily the same as inventing or creating a product. It is however, interesting to investigate the possible discrepancies between innovative thinking and acting and between definitions in the literature and views among the students. Further studies are planned in order to investigate these discrepancies.

6.3 The dementia task

As stated in the introduction, the Danish FabLab@School survey consists of different types of questions. More specifically the questions range from closed items asking about opinions or self-perceived abilities through multiple-choice tasks and to open-ended problems. One such problem is a task of preventing demented elderly from getting lost (and sometimes dying before they are found), from their nursing homes. This is an example of a design problem or a so-called *wicked problem* (Buchanan 1992). It is a characteristic of wicked problems, that they are indeterminate. That is, they do not have one true solution. Thus per definition, suggesting a solution to a wicked problem requires judgment. According to pragmatist design literature (e.g. (Löwgren and Stolterman 2004)) this judgment is exercised on a basis of knowledge generated in an iterative process – for example through externalizations (i.e. sketches, mockups and prototypes, etc.). Thus according to *Design Thinking* (Cross 2011), a designer would approach the wicked problem in an investigative (design) process. However, processual thinking and complex problem solving is not necessarily part of the current Danish school reality.

We had the hypothesis, that the students lacked the necessary tools with which to approach the dementia task. That is, they would be inclined to suggesting solutions and inventing ideas rather than approaching the problem as a complex challenge in need of further investigation. Our aim was to investigate what the students, despite their lack of insight into such processes, would respond or consider as alternative ways of approaching the challenge.

The dementia case was a real-world problem discussed in the Danish media at the time of the survey.[10] The wording of the open-ended question translates from Danish to the following:

> ”In the beginning of the year 2014, 9 grandparents disappeared from their nursing home because of their loss of memory (dementia). The problem for the nursing home is to create security for the elderly without taking away their freedom.
>
> If you were asked to solve this problem, what would you do?”[11]

[10] The number of elderly refers to a Danish context (population approx. 5.7 million)
[11] Translated from Danish

Posing a good question, which could probe the current state/understanding of *design*, *process* and *inquiry* among the students in a valid way was difficult. We are aware that the framing of the question asked, could have easily prompted the respondents to come up with a solution rather than a process. Nevertheless, the results of the answers are interesting for various reasons, discussed below. Further, it is our assumption that responses to similar questions, between the baseline survey and the endline survey, will reveal a shift in the number of students who have been exposed to design processes in FabLab@School activities. The assumption is, that it will be more frequent for the latter to suggest processual and investigative approaches to complex challenges.

After having answered the open-ended question, the students were asked to rank suggested stakeholders and activities within their process of solving the problem. This task is discussed in the paragraphs 6.3.2 and 6.3.3 below.

6.3.1 Coding the responses

In order to score the responses to the open-ended question, the answers were coded in a grounded theory approach (Strauss and Corbin 1990). Rather than making a coding system based on an initial hypothesis, the responses were grouped based on the given answers. Each time a new type of answer appeared, a new code was created. When the amount of codes stabilized after approximately 220 respondents, a total of18 codes had been made. The 18 codes were then collapsed and categorized into three categories:

1. Creating a situation in which the demented do not try to leave or get lost
2. Preventing the demented from leaving the nursing home
3. Keeping track of and finding the demented, once they have left the nursing home

Within each of these categories, a taxonomy of 4 levels was created, resulting in a total of 12 codes. The highest level (level four) within each category was reserved for the responses, which, within the category in question, proposed to start an investigation into the problem. The preliminary version of the coding system looked like this:

A. Creating a situation in which the demented do not leave/get lost

1. Convince the elderly not to leave/ let the elderly stay in their own home/ cure the dementia
2. Make sure the demented have a good time (get a lot of visits/ participate in activities/ create better surroundings/ have more caretakers/ have more freedom)
3. Make the demented feel more at home (e.g. by making their rooms/ apartments resemble their previous private homes)
4. Investigate what makes the demented leave and get lost

B. Preventing the demented from leaving the nursing home

1. Put a fence around the nursing home/lock the doors/surveil the elderly/guard the doors
2. Place a chip on (or inside) the demented elder and a sensor at the door, or using other

kinds of technology with the purpose of preventing the demented from passing or leaving with no concrete suggestions of placement or function

3. Place a chip on (or inside) the demented or using other kinds of technology with the purpose of preventing them from leaving the home. Including reflections on where to place it or how it should function
4. Investigate, how the demented could be prevented from leaving and what this would affect their lives

C. Tracking and finding the demented, once they have left

1. Look for the demented/ call the police to have them look for the demented
2. Place a tracking device on/in the demented without reflecting upon how to place it or how it should function, or put up signs, which show the direction home, in the neighborhood
3. Put a tracking device on/in the demented including reflections about how to place it and how it should function
4. Investigate, why the demented get lost, how to best find them and how this possible solution would affect their lives

Table 5: The initial 12 codes in the coding system

The coding system captured differences in approaches, ideas and solutions to the problem, and indicated how many students opted to set up an inquiry or design process in response to the challenge. The coding system, however, still presented some challenges. Often, it was difficult to distinguish between some of several codes within a category (e.g. whether a suggestion for placing a gps on the elderly was reflected with regards to usage (C3) or not (C2)). In order to avoid this ambiguity, the codes B2 and B3 was collapsed into one as was C2 and C3. A further problem, which manifested itself during the coding, was an uncertainty whether simply locking the doors with keys (B1) was at a different taxonomical level than preventing the demented from leaving by using chips, sensor or codes at the (locked) doors (B2+B3). Seen from the perspective of the elderly the result remained the same, as they would not have the possibility of leaving the premises. Therefore, B1, B2 and B3 ended up in one collapsed variable.

Responses, which suggested that staff from the nursing home should take the demented for walks outside the home, posed challenges of ambiguity. These responses could stem from both an emphatic and an instrumental approach to the elderly. This type of suggestion could have the purpose of improving the happiness of the demented and thus (according to the responses), make them less likely to leave. On the other hand, the same response could be made with the purpose of surveilling the elderly. In this way, responses including escorts or walks could be seen as both a limitation of their freedom (B1+B2+B3: Prevent the demented elderly from leaving/escaping) and an increase in their freedom (A2: improve the life of the demented elderly). The responses in the end were coded based on an interpretation of the intention of the respondent.

In the end, a new collapsed coding system was made with the following codes:

Resulting codes for answers to the task of saving demented elderly

1. I don't know and other similar responses
2. Cure the elderly or persuade them not to leave
3. Prevent the demented elderly from leaving/escaping
4. Find the demented elderly once they have left
5. Improve the life of the demented elderly
6. Track the demented elderly (GPS)
7. Investigate the problem further (processual approach)

Based on the collapsed codes, the number of responses in each category created the following representation (Figure 18):

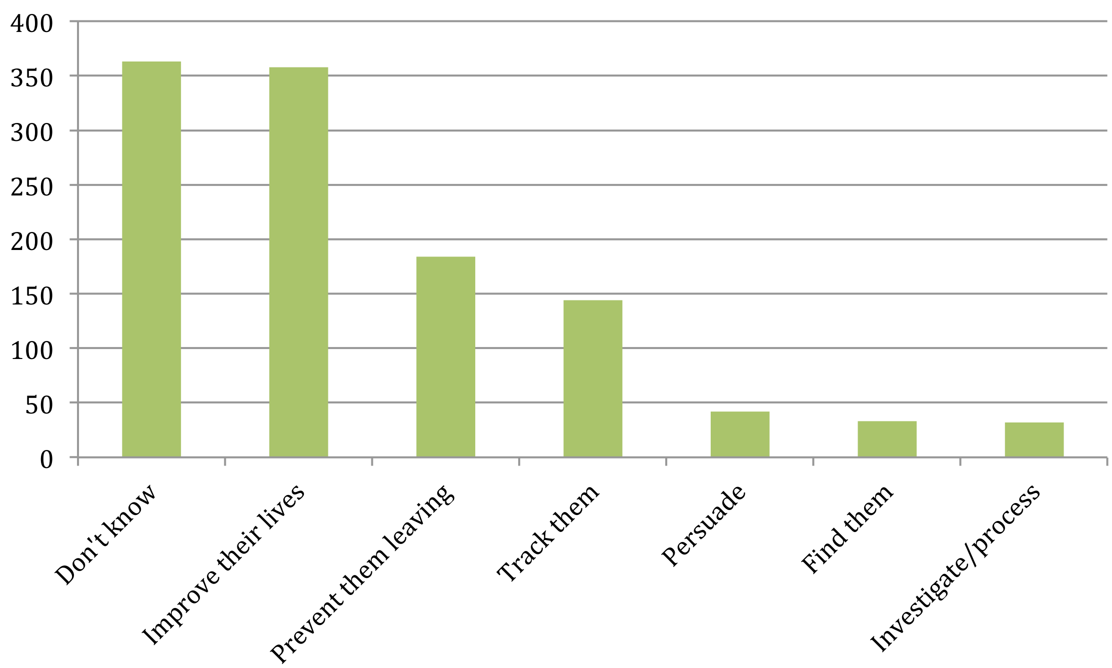

Figure 18: Distribution of answers in final version of the coding of the open-ended dementia problem. Ordered by frequency.

As seen in Figure 18, the two most popular categories were "I don't know" (31%), and "improve the life of the demented elderly" (27%), including more than 700 responses in total. This is followed by 184 responses (16%), proposing that the elderly should be prevented from leaving the nursing home (by means of locks, bodyguards, RFID chips, fences, etc.). A total of 144 respondents (12%) suggested some form of tracking – often including GPS-technology. The following two categories show a lack of insight into the problem area. If one could simply persuade the elderly to stay, which 42 respondents (4%) proposed or find the easily elderly, which 33 respondents (3%) suggested, this would not be a societal challenge in the first place.

Thus 31% of the respondents thought they should come up with a solution to the complex problem of demented elderly leaving their nursery home, but they where not able to suggest such a solution. On the other hand, 66% of the respondents suggested solutions with varying degrees of insight and appropriateness. Only 32 respondents (3%) responded, that they would initiate some kind of inquiry or process. Thus, the data suggests a general lack of focus on teaching the students processual approaches and to ways of addressing complex and societal challenges. But this will require further research.

Figure 19 is another representation of the same data.

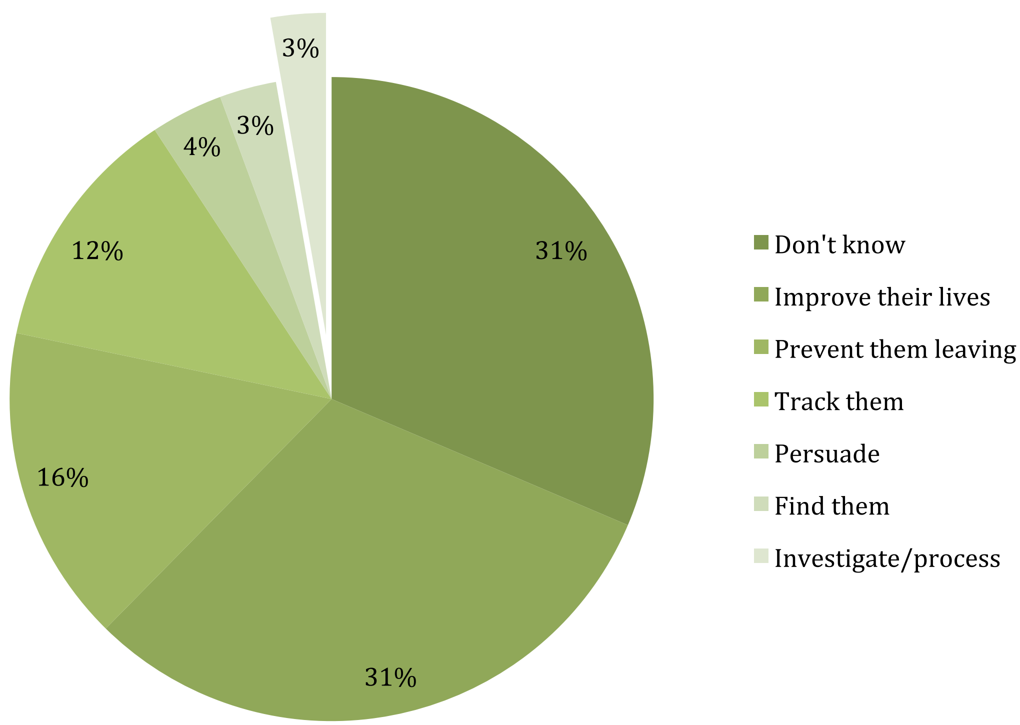

Figure 19: Pie chart of the distribution of responses on the open-ended dementia challenge.

Overall, the data shows an example of how the students addressed a concrete societal challenge, and the tendency to provide final ideas or solutions rather than processes of inquiry, which could lead to a solution. There can be many reasons for this, one clearly resulting from the wording of the question. This is nevertheless a very interesting finding, which calls for further investigation.

6.3.2 Importance of stakeholders

After answering how to solve the dementia problem, the students were asked to rate the importance of specific (possible) stakeholders on a scale of 1 (not important at all) to 6 (very important). This instrument was meant to give insights into students' abilities to identify important stakeholders, as part of solving the challenge. The elders, their relatives, the nursing staff, as well as an industrial designer, the police, NASA, and others were included as possible stakeholders. This was done in order to gauge the extent to which the students, given possible relevant answers, could see the benefit of involving different stakeholders into the process. We wanted to investigate if some students would choose to solve the problem on their own without involving anyone (relying on their own ideas), or whether they were aware of the benefits of involving multiple stakeholders.

A chart with the 6 values collapsed into three categories[12] (see Figure 20 below), illustrates which stakeholders the students considered to be the most important.

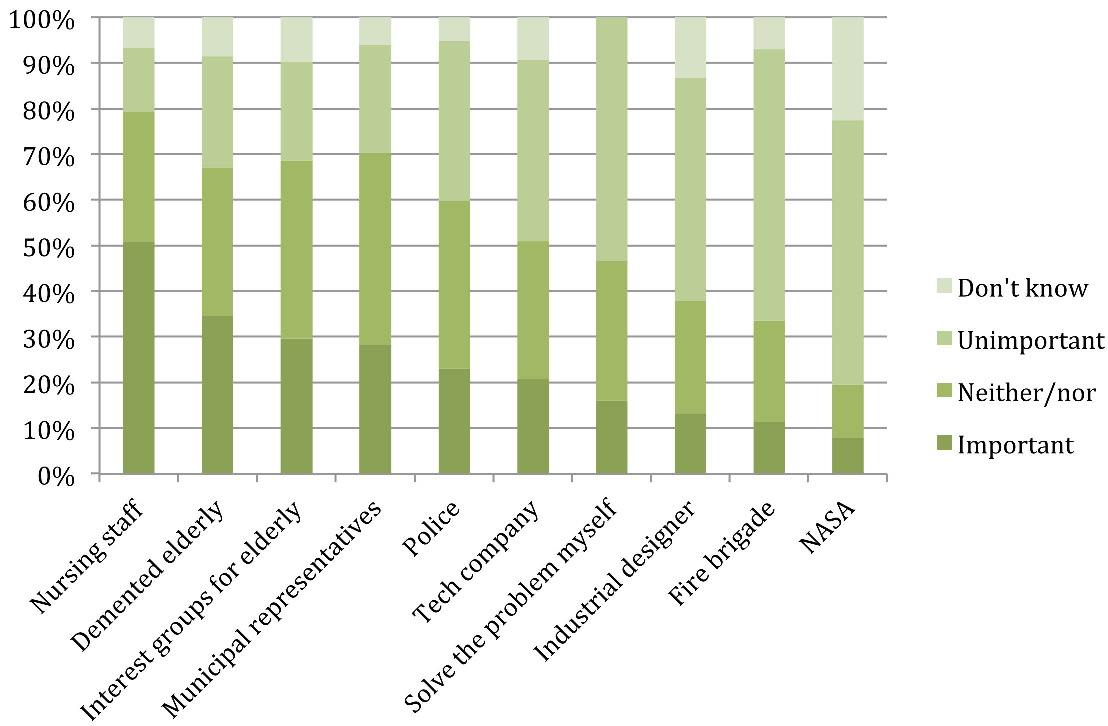

Figure 20: Who would be important for you to collaborate with? Scale collapsed from 6 to 3 categories. Ordered by "important".

The four groups of stakeholders, which most respondents considered to be important, were nursing staff (51%), the demented themselves (35%), interest groups for the elderly (30%) and municipal representatives (28%). These are also stakeholders, who are already involved in the problem. Thus they are important for understanding the problem ecology. Furthermore, to the notion of solving the problem without involving any stakeholders, 54% of the students answered 1 or 2 on the 6-point scale, indicating that they did not see this as an attractive

[12] We have chosen to call these categories Unimportant (values 1+2), neither/nor (values 3+4) and important (values 5+6) respectively.

approach.[13] This leads to us to conclude, that when prompted, many students were able to identify the most important stakeholders for understanding the problem, and that most students saw the value of including (some) stakeholders.

As stated, most students valued stakeholders, who had knowledge of the problem ecology. On the other hand only relatively few respondents considered it important to involve a tech company (21%) or an industrial designer (13%). This valuation of their importance appears to be low in relation to their potential role in solving the challenge, but it corresponds well with the fact that 16% of the students point to technological solutions in the above open-ended task.

A sizable part of the respondents did not even see the value of involving the nursing staff (14%), the demented (24%), their interest groups (22%) or the municipal representatives (24%) and 16% preferred to just solve the problem without involving others. Thus, there was a group of students, who, even when prompted, did not see the value in involving stakeholders at all.

When confronted with a complex real-world challenge, the students tend to offer possible solutions without considering potential stakeholders, but when asked specifically about the importance of involving specific stakeholders, most students seemed able to identify, who were most relevant for them to involve.

6.3.3 The process

We wanted to test further, the students' understanding of inquiring, creative and exploratory (design) processes. We were aware that these skills were not taught (as such) in the Danish schools, but wished to establish a baseline against which we would later be able to measure the impact of working with design processes in FabLab@School activities. Therefore, the students were asked to a series of suggestions for the activities in the process they would set up to solve the dementia problem. Again they were asked to score the items on a scale of 1 (not important at all) to 6 (very important).

In Figure 21 and Figure 22 below, the values of responses to these items are collapsed into three possibilities,[14] and the data is split into two charts. The activities, which were rated as important for the process more often than unimportant, are shown in Figure 21. The remaining activities are shown in Figure 22. The activities that most students identified as important for the process, were making all the stakeholders agree on a solution (57%), setting up a meeting with staff and relatives (54%), and visiting nursing home to explore the problem (54%). Only secondarily the students pointed to creating a thorough plan (43%) and

[13] As described the scale ranges from unimportant to important, whereas the wording of this specific item would be better suited for a scale from disagree to agree. This could potentially lead to confusion, but since no students have answered, "I don't know", this does not seem to be the case.
[14] We have chosen to call these categories unimportant (values 1+2), neither/nor (values 3+4) and important (values 5+6) respectively.

testing a possible solution with the elderly (46%), while using disagreements in a fruitful way to reach the best solution was rated (32%).

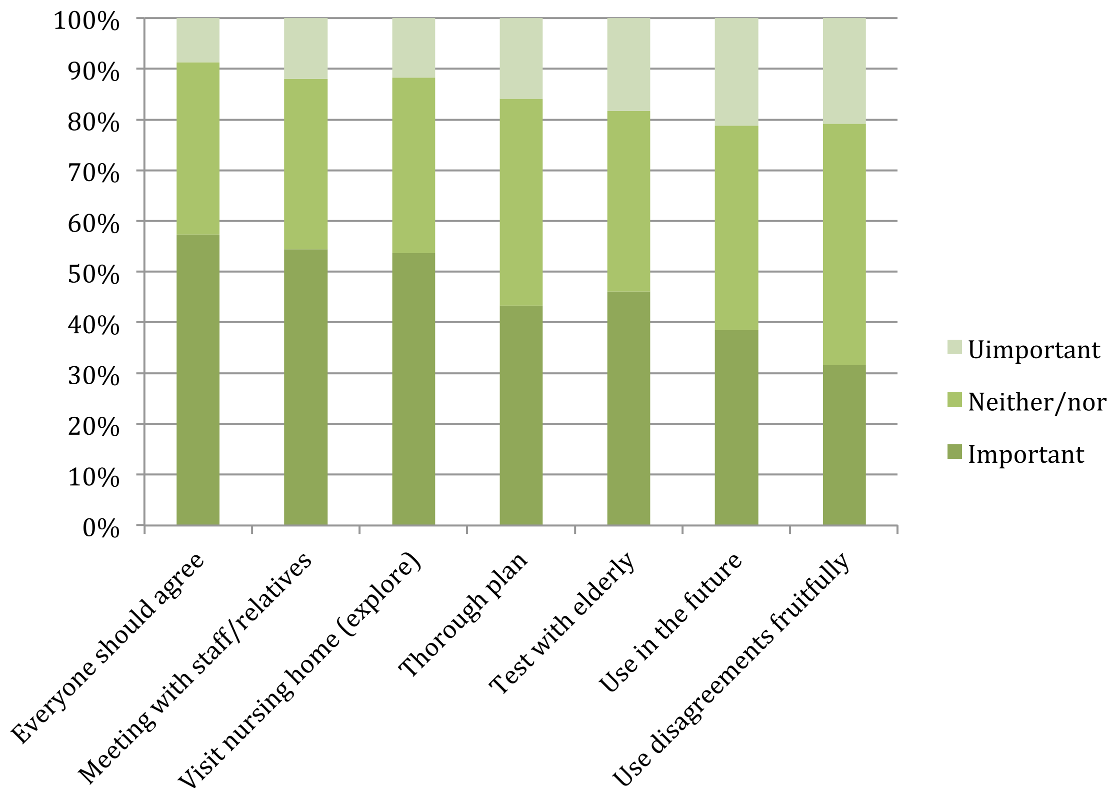

Figure 21: What parts of the process would be most important to you? Scale collapsed from 6 to 3 categories. Ordered by average score.

Figure 22 shows the suggested activities, which a larger group of students found 'unimportant' than 'important'. It is clear from the responses that the students viewed model building as very unimportant: The students rated the three suggestions that entailed building a cardboard model (6%), testing a cardboard model in a nursing home (10%) and repeating this test with a new model (11%) as having little relevance or importance. In line with this, sketching on paper was important to only 21% of the students, just above patenting ones idea (19%), or waiting for a good idea to emerge (17%). When considering that sketching and using mock-ups and paper prototypes are essential parts of creative and professional (design) practices, this is an interesting result that suggests that the students are not familiar with such creative processes.

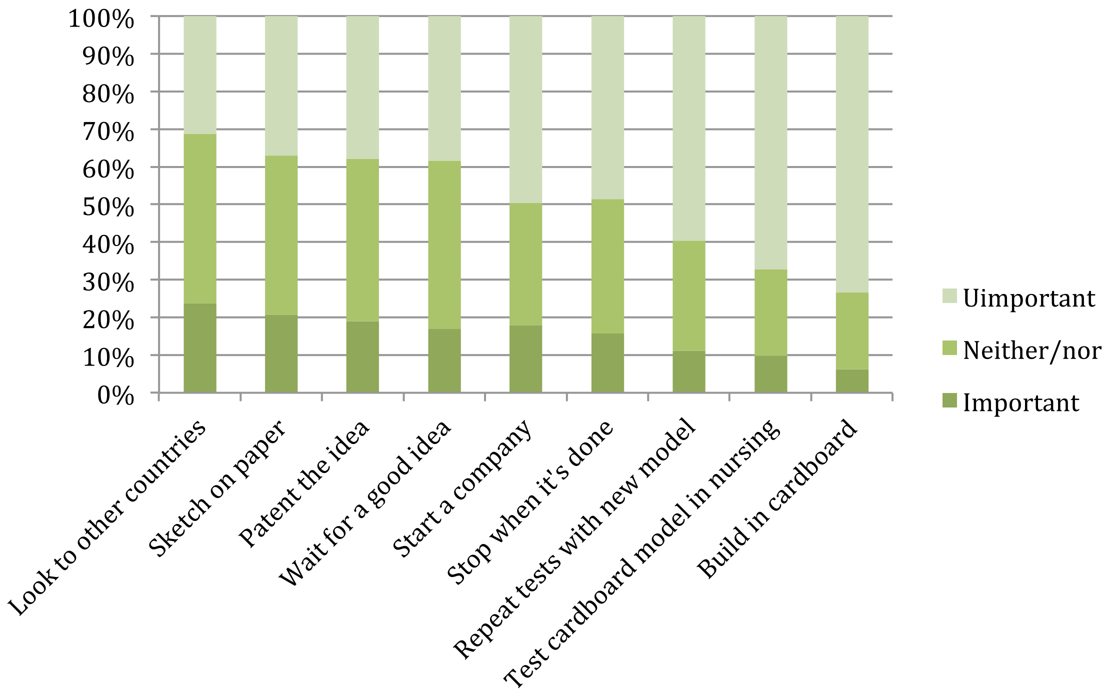

Figure 22: What parts of the process would be most important to you? Scale collapsed from 6 to 2 categories. Ordered by average score.

6.4 Summary

In order to gain insight into the students' knowledge of design processes we asked a range of questions combining measures of self-perceptions, experiences, approaches to real-world problems and valuations of process parts and stakeholders.

Most students rated themselves high in terms of their creative (73%), imaginative (80%) and collaborative (84%) abilities. The data further indicates that according to the students, being creative, imaginative and generating new ideas is not necessarily linked to inventing things, as the students did not see inventing as important to them.

Only 12% of the students reported, that they had had an idea for a product and invention, and that they had realized this idea.

When asked an open-ended question of solving a complex societal issue (the dementia problem), 31% of the respondents did not know what to answer, and only 3% of the students proposed to investigate the problem further.

The Danish students, which were asked to rate different stakeholders and potential activities of an inquiry and/or creative process, were good at identifying relevant stakeholders and they addressed some relevant activities involved in a typical design process. The students did not, however, show an understanding of the value of externalizing ideas, through activities such as sketching and building mock-ups, for gaining insights and knowledge to inform the production of a possible solution.

Probing into design process skills and design thinking knowledge is difficult in a survey like the one, which this report is based on. Each of the approaches reported in this chapter point to the need for further investigation. However, by approaching the subject of students' knowledge and skills with regards to design processes from different angles, a fuller understanding is possible. What has emerged from the evaluation of the data, is that there is a possible connection between not valuing externalizations, trying to come up with final solutions instead of starting investigations into the problem space and not having produced ones idea(s) - suggesting that the students, however creative they perceive themselves to be, on average are lacking skills for acting on ideas and for dealing with complex problem solving.

7 Summary and Conclusion

This is the report on the baseline survey for the FabLab@school.dk research project. 1156 students aged 11-15 years, answered 227 questions in total. The questions were about their use and knowledge of digital technologies, both in and outside of school, about design and creativity, and about their perspectives on hacking, open data and privacy issues. The sample of students in this survey was not randomly selected, and thus we cannot claim representativity. This means that claims are made for the sample only. Below is a summary of the most important findings for this sample of students from the participating four municipalities.

Students are consumers (rather than producers) of digital media and technology

From the data, we have concluded, that rather than producing, the students spend a lot of time consuming digital media and content on computers, tablets and phones. They do this by playing games, surfing the net, chatting, liking, and commenting posts and updates from others. Most students reported to have some or even good knowledge of using computers, tablets and phones for consumption purposes. On the other hand, many of the students in our survey reported, that they had relatively poor knowledge of tools for producing images, videos and webpages and thus move beyond consumption of digital content.

When spending time with computers, TVs and phones is the most popular leisure activity, it is tempting to talk about the students in our sample as digital natives: Adolescents who were born in a digital world and to whom all things digital are as easy as they are natural to them. As seen in both this report and in the ICIL study, the school system cannot take this for granted.

Few students have knowledge of digital fabrication

Few students in our sample reported to have knowledge of digital fabrication tools such as 3D printers, laser cutters and microcontroller boards such as Arduino and Makey Makey. This was to be expected, since digital fabrication technologies are not widely available, and since the respondents (as requested) had not yet taken part in FabLab@School activities.

Schools focus on teaching "Office Literacy"

According to most of the students in our sample, they are taught to use office programs in school, and they acquire some form of Office Literacy. It also seems, that there is not the same amount of focus on teaching how to use image/video editing software, and that very few students have worked with digital fabrication technologies in school. A large group of students report, that they have not learned how to use image-/video editing software and digital fabrication technologies. Thus a focus on image-/video editing software or digital fabrication technologies could possibly expand the range of digital literacies among Danish students.

Most students do not act on their creative ideas

Most students in our sample rated themselves high in terms of their creative (73%), imaginative (80%) and collaborative (84%) abilities. The data further indicates that according to the students, being creative, imaginative and generating new ideas is not necessarily linked to inventing things, as the students did not see inventing as important to them. Only 12% of the students reported, that they had had an idea for a product and invention, and that they had realized this idea.

Students lack knowledge of design processes

The Danish students in our sample do not seem to have knowledge and experience with design processes as a way to engage in complex problem solving. When asked an open-ended question of solving a complex societal issue (the dementia problem), 31% of the respondents did not know what to answer, and only 3% of the students proposed to investigate the problem further.

The Danish students, which were asked to rate different stakeholders and potential activities of an inquiry and/or creative process, were good at identifying relevant stakeholders and they addressed some relevant activities involved in a typical design process. The students did not, however, show an understanding of the value of externalizing ideas, through activities such as sketching and building mock-ups, for gaining insights and knowledge to inform the production of a possible solution.

There is a possible connection between not valuing externalizations, trying to come up with final solutions instead of starting investigations into the problem space and not having produced ones idea(s) - suggesting that the students, however creative they perceive themselves to be, on average are lacking skills for acting on ideas and for dealing with complex problem solving.

8 Literature

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Appendix I: Comparing the sample with the population

In order to compare our sample of schools with the population of Danish schools in general, a t-test on the average exam scores was run.

Schools – calculation of variance and standard error

Firstly two schools were deleted from the school data, since they did not have 9th grade and thus have no relevant data. The category "missing" consisting of 4 students who had not put a relevant school name in the field asking them to do so was also removed.

The standard error on the scores for the schools in our sample has been calculated using R with the following code:

```
library(ggplot2)
setwd('/.../data')
csv.data <- read.csv2("skoledata.csv")
mean_se(skoledata$Karaktergennemsnit, mult=1)
```

Which gives a mean of 6.95 and a standard error of 0.123. The average score of Danish schools in the same period, was 6.6.

In order to see, whether our sample is significantly different from the population, a two-sided t-test was used:

$$t = \frac{\mu_{sample} - \mu_{population}}{Standard\ error}$$

Table 6: Test of significant difference between sample and population with regards to average score of the schools

μ_{sample}	6.95
$\mu_{population}$	6.6
Standard error	0.123
T-test value: H_0: $\mu_{sample} = \mu_{population}$	2,85

With a 95% confidence interval and 36 degrees of freedom, the t-value should lie within the -2.04 to 2.04 interval for the H_0 hypothesis to be true. Thus the H_0 hypothesis is rejected, which means, that the difference between the average scores of our sample and the population of Danish schools, is significant ($p<0.05$).

Comparing project schools with non-project schools

In order to compare the two groups of schools, a Welch two-sample t-test was run using R Studio.

The Code:

```
FABLAB=skoledata[skoledata$FABLAB.=="1",]
NONFAB=skoledata[skoledata$FABLAB.=="0",]
sd(FABLAB$Karaktergennemsnit)
sd(NONFAB$Karaktergennemsnit)
t.test(FABLAB$Karaktergennemsnit, NONFAB$Karaktergennemsnit)
```

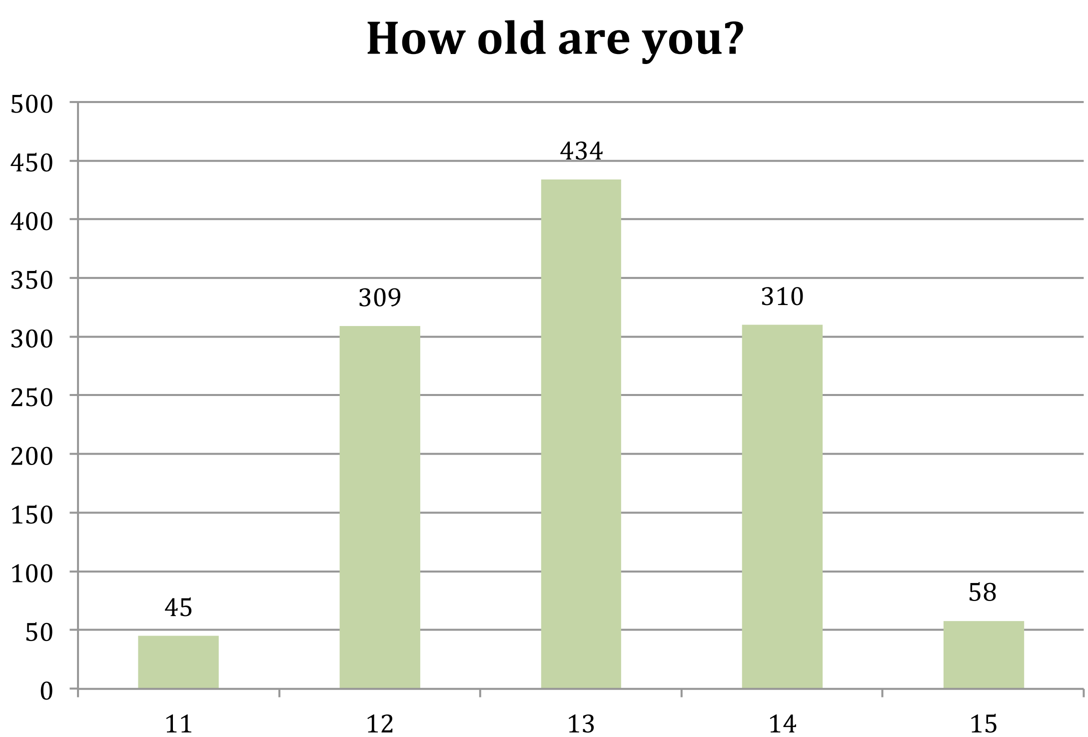
Gave

```
> FABLAB=skoledata[skoledata$FABLAB.=="1",]
> NONFAB=skoledata[skoledata$FABLAB.=="0",]
> sd(FABLAB$Karaktergennemsnit)
[1] 0.8370015
> sd(NONFAB$Karaktergennemsnit)
[1] 0.6060459
> t.test(FABLAB$Karaktergennemsnit, NONFAB$Karaktergennemsnit)

        Welch Two Sample t-test

data:  FABLAB$Karaktergennemsnit and NONFAB$Karaktergennemsnit
t = 1.0572, df = 34.937, p-value = 0.2977
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.2309039  0.7326897
sample estimates:
mean of x mean of y
 7.057143  6.806250
```

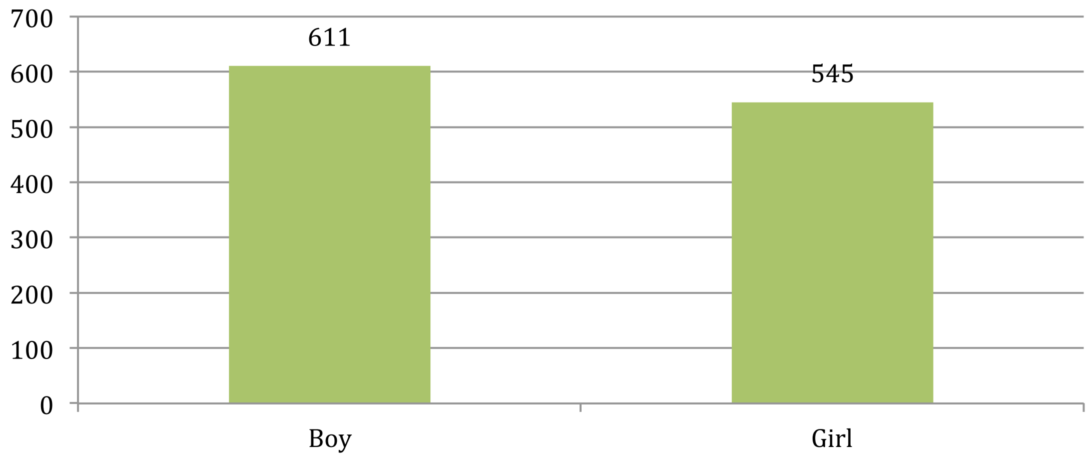
Thus on average, participating schools from the FABLAB group had a higher average score ($M = 7.06$, $SE = 0.84$), than participating schools from the NON-FABLAB group ($M = 6.81$, $SE = 0.61$). This difference was however, not significant $t(34.9) = 1.06$, $p = 0.30$.

Appendix II: Answers to quantitative questions in the questionnaire

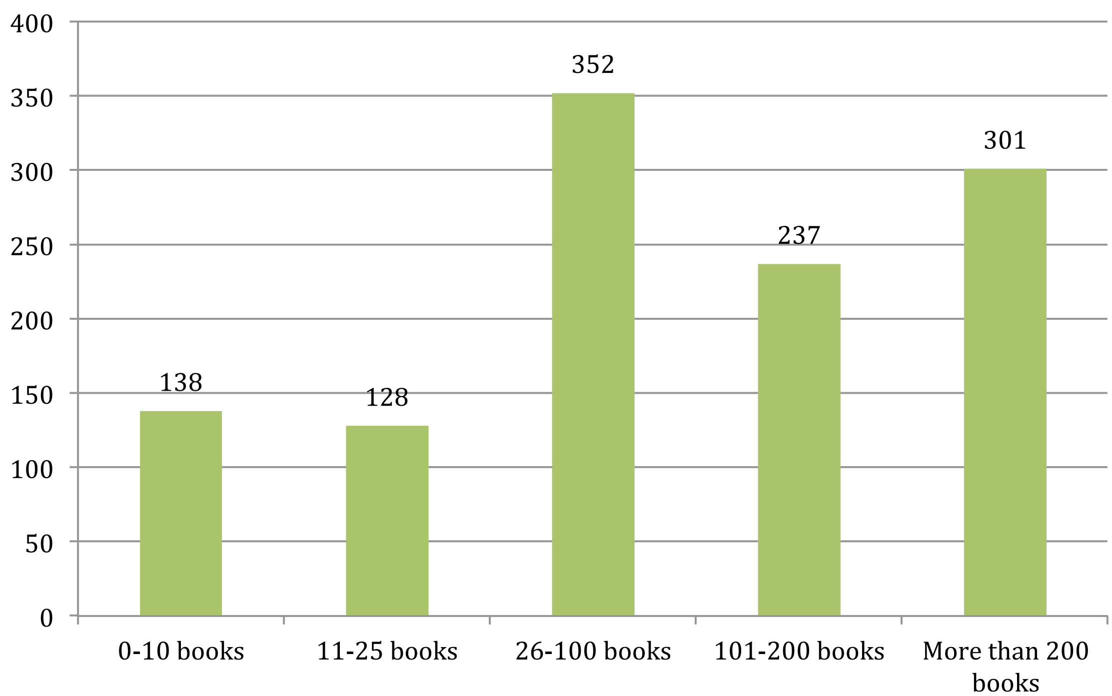
In the following pages, tables and charts with results from quantitative questions on the survey are displayed. Texts are translated from the Danish questionnaire, which means, that even in the case, where these question originate from Stanfords work, the wording might be different. All tables have a corresponding chart below them. In the charts, text have been shortened due to readability.



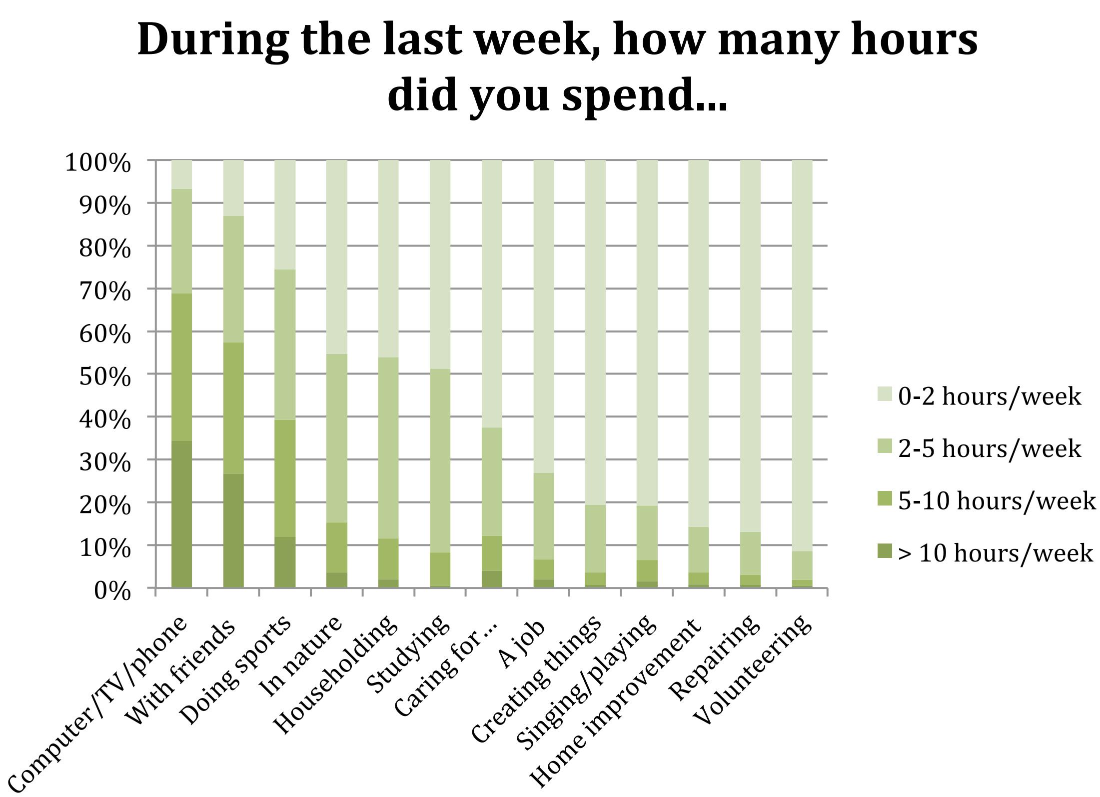
What is your gender?



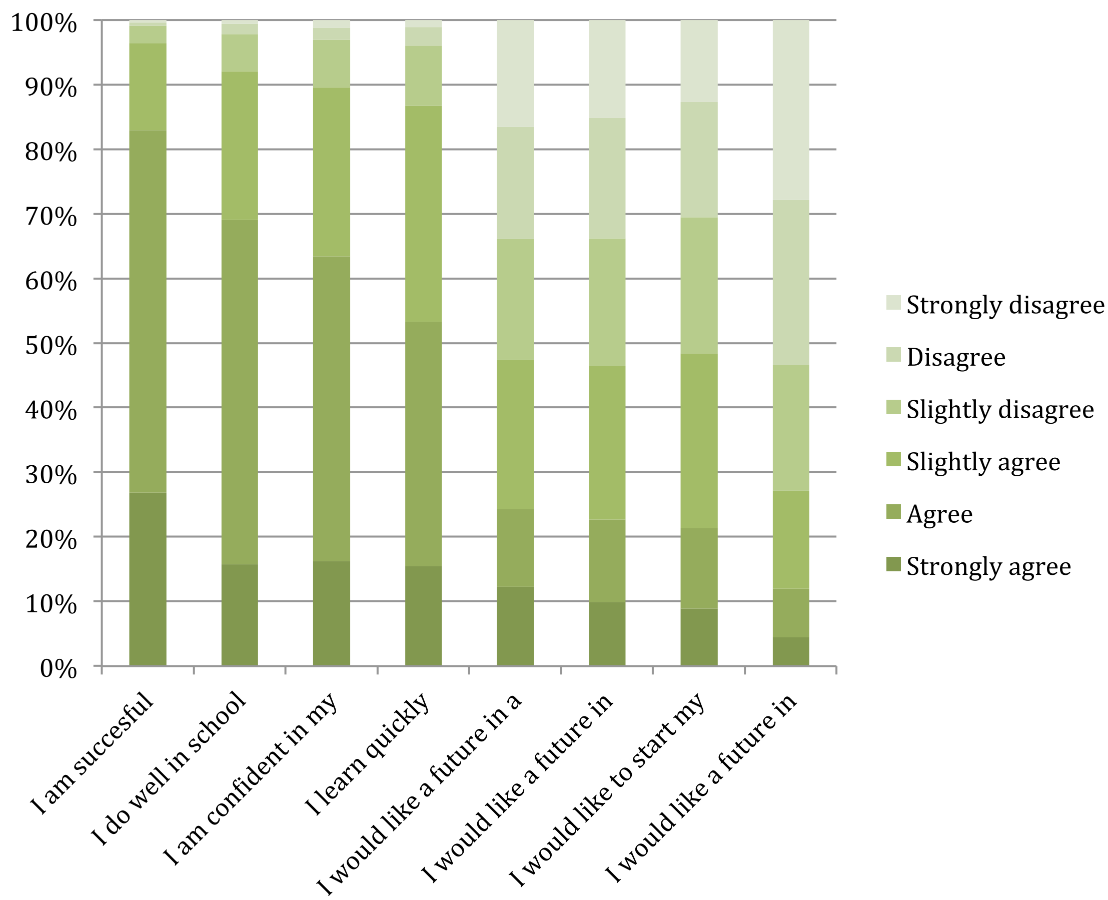
How many books are in your home?



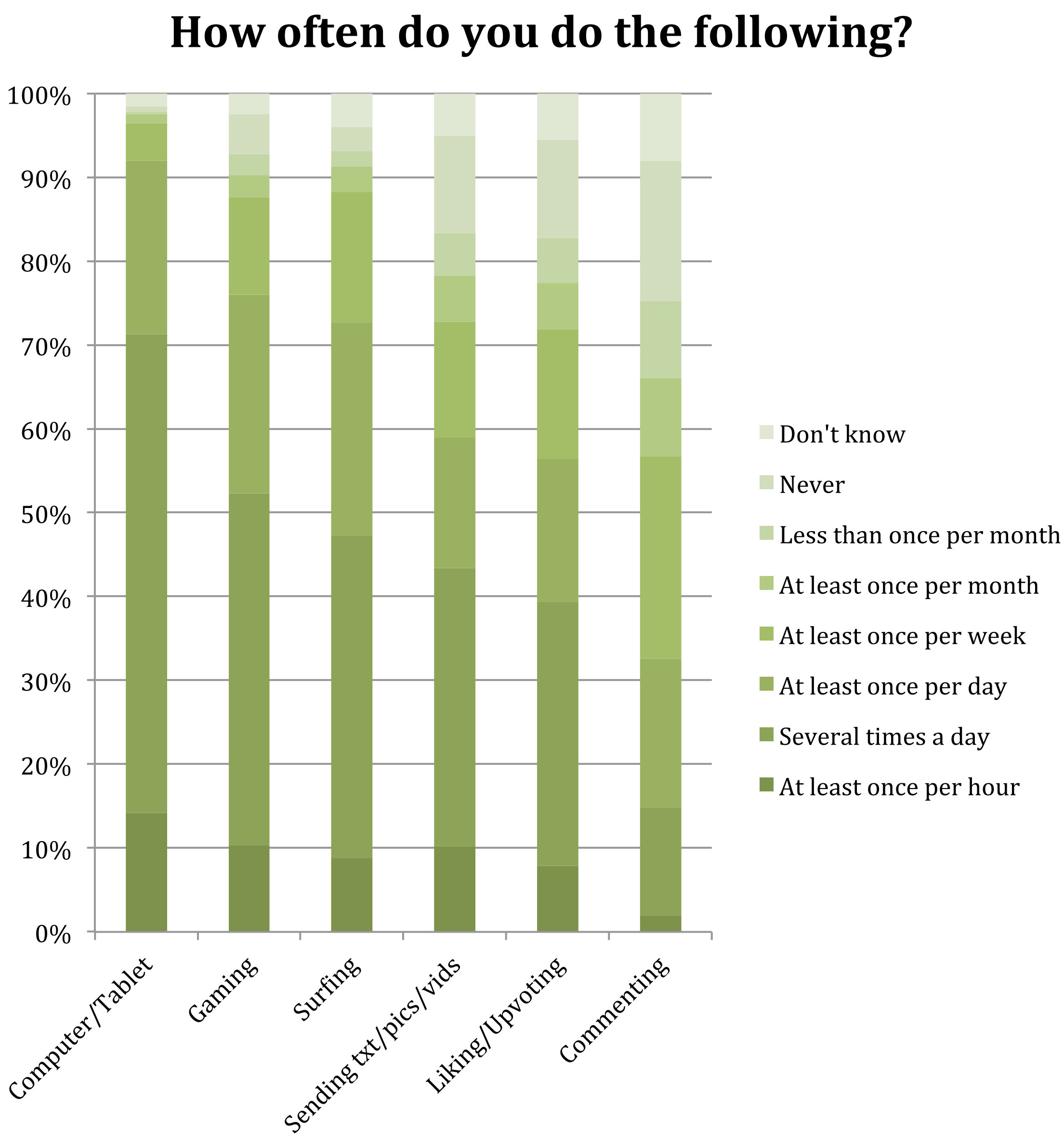
During the last week, how many hours did you spend...?	> 10 h/week	5-10 h/week	2-5 h/week	0-2 h/week
On computer, TV, phone etc.	398	399	282	77
Being with friends	309	355	341	151
Participating in any kind of sports	138	316	407	295
In nature	42	135	455	524
Performing household chores	23	111	490	532
Studying	6	91	496	563
Caring for siblings, pets etc.	46	96	291	723
Working at a job that pays an income	23	55	233	845
Creating things from e.g. wood, paint or textiles	8	34	182	932
Singing or playing an instrument or in a band	19	56	147	934
Working on home improvement or construction projects	10	33	122	991
Repairing furniture, bicycle or electronic devices in your home	9	27	116	1004
Volunteering in your community	6	16	78	1056

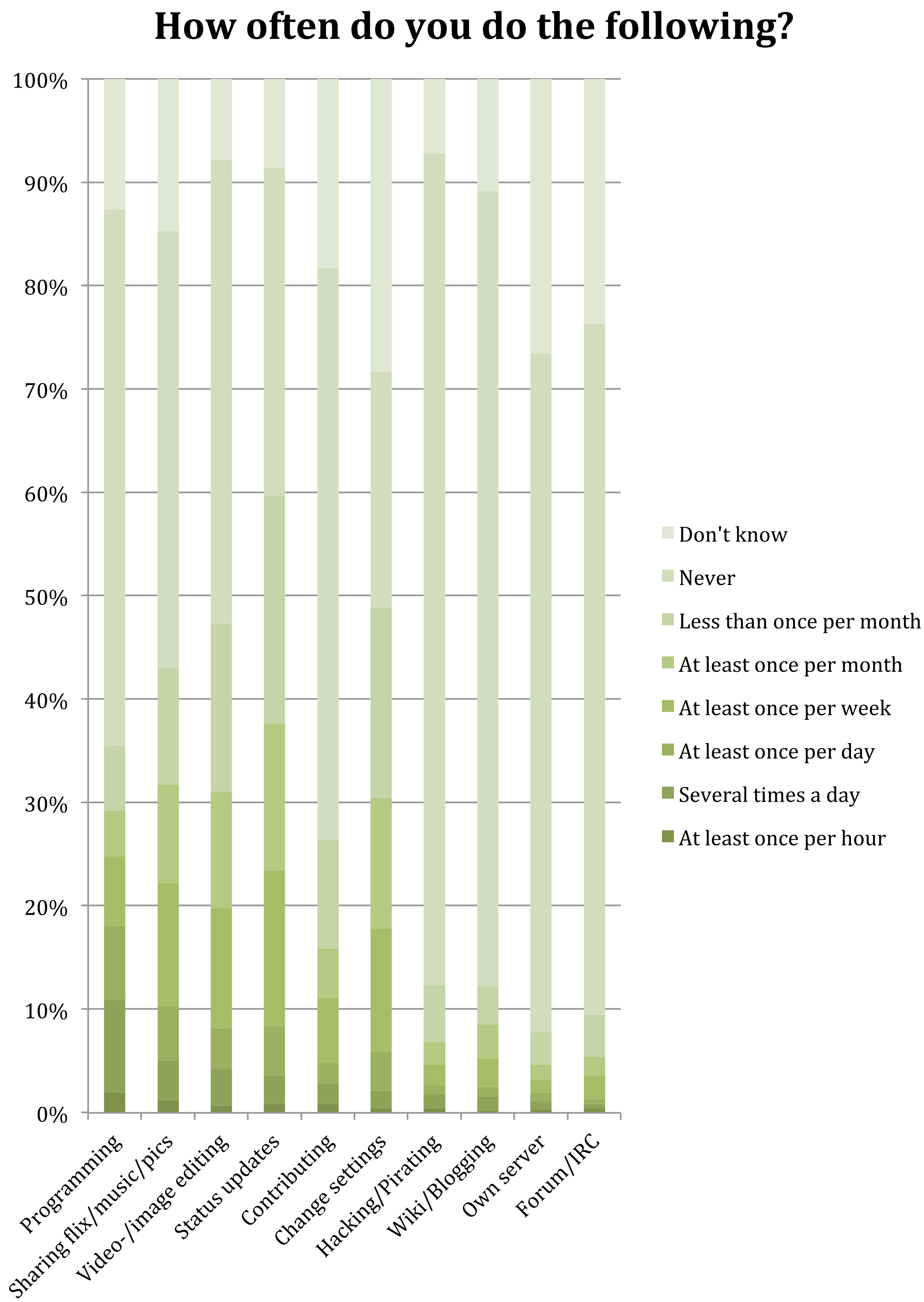


To what extent do you agree?	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
I am succesful	4	6	31	154	639	307
I do well in school	7	18	66	262	610	178
I am confident in my academic abilities	13	21	85	301	537	184
I learn new concepts quickly	12	34	106	381	433	175
I want a future within a creative profession	186	199	213	266	137	140
I want a future within technology and design	172	213	225	274	146	111
I want to start my own business	142	204	242	310	143	100
I want a future in engineering or science	318	292	221	172	88	50

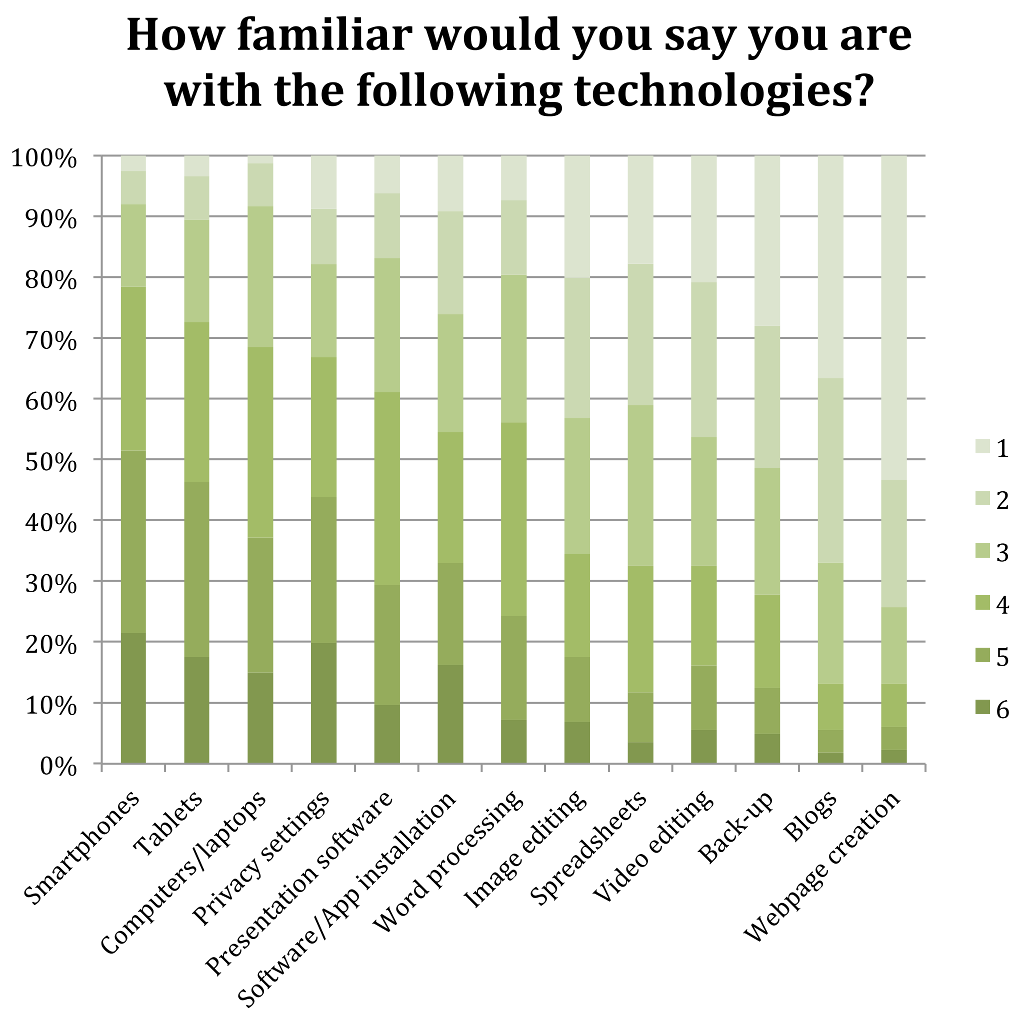


How often do you do the following?	At least once per hour	Several times a day	At least once per day	At least once per week	At least once per month	Less than once per month	Never	Don't know
Use computer or tablet at home	164	660	239	52	13	3	7	18
Play computer-, mobile- or videogames	120	485	274	134	31	29	55	28
Surf or watch videos on the internet	102	444	294	180	36	21	33	46
Communicate with images, videos or text (e.g. Facebook, Instagram, Snapchat)	118	384	180	159	64	59	134	58
Deal out likes or upvotes on Facebook, Instagram, Reddit, etc.	91	364	197	179	64	62	135	64
Commenting on the posts and updates of others	23	149	205	279	108	106	193	93
Program webpages, games, apps, etc.	23	103	83	78	51	72	600	146
Share files such as movies, music and images (e.g. Youtube, Soundcloud, Pinterest)	14	44	61	138	110	130	489	170
Work with video or images (e.g. In Photoshop)	8	41	46	134	130	188	519	90
Write status updates	10	32	54	175	164	255	367	99
Contribute to a fashion blog, a Minecraft server, film projects etc.	10	23	23	72	56	122	638	212
Change app settings (e.g. Security or layout)	5	20	43	138	146	213	264	327
Participate in hacking, remixing, pirating, etc.	5	16	10	23	25	64	930	83
Write on wikis, blogs, own webpage, etc.	2	16	11	32	38	43	889	125
Share files on your own server (e.g. FTP) or P2P network (e.g. Bittorrent)	4	9	10	14	17	36	759	307
Participate on forums, IRCs or mailing lists	5	5	6	26	21	47	772	274

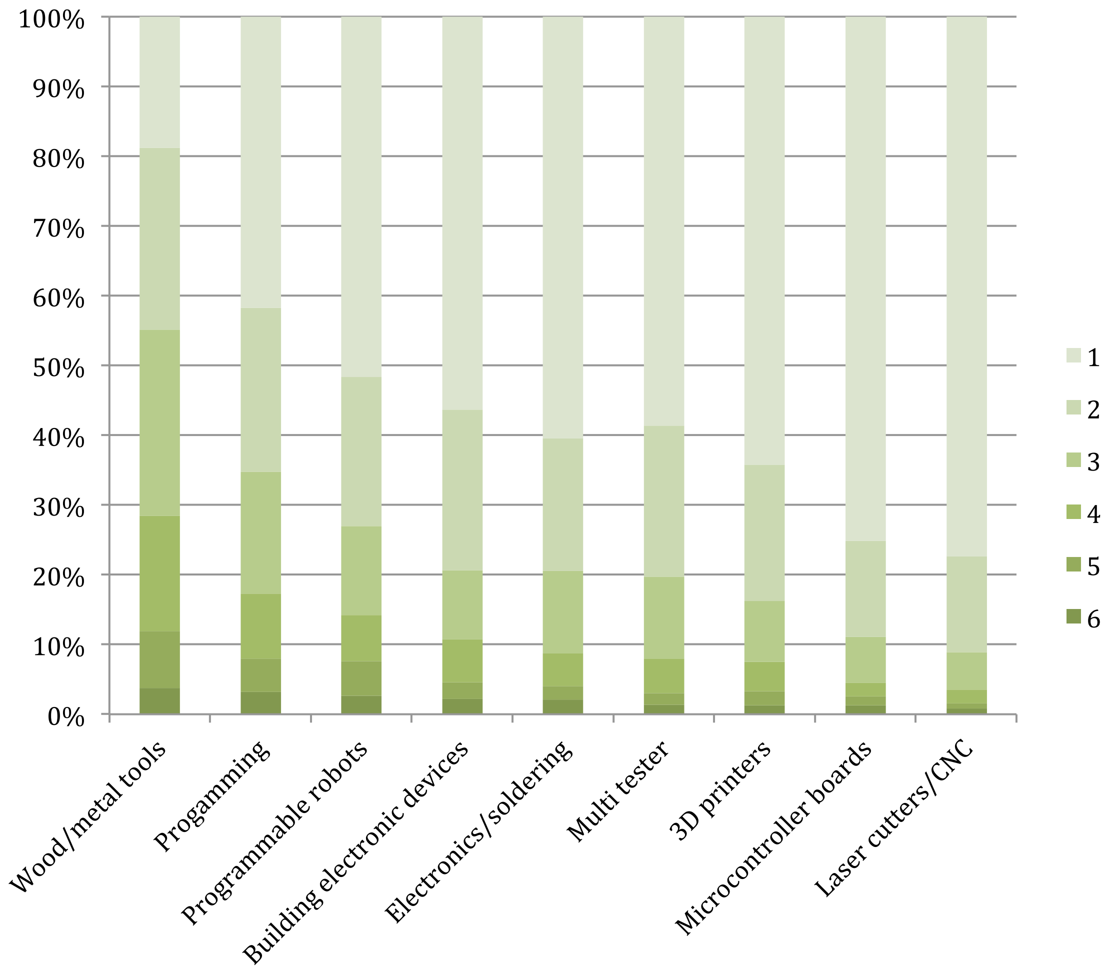

How often do you do the following?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Computer/Tablet
Gaming
Surfing
Sending txt/pics/vids
Liking/Upvoting
Commenting
Don't know
Never
Less than once per month
At least once per month
At least once per week
At least once per day
Several times a day
At least once per hour


How often do you do the following?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Programming
Sharing flix/music/pics
Video-/image editing
Status updates
Contributing
Change settings
Hacking/Pirating
Wiki/Blogging
Own server
Forum/IRC
Don't know
Never
Less than once per month
At least once per month
At least once per week
At least once per day
Several times a day
At least once per hour

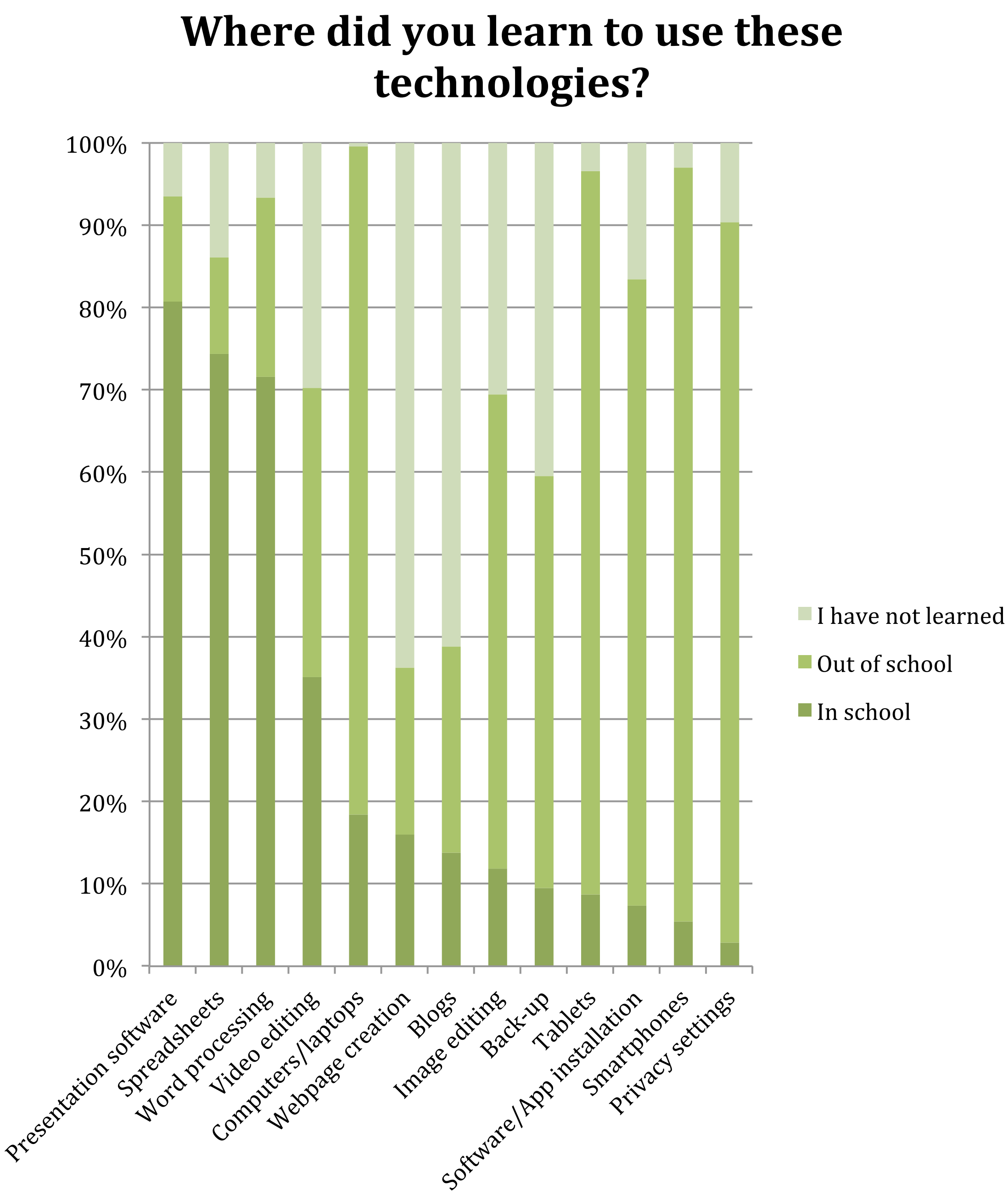
How familiar would you say you are with the following technologies? Please rate yourself on a scale from 1 to 6, where 1 is "I know nothing about it" and 6 is "I could teach other people about it"						
	1	**2**	**3**	**4**	**5**	**6**
Smartphones	29	64	156	311	347	249
Tablets	39	83	194	304	333	203
Computers/laptops	14	82	267	363	257	173
Changing privacy settings on e.g. Facebook, Gmail, Instagram	101	106	176	266	278	229
Presentation software (e.g. Powerpoint, Prezi)	72	122	256	366	229	111
Software or App installation	106	195	224	250	193	188
Word processing (e.g. Word, Google Docs)	85	141	281	368	198	83
Image editing	232	266	260	195	123	80
Spreadsheets (e.g. Excel, Google Sheets)	206	268	306	240	95	41
Production or editing digital movies/videos	241	294	244	190	123	64
Back-up of documents, contacts, mails, etc.	324	269	241	178	87	57
Blogs	423	350	230	89	42	22
Webpage creation	616	243	144	83	44	26
Working with wood/metal tools	217	302	308	191	95	43
Programming (e.g. Coding of apps)	483	271	203	107	55	37
Building programmable robots (e.g. Lego Mindstorms)	597	247	148	76	57	31
Building electronic devices or simple machines from scratch	651	266	115	71	28	25
Electronics and soldering (e.g. LEDs and resistors)	699	219	137	54	23	24
Multi tester (Volt- or Ohmmeter)	678	250	136	57	19	16
3D printers	742	226	101	49	23	15
Microcontroller boards (e.g. MakeyMakey and Arduino)	869	159	76	22	15	15
Laser cutters and CNC routers	894	159	63	22	9	9


How familiar would you say you are with the following technologies?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Smartphones
Tablets
Computers/laptops
Privacy settings
Presentation software
Software/App installation
Word processing
Image editing
Spreadsheets
Video editing
Back-up
Blogs
Webpage creation
1
2
3
4
5
6

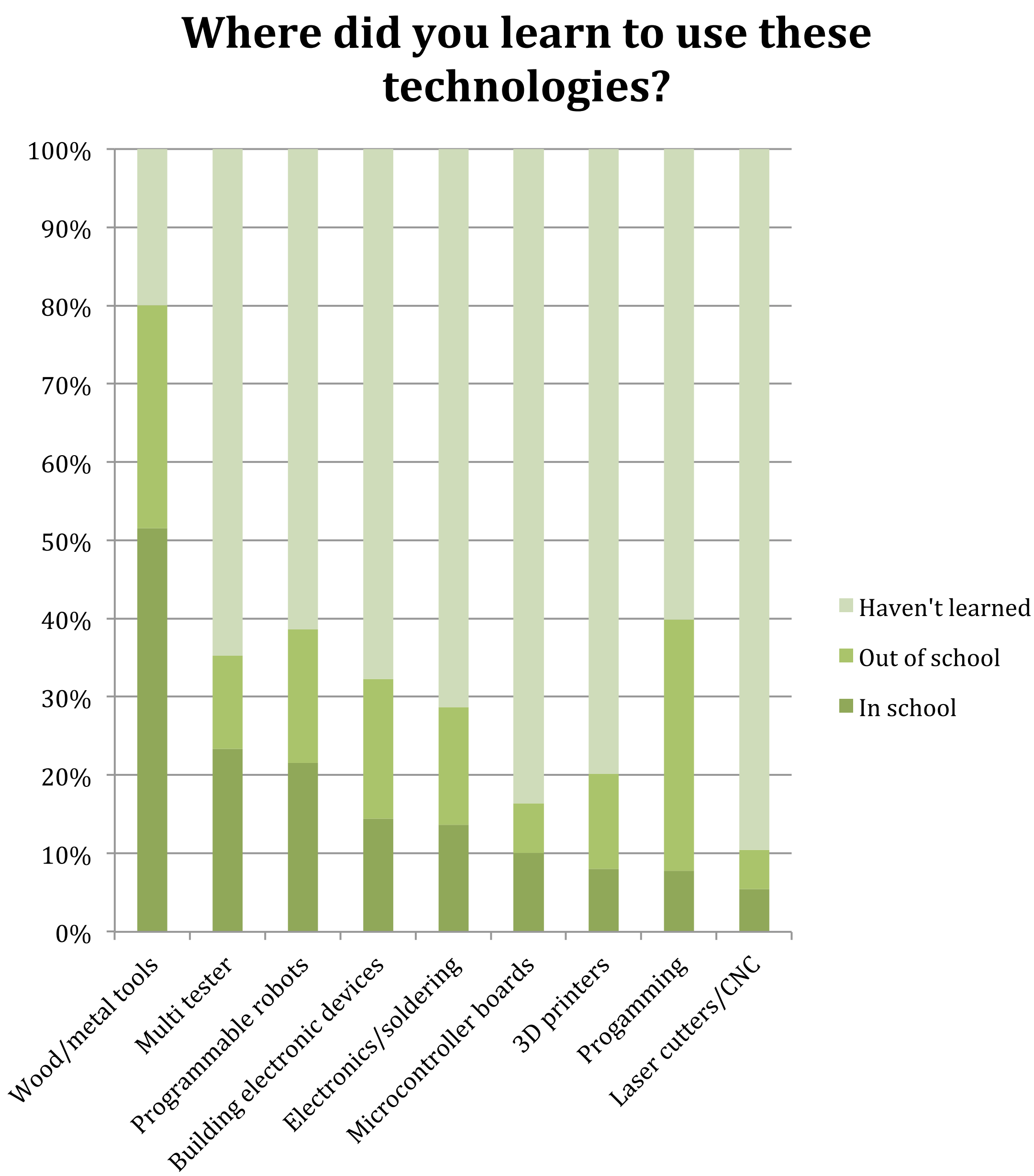
How familiar would you say you are with the following technologies?



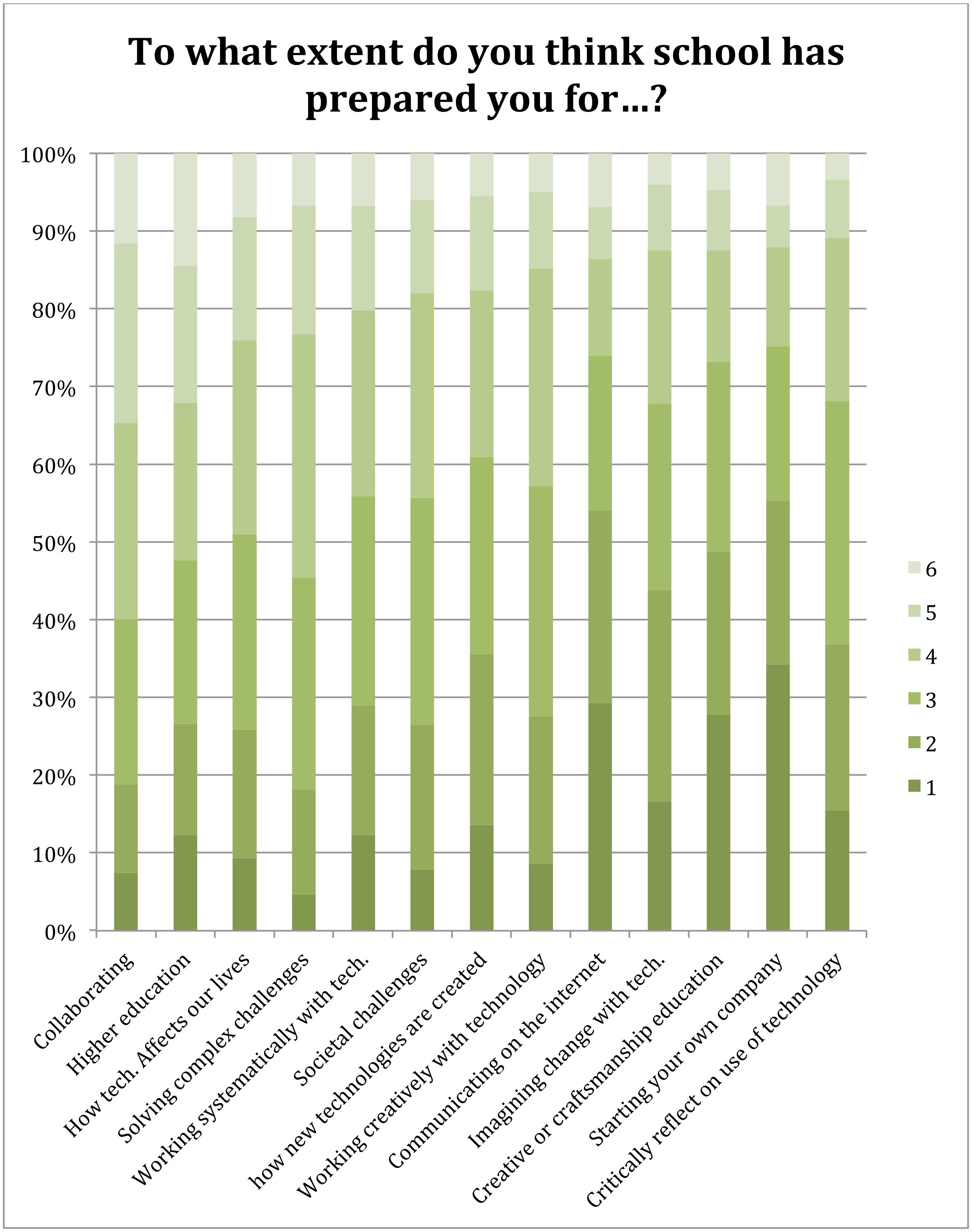
Where did you learn to use these technologies?	In school	Outside of school	I have not learned to use it
Presentation software (e.g. Powerpoint, Prezi)	933	148	75
Spreadsheets (e.g. Excel, Google Sheets)	860	135	161
Word processing (e.g. Word, Google Docs)	828	251	77
Production or editing digital movies/videos	406	406	344
Computers/laptops	213	938	5
Webpage creation	185	234	737
Blogs	159	290	707
Image editing	137	666	353
Back-up of documents, contacts, mails, etc.	110	578	468
Tablets	101	1015	40
Software or App installation	85	880	191
Smartphones	63	1058	35
Changing privacy settings on e.g. Facebook, Gmail, Instagram	33	1012	111
Working with wood/metal tools	596	329	231
Multi tester (Volt- or Ohmmeter)	270	138	748
Building programmable robots (e.g. Lego Mindstorms)	249	198	709
Building electronic devices or simple machines from scratch	167	206	783
Electronics and soldering (e.g. LEDs and resistors)	158	174	824
Microcontroller boards (e.g. MakeyMakey and Arduino)	116	74	966
3D printers	93	140	923
Programming (e.g. Coding of apps)	90	371	695
Laser cutters and CNC routers	63	58	1035



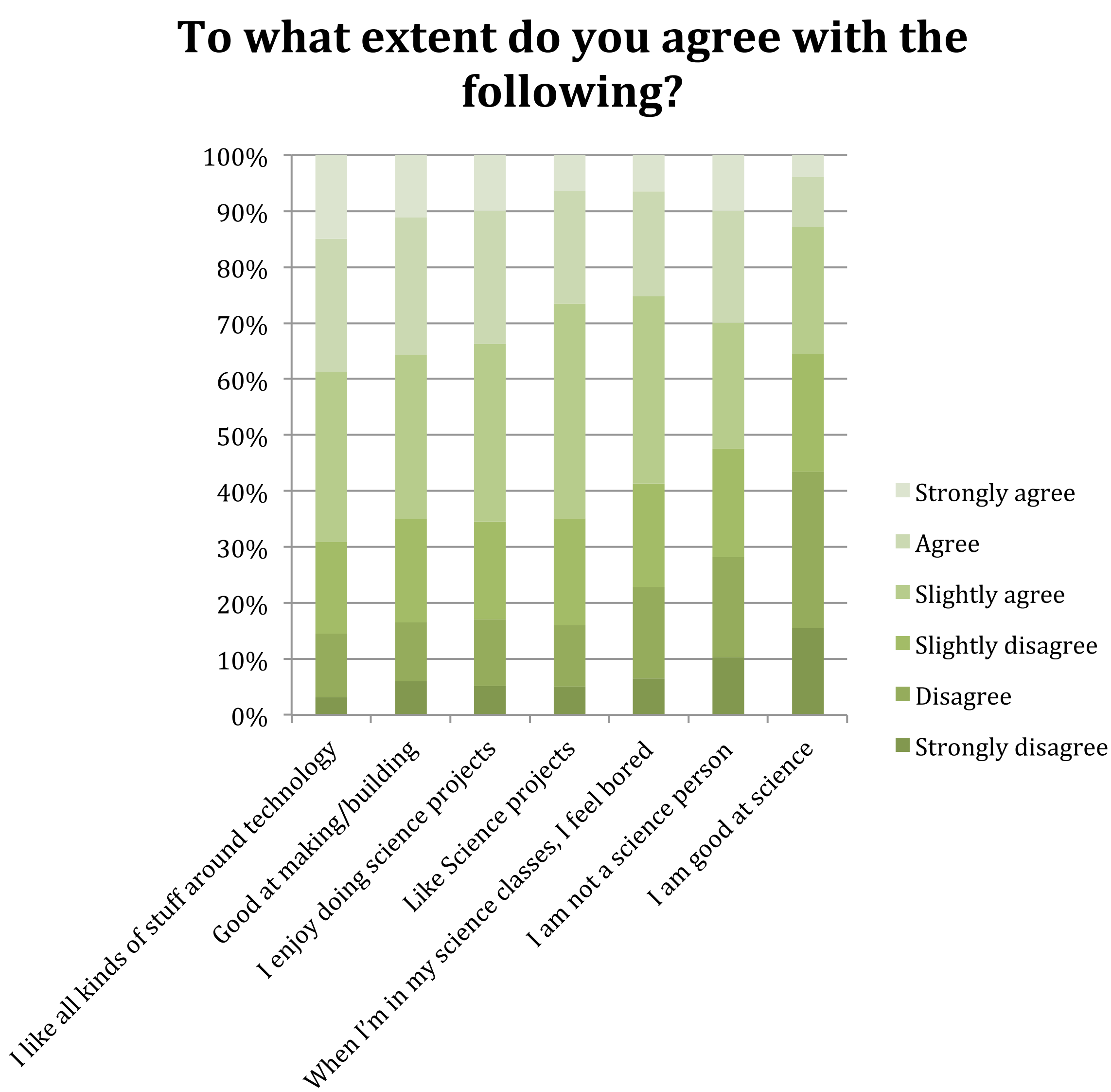
Where did you learn to use these technologies?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Presentation software
Spreadsheets
Word processing
Video editing
Computers/laptops
Webpage creation
Blogs
Image editing
Back-up
Tablets
Software/App installation
Smartphones
Privacy settings
I have not learned
Out of school
In school


Where did you learn to use these technologies?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Haven't learned
Out of school
In school
Wood/metal tools
Multi tester
Programmable robots
Building electronic devices
Electronics/soldering
Microcontroller boards
3D printers
Progamming
Laser cutters/CNC

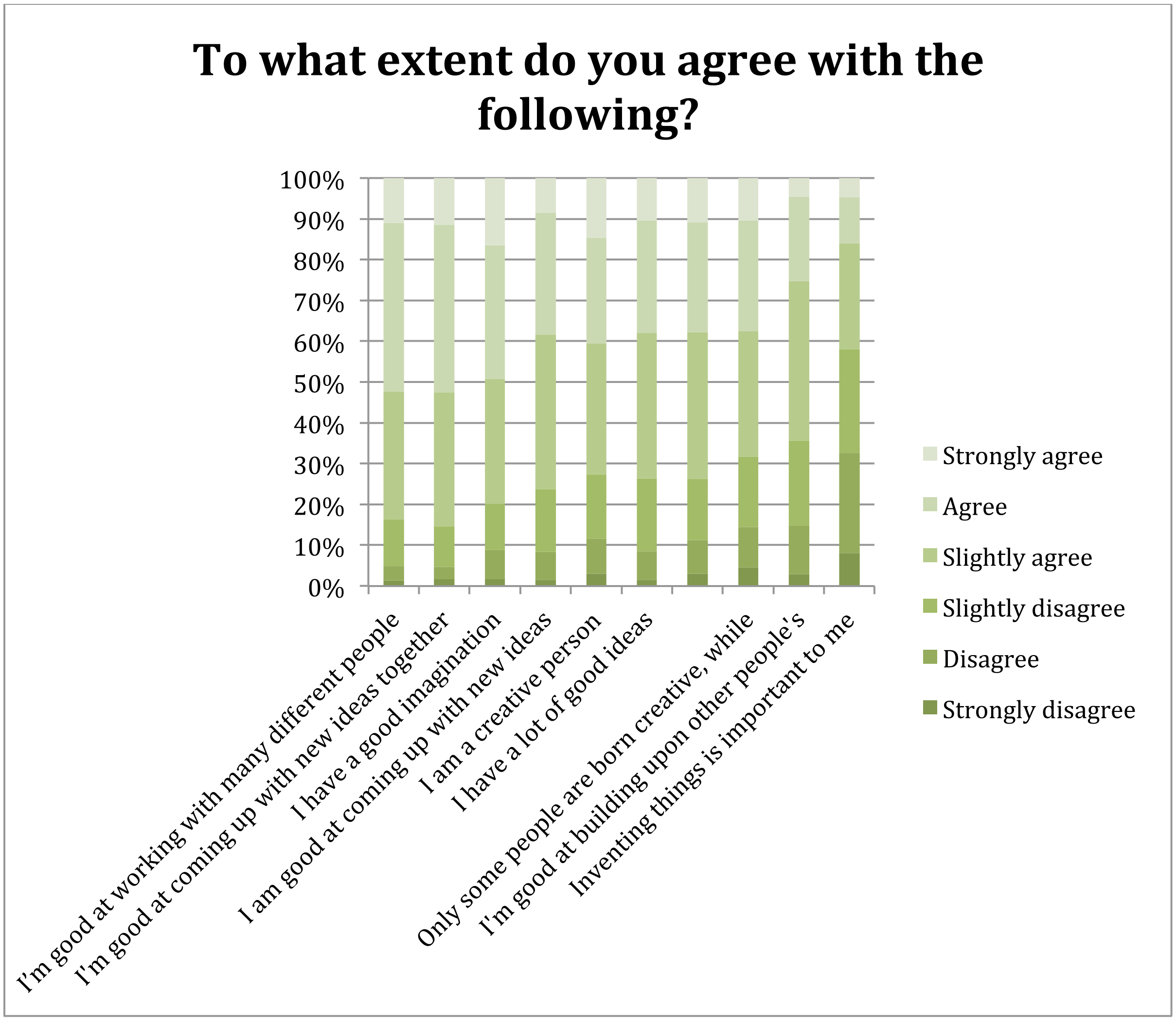
To what extent do you think school has prepared you for...?	1 (Not at all)	2	3	4	5	6 (To a large extent)
Collaborating in heterogeneous groups	86	132	245	292	267	134
Getting a degree in higher education	142	166	243	234	204	167
Learning how technology affects our lives	108	191	291	288	183	95
Learning to solve difficult or complex challenges	54	156	315	362	192	77
Using technology to work systematically with tasks (in e.g. Physics/Chemistry, Science/Technology)	142	193	311	277	155	78
Learning to relate to societal challenges	91	215	338	304	139	69
Learning how novel ideas, things and technologies are created	157	254	293	248	140	64
Working creatively with technology	99	220	342	324	114	57
Communicating with different people on the internet	338	287	230	144	77	80
Imagining how you change things, e.g. with technology	192	315	277	228	98	46
Getting a creative or craftsmanship education	321	243	282	166	90	54
Starting your own company	396	243	230	148	62	77
Critically reflect on own and others' use of technology	179	247	361	243	87	39


To what extent do you think school has prepared you for…?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Collaborating
Higher education
How tech. Affects our lives
Solving complex challenges
Working systematically with tech.
Societal challenges
how new technologies are created
Working creatively with technology
Communicating on the internet
Imagining change with tech.
Creative or craftsmanship education
Starting your own company
Critically reflect on use of technology
6
5
4
3
2
1

To what extent do you agree with the following?	Strongly disagree	Dis-agree	Slightly disagree	Slightly agree	Agree	Strongly agree
I like all kinds of stuff around technology	37	131	189	351	276	172
Good at making/building	70	121	214	338	284	129
I enjoy doing science projects	60	138	201	367	276	114
Like Science projects	59	127	220	444	233	73
When I'm in my science classes, I feel bored	75	189	214	387	216	75
I am not a science person	119	207	224	260	232	114
I am good at science	179	323	244	262	103	45

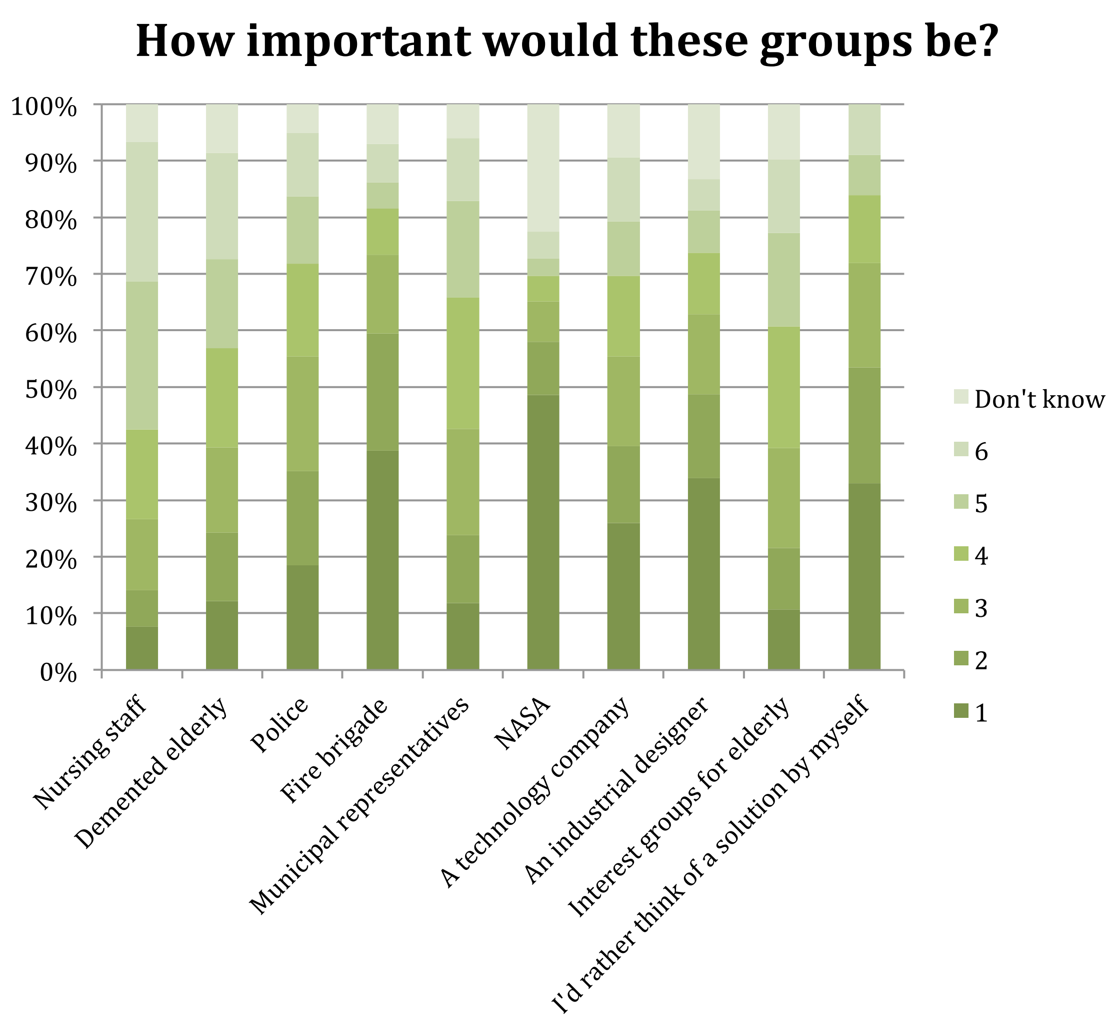


To what extent do you agree with the following?						
	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
I'm good at working with many different people in the groups	16	41	132	362	478	127
I'm good at coming up with new ideas together with my peers	19	36	114	379	475	133
I have a good imagination	20	82	131	353	380	190
I am good at coming up with new ideas	17	79	178	438	346	98
I am a creative person	36	98	182	371	299	170
I have a lot of good ideas	18	80	206	414	319	119
I am interested in the things we do in the creative crafts and arts	35	96	172	416	312	125
Only some people are born creative, while others never learn it	52	115	200	355	314	120
I'm good at building upon other people's thoughts and ideas	33	137	242	451	240	53
Inventing things is important to me	93	284	295	299	131	54

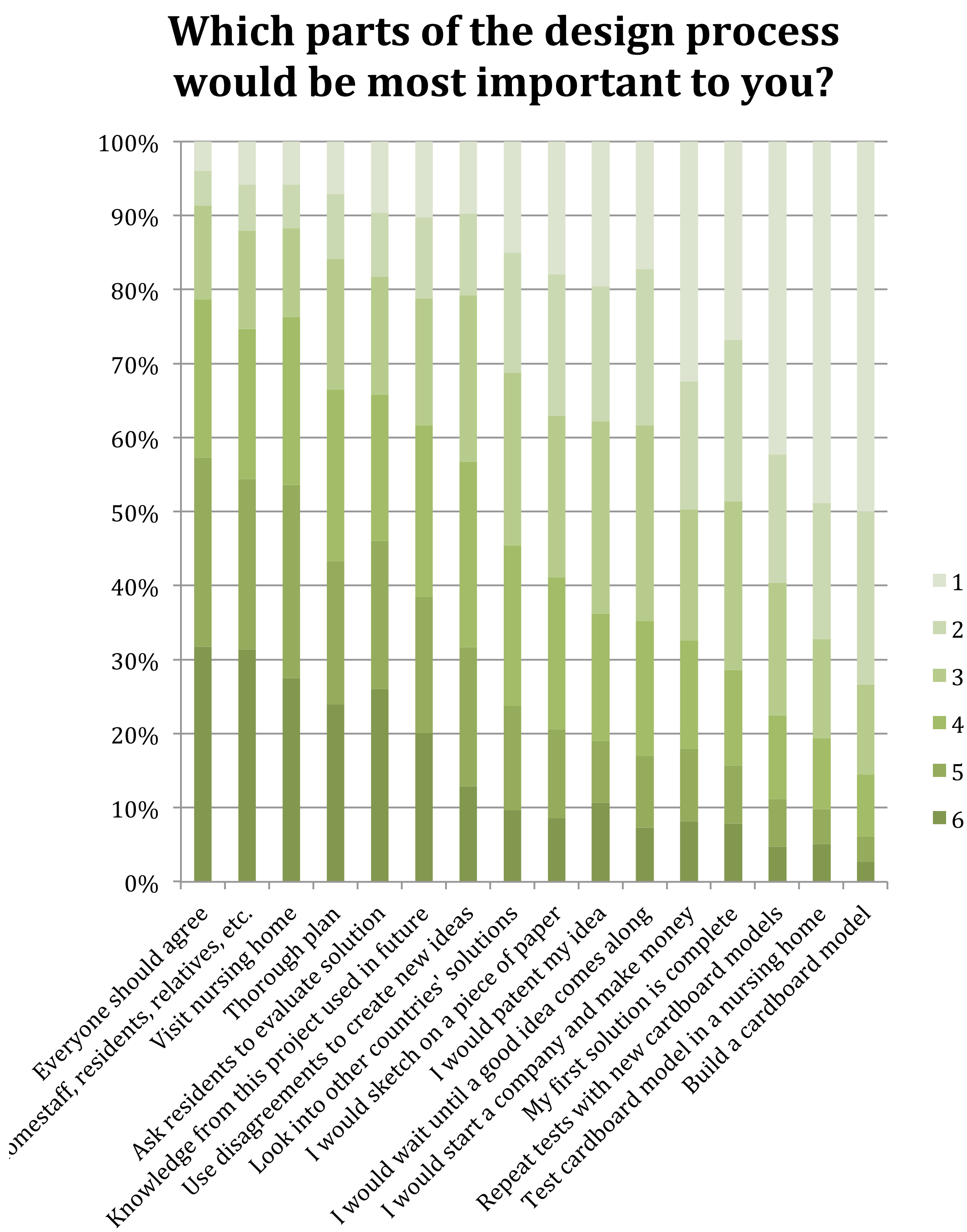


To what extent do you agree with the following?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
I'm good at working with many different people
I'm good at coming up with new ideas together
I have a good imagination
I am good at coming up with new ideas
I am a creative person
I have a lot of good ideas
Only some people are born creative, while
I'm good at building upon other people's
Inventing things is important to me
Strongly agree
Agree
Slightly agree
Slightly disagree
Disagree
Strongly disagree

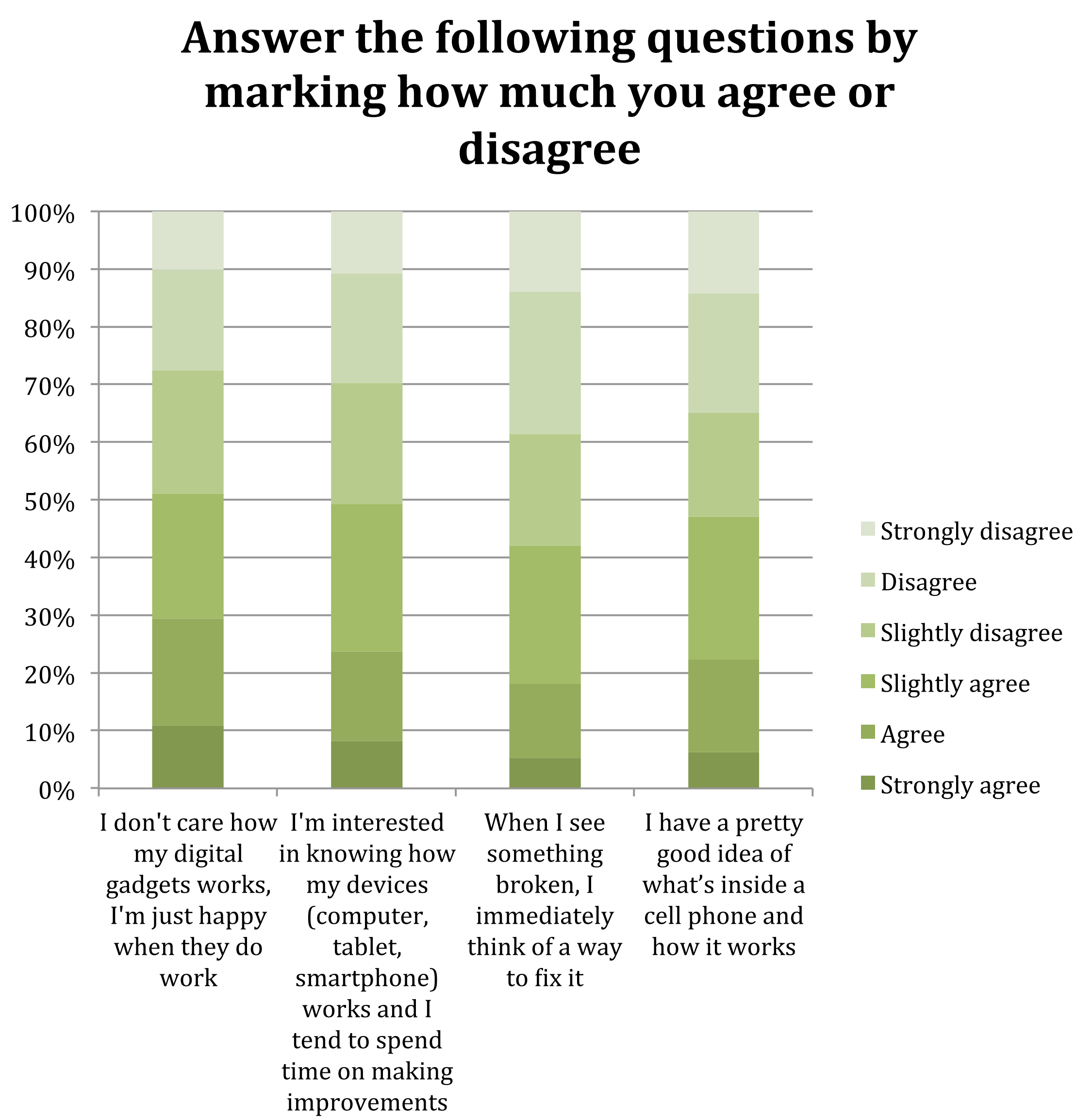
If you were to find a solution in collaboration with others, how important would these people or groups be on a scale of 1-6 (1 = not important, 6 = very important)?							
	1	**2**	**3**	**4**	**5**	**6**	**Don't know**
Nursing staff	88	75	145	184	301	286	77
Demented elderly	141	140	174	203	182	217	99
Police	214	192	235	189	138	129	59
Fire brigade	448	239	161	95	54	78	81
Municipal representatives	137	138	218	268	198	128	69
NASA	562	108	83	52	36	55	260
A technology company	300	158	183	165	110	131	109
An industrial designer	392	172	163	125	87	64	153
Interest groups for elderly	124	126	204	248	191	151	112
I'd rather think of a solution by myself	381	237	214	138	82	104	0



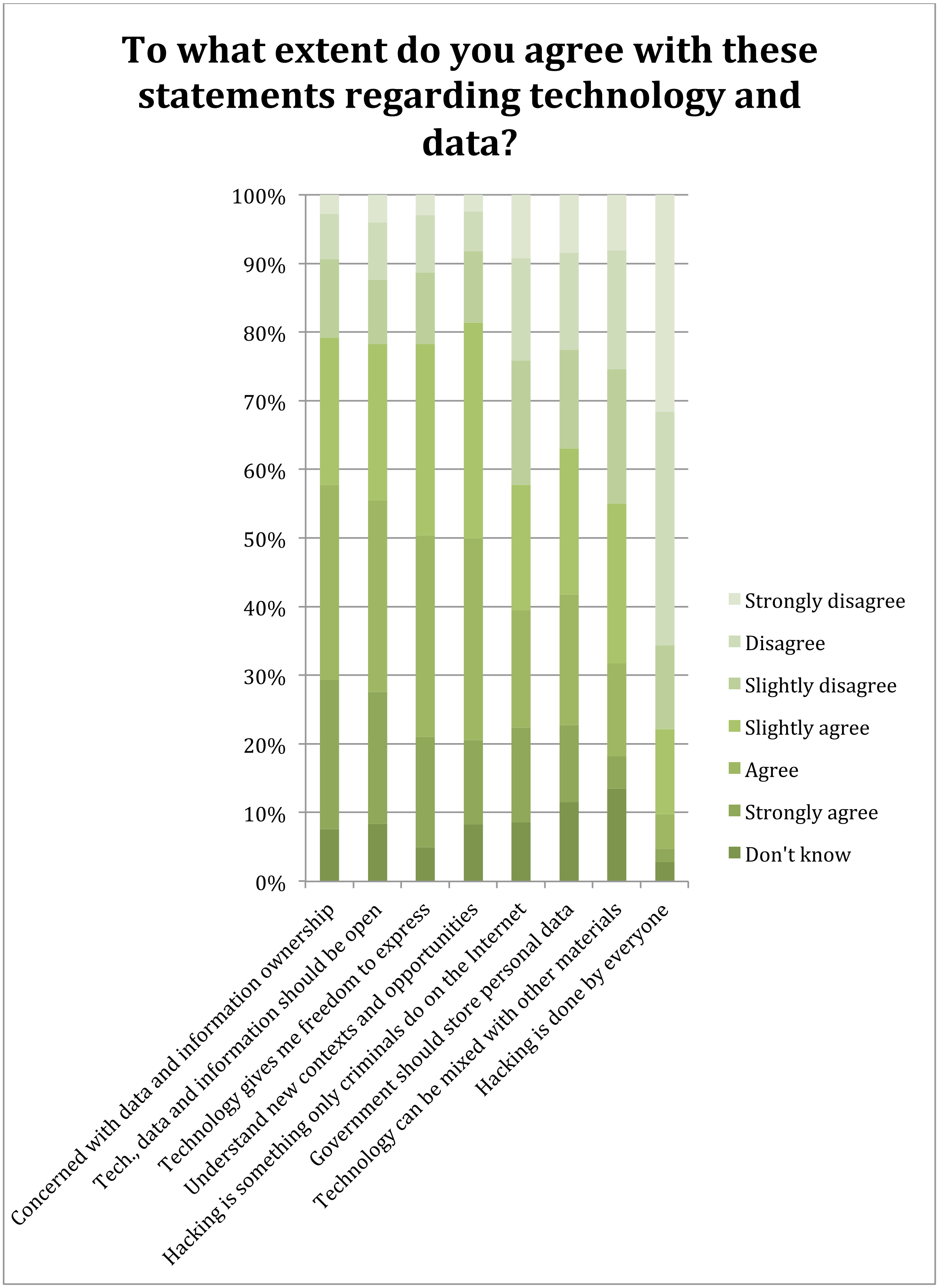
How would you come up with the right solution? Which parts of the design process would be most important to you? (1 = not important at all, 6 = important).						
	1	**2**	**3**	**4**	**5**	**6**
I would make sure that everyone agrees on the final solution	45	55	146	247	296	367
I would have a meeting with nursing homestaff, its residents, relatives and others interesting partners to discuss my solution	67	72	154	234	266	363
I would visit a nursing home to further explore the issue	67	68	139	262	302	318
I would do a thorough plan for the entire project	82	102	203	268	224	277
I would ask residents in the nursing home what they think of my solution	111	100	184	228	232	301
I would consider how the knowledge gained from this project can be used in future projects	118	127	198	268	212	233
I would use disagreements between individuals and groups to create new ideas and solutions	113	127	260	290	217	149
I would figure out how people tackle the problem in other countries	174	187	270	250	163	112
I would outline possible solutions on a piece of paper	207	221	253	237	139	99
I would patent my idea	226	211	300	199	96	124
I would wait until a good idea comes along	199	244	306	211	111	85
I would start a company to market my solution and make money	374	200	205	169	113	95
As soon as my first solution is complete, I would stop working on the problem	310	252	263	149	91	91
I would repeat my tests with a new sketch or cardboard model several times over	489	200	207	131	74	55
I would test my cardboard model in a nursing home	564	213	154	111	55	59
I would build my idea in cardboard	578	270	141	96	40	31


Which parts of the design process would be most important to you?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
Everyone should agree
omestaff, residents, relatives, etc.
Visit nursing home
Thorough plan
Ask residents to evaluate solution
Knowledge from this project used in future
Use disagreements to create new ideas
Look into other countries' solutions
I would sketch on a piece of paper
I would patent my idea
I would wait until a good idea comes along
I would start a company and make money
My first solution is complete
Repeat tests with new cardboard models
Test cardboard model in a nursing home
Build a cardboard model

Answer the following questions by marking how much you agree or disagree	Strongly dis-agree	Dis-agree	Slightly dis-agree	Slightly agree	Agree	Strongly agree
I don't care how my digital gadgets works, I'm just happy when they do work	117	202	246	251	214	126
I'm interested in knowing how my devices (computer, tablet, smartphone) works and I tend to spend time on making improvements	124	220	242	296	179	95
When I see something broken, I immediately think of a way to fix it	161	285	224	276	149	61
I have a pretty good idea of what's inside a cell phone and how it works	164	239	208	287	186	72



To what extent do you agree with these statements regarding technology and data?	Strongly dis-agree	Dis-agree	Slightly dis-agree	Slightly agree	Agree	Strongly agree	Don't know
I'm concerned with data and information ownership on my data such as pictures, video and music etc..	32	76	133	247	329	251	88
Technology, digital data and information should be open and accessible for all	46	97	108	263	323	222	97
Technology gives me the freedom to express my interests and goals	34	97	120	323	339	185	58
Technology allows me to understand new contexts and opportunities	28	67	120	364	339	142	96
Hacking of technology, data and information is something only criminals do on the Internet	106	173	209	211	198	160	99
The government should collect, store and protect personal data and information	98	163	166	246	220	130	133
I use technology and data on the same footing as wood, paper and soft fabrics	93	201	226	269	156	55	156
Hacking is done by everyone	365	393	142	143	58	22	33



To what extent do you agree with these statements regarding technology and data?
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Strongly disagree
Disagree
Slightly disagree
Slightly agree
Agree
Strongly agree
Don't know
Concerned with data and information ownership
Tech, data and information should be open
Technology gives me freedom to express
Understand new contexts and opportunities
Hacking is something only criminals do on the Internet
Government should store personal data
Technology can be mixed with other materials
Hacking is done by everyone

What kind of parts do you think are inside of this key-fob? For each part, write 1 for "Yes" or 0 for "No", AND write a number from 1 to 10 to show how sure you are. (1 = you're not sure at all, 10 = you're really sure)			
	Yes	**No**	**Level of confidence**
Motor	101	1047	7,6
Temperature sensor	139	1009	6,7
Gear	80	1068	7,4
Batteries	941	207	7,3
LEDs	545	603	5,2
Microcontroller	801	347	5,5
Light bulb	300	848	6,1
Screws	763	385	6,4
Light sensor	359	789	5,6
Antenna	439	709	6,3
Laser	275	873	6,2
Mechanical switches	692	456	7,2
Transistor	370	778	4,5
Microphone	54	1094	7,3

Appendix III: The questionnaire

In the following pages is a print out of the original questionnaire. It is included in the original wordings (in Danish)

Teknologi i skole og fritid

Velkommen til Aarhus Universitets spørgeskema om dig og dit forhold til teknologi i skole og fritid.

Personlig information

Vi vil først gerne vide noget om dig og din skole

Hvad er dit UNI-login (brugernavn)? ____________________

Hvor gammel er du? ____________________

Hvad hedder din skole? ____________________

Hvilket køn er du?

- ☐ Dreng
- ☐ Pige

Hvilket klassetrin går du på?

- ☐ 6.
- ☐ 7.
- ☐ 8.
- ☐ 9.
- ☐ 10.

Hvor mange bøger er der ca. i dit hjem?

(du skal ikke tælle blade, aviser eller dine skolebøger med)

- ☐ 0-25 bøger
- ☐ 10-25 bøger
- ☐ 25-100 bøger
- ☐ 100-200 bøger
- ☐ Over 200 bøger

Skole og fritid

I løbet af den sidste uge, hvor mange timer brugte du på...

	0-2 timer pr. uge	2-5 timer pr. uge	5-10 timer pr. uge	Over 10 timer pr. uge
Lektier derhjemme	☐	☐	☐	☐
Passe dine søskende, familiens kæledyr osv.	☐	☐	☐	☐
Hjælpe til i hjemmet (rengøring, madlavning osv.)	☐	☐	☐	☐

Arbejde på gør-det-selv byggeprojekter	☐	☐	☐	☐
Reparation af f.eks. møbler, cykler eller elektriske apparater i dit hjem	☐	☐	☐	☐
At arbejde kreativt med f.eks. træ, maling eller stof.	☐	☐	☐	☐
Fritidsjob (med løn)	☐	☐	☐	☐
Være på computer, TV, mobil osv.	☐	☐	☐	☐
Sportsaktiviteter	☐	☐	☐	☐
At synge, spille et instrument eller i band	☐	☐	☐	☐
At være sammen med dine venner (fysisk/online)	☐	☐	☐	☐
Frivilligt arbejde (f.eks. foreningsarbejde)	☐	☐	☐	☐
At være i naturen	☐	☐	☐	☐

Her spørger vi dig om dit forhold til skolen og din fremtid.
Hvor enig er du?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Jeg klarer generelt mig godt i livet	☐	☐	☐	☐	☐	☐
Jeg stoler på mine egne faglige evner	☐	☐	☐	☐	☐	☐
Jeg klarer mig godt i skolen	☐	☐	☐	☐	☐	☐
Jeg lærer hurtigt nye ting	☐	☐	☐	☐	☐	☐
Jeg vil have en fremtid indenfor et kreativt fag (f.eks. håndværk, film eller musik)	☐	☐	☐	☐	☐	☐
Jeg vil have en fremtid indenfor teknologi og design	☐	☐	☐	☐	☐	☐
Jeg vil have en fremtid som ingeniør eller indenfor naturvidenskab	☐	☐	☐	☐	☐	☐
Jeg vil starte min egen virksomhed	☐	☐	☐	☐	☐	☐

Teknologi i hverdagen

Her spørger vi om din brug af teknologi og deltagelse i online fællesskaber.
Hvor ofte gør du følgende?

	Hvor ofte?							
	Min. hver time	Flere gange om dagen	Min. en gang om dagen	Min. en gang om ugen	Min. en gang om måneden	Højst en gang om måneden	Aldrig	Ved ikke
Bruger computer eller tablet derhjemme	☐	☐	☐	☐	☐	☐	☐	☐
Spiller computer-, mobil- eller videospil	☐	☐	☐	☐	☐	☐	☐	☐
Surfer eller ser video på Internettet	☐	☐	☐	☐	☐	☐	☐	☐
Uddeler f.eks. likes eller upvotes på Facebook, Instragram, Reddit, osv.	☐	☐	☐	☐	☐	☐	☐	☐
Kommenterer andres posts og opdateringer	☐	☐	☐	☐	☐	☐	☐	☐
Skriver statusopdateringer	☐	☐	☐	☐	☐	☐	☐	☐
Kommunikerer med billeder, video og tekst (f.eks. Facebook, Instagram, Snapchat)	☐	☐	☐	☐	☐	☐	☐	☐
Deler filer som film, musik og billeder (f.eks. YouTube, Soundcloud, Pinterest)	☐	☐	☐	☐	☐	☐	☐	☐
Ændre app indstillinger (f.eks. sikkerhed eller layout)	☐	☐	☐	☐	☐	☐	☐	☐
Skriver på Wikis, blogs, egen hjemmeside, osv.	☐	☐	☐	☐	☐	☐	☐	☐
Arbejder med video eller billeder (f.eks. i Photoshop)	☐	☐	☐	☐	☐	☐	☐	☐
Deltager på forum, IRC kanaler eller mailing lister	☐	☐	☐	☐	☐	☐	☐	☐

Deltager i hacking, tilpasning, piratkopiering, osv.	☐	☐	☐	☐	☐	☐	☐	☐
Programmerer hjemmesider, spil, apps, osv.	☐	☐	☐	☐	☐	☐	☐	☐
Deler filer på egen server (f.eks. FTP) eller P2P netværk (f.eks. Bittorrent)	☐	☐	☐	☐	☐	☐	☐	☐
Bidrager til en modeblog, en Minecraft server, filmprojekter, osv.	☐	☐	☐	☐	☐	☐	☐	☐

Teknologi i skolen

Hvad du ved om teknologi og hvordan du bruger den i skolen?
Skriv kort om din bedste oplevelse med teknologi i skolen. Skriv hvad og hvorfor det var spændende.

Hvor godt kender du disse teknologier?
Bedøm dig selv på en skala fra 1 til 6, hvor 1 er "*Det ved jeg ikke noget om*" og 6 er "*Jeg kunne undervise andre om det.*"

	1	2	3	4	5	6
Computer / bærbar	☐	☐	☐	☐	☐	☐
Smartphones	☐	☐	☐	☐	☐	☐
Tablets eller iPads	☐	☐	☐	☐	☐	☐
Blogs	☐	☐	☐	☐	☐	☐
Tekstbehandling (f.eks. Word, Google Docs)	☐	☐	☐	☐	☐	☐
Regneark (f.eks. Excel, Google Spreadsheets)	☐	☐	☐	☐	☐	☐
Præsentationsprogrammer (f.eks. Powerpoint, Prezi)	☐	☐	☐	☐	☐	☐
Produktion eller redigering af digitale film/videoer	☐	☐	☐	☐	☐	☐
Lave en hjemmeside	☐	☐	☐	☐	☐	☐
Redigering af digitale billeder	☐	☐	☐	☐	☐	☐
Installation af software eller apps	☐	☐	☐	☐	☐	☐
Back-up af dokumenter, kontakter, mails, osv.	☐	☐	☐	☐	☐	☐
Ændring af privatindstillinger på f.eks. Facebook, Gmail, Instagram	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

Hvor godt kender du disse teknologier?

	1	2	3	4	5	6
Programmering (f.eks. kodning af apps)	☐	☐	☐	☐	☐	☐
Bygge elektroniske dimser eller simple maskiner fra bunden	☐	☐	☐	☐	☐	☐
Bygge programmérbare robotter (f.eks. Lego Mindstorms)	☐	☐	☐	☐	☐	☐
Arbejde med træ- og metalværktøj	☐	☐	☐	☐	☐	☐
Lasercutters eller CNC fræsere	☐	☐	☐	☐	☐	☐
3D-printere	☐	☐	☐	☐	☐	☐
Elektronik og lodning (f.eks. dioder og modstande)	☐	☐	☐	☐	☐	☐
Microcontroller boards (f.eks. MakeyMakey og Arduino)	☐	☐	☐	☐	☐	☐
Multimeter (f.eks. volt eller ohm måler)	☐	☐	☐	☐	☐	☐

Hvor har du lært at bruge disse teknologier?

	Primært i skolen	Primært hjemme	Har ikke lært det
Computer / bærbar	☐	☐	☐
Smartphones	☐	☐	☐
Tablets eller iPads	☐	☐	☐
Blogs	☐	☐	☐
Tekstbehandling (f.eks. Word, Google Docs)	☐	☐	☐
Regneark (f.eks. Excel, Google Spreadsheets)	☐	☐	☐
Præsentationsprogrammer (f.eks. Powerpoint, Prezi)	☐	☐	☐
Produktion eller redigering af digitale film/videoer	☐	☐	☐
Lave en hjemmeside	☐	☐	☐
Redigering af digitale billeder	☐	☐	☐
Installation af software eller apps	☐	☐	☐
Back-up af dokumenter, kontakter, mails osv.	☐	☐	☐
Ændring af private indstillinger på f.eks. Facebook, Gmail, Instagram	☐	☐	☐

Hvor har du lært at bruge disse teknologier?

	Primært i skolen	Primært hjemme	Har ikke lært det
Programmering (f.eks. kodning af apps)	☐	☐	☐
Bygge elektroniske dimser eller simple maskiner fra bunden	☐	☐	☐
Bygge programmérbare robotter (f.eks. Lego Mindstorms)	☐	☐	☐
Arbejde med træ- og metalværktøj	☐	☐	☐
Lasercutters eller CNC fræsere	☐	☐	☐
3D-printere	☐	☐	☐
Elektronik og lodning (f.eks. dioder og modstande)	☐	☐	☐
Microcontroller boards (f.eks. MakeyMakey og Arduino)	☐	☐	☐
Multimeter (f.eks. volt eller ohm måler)	☐	☐	☐

Har du nogensinde arbejdet med digital fabrikationsteknologi på din skole f.eks. i et FabLab eller værksted?

Digital fabrikationsteknologi er f.eks. MakeyMakey, loddekoble eller 3D printer

☐ Ja
☐ Nej
☐ Ved ikke

Beskriv kort, hvad du har lavet, hvilken teknologi brugte du og til hvad?

1. projekt

2. projekt

Hvordan var det at arbejde med digital fabrikation i skolen/FabLab?

	Meget uenig	Uenig	Hverken enig/uenig	Enig	Meget enig
Jeg kedede mig	☐	☐	☐	☐	☐
Jeg kan godt lide at være i værkstedet/FabLab	☐	☐	☐	☐	☐
Undervisningen er interessant	☐	☐	☐	☐	☐
Undervisningen er spild af min tid	☐	☐	☐	☐	☐
Jeg vil gerne bruge teknologierne til mine egne projekter udenfor skolen	☐	☐	☐	☐	☐
Det, vi lærer i værkstedet/FabLab, kan jeg bruge i fremtiden	☐	☐	☐	☐	☐
Jeg elsker at arbejde på digital fabrikations projekter	☐	☐	☐	☐	☐
Jeg lærer meget i værkstedet/FabLab	☐	☐	☐	☐	☐
Jeg tænker på det, vi har lært, når jeg er derhjemme	☐	☐	☐	☐	☐

Har du nogensinde modtaget undervisning i elektronik, robot-teknologi eller programmering uden for skolen - f.eks. på en workshop eller sommerlejr?

☐ Ja
☐ Nej
☐ Ved ikke

Skriv navnet på begivenheden, og hvor lang tid den varede (f.eks. 5 dage):

Beskriv kort hvad du lavede til begivenheden

I hvor høj grad synes du at *skolen* har hjulpet dig til ...

Bedøm på en skala fra 1 til 6, hvor 1 er "*Slet ikke*" og 6 er *"I høj grad*".

	1	2	3	4	5	6
At arbejde kreativt med teknologi	❑	❑	❑	❑	❑	❑
At lære at løse svære eller komplekse udfordringer	❑	❑	❑	❑	❑	❑
At lære at forholde dig til samfundsmæssige problemer	❑	❑	❑	❑	❑	❑
At forestille dig, hvordan du kan forandre ting, f.eks. med teknologi	❑	❑	❑	❑	❑	❑
At samarbejde med mennesker med forskellig baggrund og evner	❑	❑	❑	❑	❑	❑
At lære hvordan teknologi påvirker den måde, vi lever på	❑	❑	❑	❑	❑	❑
At lære hvordan nye ideer, ting og teknologier bliver skabt	❑	❑	❑	❑	❑	❑

...forsat fra sidste side

I hvor høj grad synes du at *skolen* har hjulpet dig til ...

	1	2	3	4	5	6
At forholde dig kritisk til din egen og andres brug af teknologi	❑	❑	❑	❑	❑	❑
At kommunikere med forskellige mennesker over Internettet	❑	❑	❑	❑	❑	❑
At bruge teknologi til at arbejde systematisk med opgaver (i f.eks. fysik/kemi, natur/teknik)	❑	❑	❑	❑	❑	❑
At ville have en videregående uddannelse	❑	❑	❑	❑	❑	❑
At ville have en kreativ eller håndværksmæssig uddannelse	❑	❑	❑	❑	❑	❑
At ville starte din egen virksomhed	❑	❑	❑	❑	❑	❑

Design og kreativitet

De næste spørgsmål handler om at få nye idéer, arbejde kreativt og skabe nye ting med teknologi.

Hvor enig eller uenig er du i følgende...

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Jeg kan lide alt, der har med teknologi at gøre	❑	❑	❑	❑	❑	❑
Jeg er god til at lave eller bygge ting	❑	❑	❑	❑	❑	❑
Det jeg lærer i natur/teknik eller fysik/kemi interesser mig	❑	❑	❑	❑	❑	❑
Jeg kan godt lide at arbejde på natur/teknik eller fysik/kemi projekter	❑	❑	❑	❑	❑	❑
Jeg keder mig, når vi har natur/teknik eller fysik/kemi	❑	❑	❑	❑	❑	❑
Jeg er ikke en naturfags-person	❑	❑	❑	❑	❑	❑

Jeg er god til natur/teknik eller fysik/kemi ❑ ❑ ❑ ❑ ❑ ❑

Hvor enig eller uenig er du i...

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Jeg er god til at finde på nye idéer	❑	❑	❑	❑	❑	❑
Jeg har en god fantasi	❑	❑	❑	❑	❑	❑
Jeg har en masse gode idéer	❑	❑	❑	❑	❑	❑
Jeg er en kreativ person	❑	❑	❑	❑	❑	❑
Nogle personer er født kreative, mens andre aldrig lærer det	❑	❑	❑	❑	❑	❑
Det jeg lærer i de kreative fag interesser mig	❑	❑	❑	❑	❑	❑
At opfinde ting er vigtigt for mig	❑	❑	❑	❑	❑	❑
Jeg er god til at bygge videre på andres tanker og ideer	❑	❑	❑	❑	❑	❑
Jeg er god til at samarbejde med forskellige mennesker i grupper	❑	❑	❑	❑	❑	❑
Jeg er god til at finde på ideer sammen med andre på min alder	❑	❑	❑	❑	❑	❑

Har du nogensinde haft en idé til et nyt produkt eller opfindelse?

❑ Ja

❑ Nej

Beskriv kort din idé

Har du skabt eller bygget din idé eller opfindelse?

❑ Ja

❑ Nej

Hvorfor ikke?

Hvordan og med hvem?

Designopgave: Plejehjemmets udfordring

I begyndelsen af 2014 forsvandt 9 bedsteforældre fra deres plejehjem pga. hukommelsestab (demens). Plejehjemmets problem er at skabe tryghed for de ældrene uden at tage deres frihed fra dem.

Hvis du blev bedt om at løse dette problem, hvad ville du så gøre?

Hvilke stikord ville du søge med på Internettet, for at få idéer til at løse problemet?

Hvem ville være vigtige for dig at samarbejde med, om at finde en løsning?

Vælg et tal fra 1 til 6 (1 = slet ikke vigtigt , 6 = virkeligt vigtigt)

	1	2	3	4	5	6	Ved ikke
Plejehjemspersonale	❑	❑	❑	❑	❑	❑	❑
Andre ældre med demens	❑	❑	❑	❑	❑	❑	❑
Politiet	❑	❑	❑	❑	❑	❑	❑
Brandvæsenet	❑	❑	❑	❑	❑	❑	❑
Folk fra kommunen	❑	❑	❑	❑	❑	❑	❑
NASA	❑	❑	❑	❑	❑	❑	❑
Et teknologi firma	❑	❑	❑	❑	❑	❑	❑
En industriel designer	❑	❑	❑	❑	❑	❑	❑
Interessegrupper for ældre (f.eks. Ældresagen)	❑	❑	❑	❑	❑	❑	❑
Jeg vil hellere tænke på en løsning selv	❑	❑	❑	❑	❑	❑	
Andet. Skriv det i tekstboksen.							

Hvordan ville du finde den rigtige løsning på problemet med de demente ældre, som bliver væk? Hvilke dele af processen ville være vigtigst for dig?

Vælg et tal fra 1 til 6 (1 = slet ikke vigtigt, 6 = virkeligt vigtigt)

	1	2	3	4	5	6
Jeg ville lave en grundig plan for hele projektet	❑	❑	❑	❑	❑	❑
Jeg ville vente til at en god idé dukkede op	❑	❑	❑	❑	❑	❑
Jeg vil besøge et plejehjem for at udforske problemet nærmere	❑	❑	❑	❑	❑	❑
Jeg ville finde ud af, hvad de gør i andre lande	❑	❑	❑	❑	❑	❑
Jeg vil skitsere mulige løsninger på et stykke papir	❑	❑	❑	❑	❑	❑
Jeg ville bygge min idé i pap	❑	❑	❑	❑	❑	❑
Jeg vil teste min pap-model på et plejehjem	❑	❑	❑	❑	❑	❑
Jeg vil gentage mine tests med en ny skitse eller pap-model flere gange	❑	❑	❑	❑	❑	❑

Jeg vil afprøve min løsning sammen med ældre plejehjemsbeboerne	❑	❑	❑	❑	❑	❑

...forsat fra sidste side

Vælg et tal fra 1 til 6 (1 = slet ikke vigtigt, 6 = virkeligt vigtigt)

	1	2	3	4	5	6
Jeg vil afholde et møde med plejehjemspersonale, pårørende, for at diskutere min løsning	❑	❑	❑	❑	❑	❑
Jeg vil sørge for, at alle er enige om løsningen	❑	❑	❑	❑	❑	❑
Jeg vil bruge uenigheder mellem personer/grupper til at udvikle nye idéer	❑	❑	❑	❑	❑	❑
Jeg vil tage patent på min idé	❑	❑	❑	❑	❑	❑
Jeg vil starte et firma til at markedsføre min løsning og tjene penge	❑	❑	❑	❑	❑	❑
Så snart min løsning er færdig, stopper jeg helt med at arbejde på problemet	❑	❑	❑	❑	❑	❑
Jeg vil bruge min viden fra dette projekt, i fremtidige projekter	❑	❑	❑	❑	❑	❑

Andet du ville gøre? Beskriv dem her.

Hacking, data og teknologi

Her handler det om dit forhold til hacking og reparation af teknologi i din hverdag. Hvor enig eller uenig er du...

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Når jeg ser en ødelagt ting, tænker jeg straks på en måde at reparere	❑	❑	❑	❑	❑	❑
Jeg er ligeglad med hvordan mine digitale dimser fungerer, bare de virker	❑	❑	❑	❑	❑	❑
Jeg har en god idé om, hvad der er inde i en mobiltelefon, og hvordan den virker	❑	❑	❑	❑	❑	❑
Jeg er interesseret i at vide, hvordan mine digitale dimser fungerer, og jeg forbedre dem ofte	❑	❑	❑	❑	❑	❑

Hvad gør du, hvis noget ikke virker på f.eks. din computer eller mobil?
Markér tre muligheder.

❑ Ringer til en ven
❑ Læser i en manual
❑ Spørger en af mine forældre
❑ Ringer til support
❑ Søger på problemet på Internettet
❑ Søger efter hjælp på specifikke hjemmesider
❑ Starter en diskussion på en f.eks. et forum
❑ Roder med forskellige indstillinger, kommandoer osv., som jeg kender
❑ Ved det ikke
❑ Andet. Skriv venligst her: ____________________

Har du nogensinde skilt din telefon eller andre digitale dimser ad?

- ☐ Ja
- ☐ Nej
- ☐ Ved ikke

Hvorfor åbnede du den? Var det f.eks. for at fikse/forbedre noget?

Hvorfor ikke?

- ☐ Hvorfor skulle jeg?
- ☐ Det kan jeg ikke finde ud af
- ☐ Så ville jeg bryde garantien
- ☐ Ved ikke
- ☐ Andet. Skriv det venligst her:____________________

Hvor enig er du i disse udsagn om teknologi og data?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig	Ved ikke
Teknologi, data og information bør være åbne og tilgængelige for alle	☐	☐	☐	☐	☐	☐	☐
Staten skal gemme alles personlige data og information	☐	☐	☐	☐	☐	☐	☐
Jeg går op i hvem der ejer mine data og informationer, f.eks. billeder og musik	☐	☐	☐	☐	☐	☐	☐
Hacking er kun noget kriminelle gør på internettet	☐	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

Hvor enig er du i disse udsagn om teknologi og data?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig	Ved ikke
Hacking er noget alle gør	☐	☐	☐	☐	☐	☐	☐
Teknologi giver mig frihed til at udfolde mine interesser	☐	☐	☐	☐	☐	☐	☐
Jeg kan se hvordan teknologi kan kombineres med andre materialer (f.eks. stof, træ eller papir)	☐	☐	☐	☐	☐	☐	☐
Teknologi giver mig mulighed for at forstå nye sammenhænge og muligheder	☐	☐	☐	☐	☐	☐	☐

Opgave: Hvilke dele er der i bilnøglen?

Fjernbetjening til billås (centrallås)

Vælg ja eller nej, vælg derefter et tal fra 1 til 10 ud fra hvor sikker du er på dit svar (1 = ved ikke/usikker, 10 = virkeligt sikker).

	I bilnøglen?		Hvor sikker er du?									
			1	2	3	4	5	6	7	8	9	10
Motor	ja	nej										
Temperaturføler	ja	nej										
Gear	ja	nej										
Batteri	ja	nej										
Lysdiode	ja	nej										
Microcontroller	ja	nej										
Lyspære	ja	nej										
Skrue	ja	nej										
Lyssensor	ja	nej										
Antenne	ja	nej										
Laser	ja	nej										
Kontakt knap (on/off)	ja	nej										
Transistor	ja	nej										
Mikrofon	ja	nej										

Tusind tak for din hjælp med at besvare vores spørgeskema.

Hvis du har andet at fortælle om dit forhold til teknologi, eller ideer til hvordan fremtidens skole kan bruge teknologi i undervisningen, så skriv dem gerne her:

Mange hilsner
Ole, Rachel, Kasper og Mikkel
Aarhus Universitet

Digital Technology and design processes II: Follow-up report on FabLab@School survey among Danish youth

Mikkel Hjorth, Kasper Skov Christensen, Ole Sejer Iversen, and Rachel Charlotte Smith

AARHUS
UNIVERSITY

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Table of Contents

1. Executive summary

This report is part of the FabLab@School.dk research program, which investigates the use of digital fabrication technologies and design activities among students aged 11-15 years in Danish schools. In order to measure the effects of the FabLab@School.dk educational program from 2014 to late 2016, this follow-up survey was administered to two groups: first, schools in which FabLab and design activities had been carried out in the FabLab@School.dk project throughout a 2-year period (FabLab schools), and second, a control group of schools that were not part of the FabLab@School.dk project (control schools). The survey reported here, is a follow-up to a similar survey conducted in the fall of 2014. The present survey was conducted in the fall of 2016 among 246 students from FabLab schools and 203 students from control schools, totaling 449 students. The students answered 111 questions, which probed their use and knowledge of digital fabrication technologies, both in and out of school, their knowledge of design, and their perspectives on the issues of hacking, open data and privacy. The sample of students in this survey was not randomly selected, and thus we cannot claim representativity. This means that claims are made for the sample only. Below is a summary of the most important findings for this sample of students from the four participating municipalities.

FabLab students improved their understandings of digital fabrication technologies

Compared to the 2014 group, the FabLab group on average had an increase in self-perceived knowledge of 3D printers, laser cutters, vinyl cutters, building electronic devices, microcontroller boards, programmable robots, text-based programming, and blockbased/visual programming.

FabLab students gained experience with a range of digital fabrication technologies

Students in the FabLab group had been exposed to more digital fabrication technologies, than was the case in the control group. Further, the FabLab students had more experience in using the technologies to work on own ideas, and they had to a higher degree worked with the technologies in school settings.

FabLab students found the work with digital fabrication technologies motivating

On average, FabLab students agreed that the work with digital fabrication in their schools had been interesting and useful for their futures. They “liked” FabLab, “loved projects with digital fabrication”, and “learned a lot.”

Learning outcomes and motivation were very dependent on schools and teachers

There were large variations within the FabLab group with regard to the number of technologies used, design process structuring, student motivation, and students’ self-perceived knowledge, as well as on self-perceived learning outcomes such as creativity with digital fabrication technologies, abilities to critically reflect on the use of digital technologies, and complex problem solving. The variations among groups of schools followed a pattern in which higher numbers of technologies, more knowledge of the design process model, higher motivation, and better learning outcomes appeared to be connected.

The FabLab@School.dk has initiated Design literacy among students

In schools in which students used a wide range of technologies, worked with own ideas with a diverse range of digital technologies, and had their work scaffolded and structured around the AU Design Process Model to a high degree, students reported that they had on average become better at imagining change with technology, at working creatively with technology, at understanding how new technologies are created, and at understanding how technology is affecting our lives as well as at solving complex problems. Thus, the FabLab@School.dk project did initiate the development of Design literacy among some students. However, it was very much up to chance, what education in digital fabrication and design processes, the students received.

2. Foreword

This report is part of the FabLab@School.dk research program, which investigates the use of digital fabrication technologies and design activities among students aged 11-15 years in Danish schools. In order to measure the effects of the FabLab@School.dk educational program from 2014 to late 2016, this follow-up survey was administered to two groups: first, schools in which FabLab and design activities had been carried out in the FabLab@School.dk project throughout a 2-year period (FabLab schools), and second, a control group of schools that were not part of the FabLab@School.dk project (control schools). The survey reported here, is a follow-up to a similar survey conducted in the fall of 2014. The present survey was conducted in the fall of 2016 among 246 students from Fablab schools and 203 students from control schools, totaling 449 students.

We would like to thank all the participating schools as well as the collaborating municipalities of Aarhus, Silkeborg, Vejle and Favrskov. We would also like to thank Martin Thorhauge for help with the charts and Mathias Milter Liboriussen for support with statistical analysis. Lastly, a special thanks to the control schools, which were not obliged to participate in the project but nonetheless found the time and resources for us to carry out our survey among their students.

We have experienced problems in printing this report directly from internet browsers. We therefore recommend printing from a dedicated pdf reader such as Adobe Reader, Apple Preview or Foxit Reader.

3. The FabLab@School.dk survey

FabLab@School.dk is a Danish research project at the Department of Aesthetics and Communications at Aarhus University supported with a grant from The Danish Industry Foundation. It is part of the global FabLab@School initiative, founded by Dr. Paulo Blikstein at the Transformative Learning Technologies Lab at Stanford University. The Danish research project focuses on FabLabs as "hybrid learning laboratories, which combine digital fabrication, design thinking, collaborative idea generation and creating in solutions to complex societal challenges" (Smith, Iversen, & Hjorth, 2015). This definition of FabLab@School places an emphasis on the entire design process—from early ideation, sketching, and mockup creation to the initial presentation of a prototype.

The survey reported here was conducted in collaboration with Stanford University. Parts of the survey have been run in various countries worldwide in order to establish the foundations for comparison on a global scale. Aarhus University is cooperating with Aarhus, Vejle and Silkeborg municipalities in the FabLab@School.dk educational project.

The survey is in part based on questions used by TLTL at Stanford University (Blikstein, Kabayadondo, Martin, & Fields, 2017). The questions reported here are translations, often abbreviated, of the Danish questions. A list of full length translations can be found in the Appendix together with the original questionnaire in Danish. Some of the survey items are tentative measures that are currently guiding our further investigations but are not yet established as valid measures of the traits concerned. This report is mainly descriptive in its approach to the collected data: it serves the purpose of presenting the data in a way, that lends itself to further exploration. In addition to the survey reported here, the research project consists of ethnographic observations and interviews with teachers and students, as well as design interventions in and with the collaborating schools.

3.1. Digital fabrication

In this report, as in the survey, we use the term "digital fabrication" to denote the use of a wide range of digital technologies with the aim of creating physical products. As is customary within the emerging research field of digital fabrication in education, such technologies include, but are not limited to, 3D printers, laser/vinyl cutters, and CNC routers. We also include programmable robots, microcontroller boards, and other means for creating physical computing products.

3.2. Content and limitations of this report

The report describes frequencies of responses to questions. It also goes further in tentatively exploring composite measures and differences between groups of schools. The findings of the report are divided into themes, which are explored from various different perspectives with various types of questions. In chapter four, students' use and knowledge of digital fabrication technologies is explored. Chapter five concerns the students' design knowledge, while chapter six reports on student motivation in work with digital fabrication. Chapter seven is the conclusion, which is followed by a list of references and an appendix containing the original questionnaire, translations into English of all the questions, charts showing the number of responses for every quantitative question asked on the report, and details with regards to statistical tests, which have been run on the data.

3.3. Research question

The main research question guiding the Danish FabLab@School research project, was:

How can design thinking and digital fabrication in Danish public schools contribute to adolescents' abilities to understand and create with digital technologies?

3.4. The Danish FabLab@School project

As stated above, this survey is part of an ongoing research project on digital fabrication in education. In 2014 the educational landscape in Denmark changed due to a new reform of standards in the Danish public schools (age six to 16). Part of the initiative was to introduce a stronger focus on competencies related to 21st century skills (Ananiadou & Claro, 2009). On this basis, The Danish FabLab@School project was initiated by the Child-Computer Interaction group at Aarhus University, in collaboration with the municipalities of Aarhus, Vejle and Silkeborg, to study how digital fabrication could promote 21st century skills in educational contexts. The aim of the FabLab@School project was and still is to develop a sustained initiative promoting digital fabrication in education within the existing framework of the Danish school system among children aged 11 to 15.

Among the 21st century skills that were considered relevant to the above-mentioned combination of digital fabrication, design thinking, collaborative idea generation and creating in solutions to complex societal challenges, were two sets of abilities:

- Abilities to use, master and understand digital technologies
- Abilities to think and act innovatively (with technology) on societal challenges

It was and is a central hypothesis of the research project that adolescents aged 11 to 15 years can improve these abilities significantly through hands-on education with digital fabrication technologies compared to existing provision in the Danish school system. It was a further hypothesis that students who had not participated in the FabLab@School.dk project would not have developed these abilities to the same extent as students who had worked with design and digital fabrication technologies.

3.5. Research design

As stated, our hypotheses were investigated through observations, interviews, and interventions, as well as by the survey presented here. In 2014 we conducted a baseline survey of 1,156 students exploring their use, knowledge of and abilities in regard to digital technology and design, as well as their attitudes to the issues of hacking, open data, and privacy. This report presents a follow-up endline survey which was conducted in late 2016 with the purpose of assessing improvements among students who had been educated in design and digital fabrication as part of their involvement in the FabLab@School.dk project. The research design resembles an experimental design: a test group (FabLab schools) and a control group (control schools) are followed in order to look for differences in their development. However, because the project was conducted in the messy context of real-world schools, this was not what is sometimes referred to as a controlled experiment. Rather, it resembled a quasi-experimental setup with great variations between schools, teachers, and implementations. Further, it was not possible to follow the same students throughout the study period. Too many of the students had graduated from school by the time we conducted the follow up study for this to be possible. However, we did specifically ask the participating FabLab schools for students, who had been a part of the FabLab@School.dk project activities, so that they could be compared to students from the control schools and to the students in the baseline survey.

Compared to the baseline survey of 2014, the endline survey, reported here, featured a smaller number of questions, for two reasons. First, in 2014 we witnessed some fatigue among students and we wished to avoid this; and second, some of the questions in the original 2014 survey had been included to probe students' use and understanding of technologies in general. Since we did not hypothesize change in their relationships with technologies other than digital fabrication technologies, we did not include such questions in the endline survey reported here.

Concurrently with the survey, we performed interviews with 11 groups of students (2-3 students in each) in eight of the FabLab schools being surveyed. We did this to gain better insights into the types of implementations, types of student responses, and types of student gains that the survey was probing. In each interview setting, students were asked to fill out the questionnaire while reflecting on their answers. Interviewers probed the reflections whenever something of interest came up. Thus, while the interviews were heavily structured by the questionnaire, they were semi-structured in the sense that interviewers would follow leads before returning to the structure of the questionnaire. Students were selected for interview by their teachers, who were asked to identify those who had gained the most from work with digital fabrication. The present report focuses on the survey part of the work, and therefore the interviews are not directly reported. Here, we our sole use of the interviews is to divide schools into groups in order to compare different groups of schools.

3.6. Ordering of questionnaire themes

The survey was conducted as an online questionnaire consisting of 111 questions probing the students' abilities to use, master and understand digital technologies, to think and act innovatively (with technology) on societal challenges, and their relationship with the issues of digital data, hacking and reparation of technology. The students' personal background was investigated through questions relating to their socio-economic status and their dreams for the future. Abilities to use, master, and understand digital technologies were gauged through questions regarding technology in everyday use, the use of technology, and learning about technology in school. Finally, abilities to think and act innovatively (with technology) on societal challenges were measured through questions regarding design and creativity, while students' relationships with digital data and hacking were probed through their attitudes towards issues of privacy and ownership of data, towards tinkering with their devices, and towards hacking[1] as criminal activity or common practice.

Areas of interest	Number of questions
Personal background and plans for the future	9
Abilities to use, master and understand digital technologies	51
Abilities to think and act innovatively (with technology) on societal challenges	35
Relationship with digital data, hacking and reparation of technology	16

Table 1 - Relationship between areas of interests and the number of questions in the survey.

3.6.1. Types of questions

In the survey, four types of questions were used to investigate the various themes. Likert-type scale questions with a scale from one (strongly disagree) to six (strongly agree) were used to gain insight into the students' views and perspectives on technology and their activities within a concrete design process. In order to gauge self-perceived abilities within the areas of interest, an additional Likert-type scale was used with values ranging from one (I know nothing about it) to six (I could teach others about it). Evaluating the students' experience with digital fabrication technologies in schools was evaluated on a five-point Likert scale. Finally, open-ended questions and tasks were used in order to evaluate student abilities and mindsets. In this latter method, responses were coded for different categories of answers. The range of question types afforded opportunities for comparing self-perceived abilities with scores or categories on specific types of performance. For example, students were asked to rate their own knowledge of the AU Design Process Model, which could be compared to a question in which students were asked for ways to solve a concrete societal challenge.

It is important to note that on many items students were asked to evaluate themselves. This method is prone to various types of bias. One bias is that students are often uncertain of their own level of competence, and male students in particular tend to score their own IT skills higher than their female counterparts do (Bundsgaard, Rasmus Puck, & Petterson, 2014). Another is the so-called demand characteristic: Students' answers are often influenced by their wish to find the "right" answer, that is, to answer what they think the researchers or teachers want to hear. Students will often experience a survey as a test and will make attempts to do well in the given task.

[1] Note that hacking in this context should be understood not as a criminal activity (which is defined as cracking), but as a mindset of exploring and tinkering with the technology so as to come up with new and creative ideas for using the technology going beyond the originally intended use.

As stated, we used Likert-type scales with five or six possible answers. An uneven number of response possibilities is often recommended when using Likert-type scales to prevent respondents whose views genuinely lie in the middle of the scale being forced to answer to one side or the other and thus to be misrepresented in the data (Marsden & Wright, 2010). On the other hand, taking away the middle category gives even those respondents who are prone to satisficing (by choosing the option in the middle) in order to finish quickly an additional incentive to reflect on whether they are on one side of the middle or the other.

3.6.2. Translations and wording of questions

Parts of the survey had been translated into Danish from survey questions used in the FabLab@School project at Stanford University. While some questions were directly translatable, the interpretation of others in a Danish context posed problems. For example, concepts such as creativity and imagination can be interpreted differently in the two different contexts. The wording of the questionnaire was carefully selected with the goal of reducing the complexity of the language and having as little text as possible in order to speed up the reading process. At the same time, our aim was to be as precise and easy to understand as possible in order to secure valid data and to minimize fatigue and satisficing resulting from this fatigue. The questions and the questionnaire were tested on students within the age group on before deployment. During the testing, students were asked to read the questions aloud and discuss their answers, in order to reveal which words and wordings were difficult to understand and which questions were worded ambiguously.

The questionnaire opened with questions of age, gender, name, and school name. Demographic characteristics (number of books at home, expectations for the future) were placed at the end of the survey, as is frequently recommended (Marsden & Wright, 2010) in order not to cause respondents to feel intimidated or otherwise put off by questions about their background. Each section of questions was grouped by content, in order to facilitate respondents' cognitive processing (Marsden & Wright, 2010). The ordering of questions and themes had two main aims: first, to create a sense of a common thread running right through the questionnaire which would help the questions make sense to the respondents, and second, to make the students respond with their own uses and views on technology and design before revealing too much about our assumptions. The last aim was important to minimize demand characteristics, which might lead students to try to give us what they thought the correct answer.

3.7. Recruitment of schools

The schools within the project (the FabLab schools) were selected with help from the municipalities. The criteria for selection were (1) to have schools from all municipalities, (2) to have a diverse set of participating schools, and (3) to include only schools and classes that had worked with digital fabrication in education to a significant degree according to the municipalities. The local FabLab@School.dk coordinators from the municipalities informed the relevant teachers, whom we then contacted by email and phone.

With regard to the control group, criteria for inclusion were based on (1) whether the school had participated in the baseline survey, and (2) matches with project-schools. The selection was made so that a control school was found for each project school. The control school was to match the project school as closely as possible with regard to socioeconomic status, school size and the school's location in a rural, suburban, or urban setting. In each control school, we asked for a group of students in the same age range as in the corresponding project school. However, not all schools were organized alike, and we sometimes had to be flexible in order to get the data. We looked both at the individual matches and at the overall averages of the two groups. Socioeconomic status was represented by the expected average score on grade 9 national exams over a three-year period (2014-2016). This score is calculated from the socioeconomic status of each student in grade nine by the Danish Ministry of Education each year, and is publicly available.

School	Group	Grade	Number of students	Expected score (SES)
1	Control	8	32	7.1
2	Fablab	8	41	7.5
3	Control	7	17	6.7
4	Fablab	7	24	6.2
5	Control	6	20	7.1
6	Fablab	6	20	7.8
7	Control	7	51	7.4
8	Fablab	7	17	7.8
9	Control	7	22	5.3
10	Fablab	7,8	20	5.9
12	Fablab	8	41	7.6
13	Control	8	22	7.4
14	Fablab	8	20	7.4
15	Control	9	20	6.6
16	Fablab	9	46	6.5
17	Control	7	19	6.9
18	Fablab	6,7,8,9	17	6.4

Table 2: Participating schools. Control schools (odd numbers) are listed together with corresponding FabLab schools (even numbers). In the case of school 12, all potential control schools declined to participate in the survey, with the result that there is no school 11.

As seen in Table 2, we were able to find matches for all but one school. The total average and weighted average SES of schools within the two groups is shown in Table 3:

	Total number of students	Average SES	Weighted average SES
Fablab	246	7.0	7.0
Control	203	6.8	6.9

Table 3: Total number of students in the FabLab and control groups, and comparison of their Socio-economic status' as represented by average expected scores on national exams.

While the weighted average SES is not identical for the two groups, the difference is very small. Thus, we do not expect any difference in responses to be due to a difference in the socio-economic status of the two groups.

3.7.1. Grade level of the respondents

In the following, we compare the grade level of the FabLab and control groups.

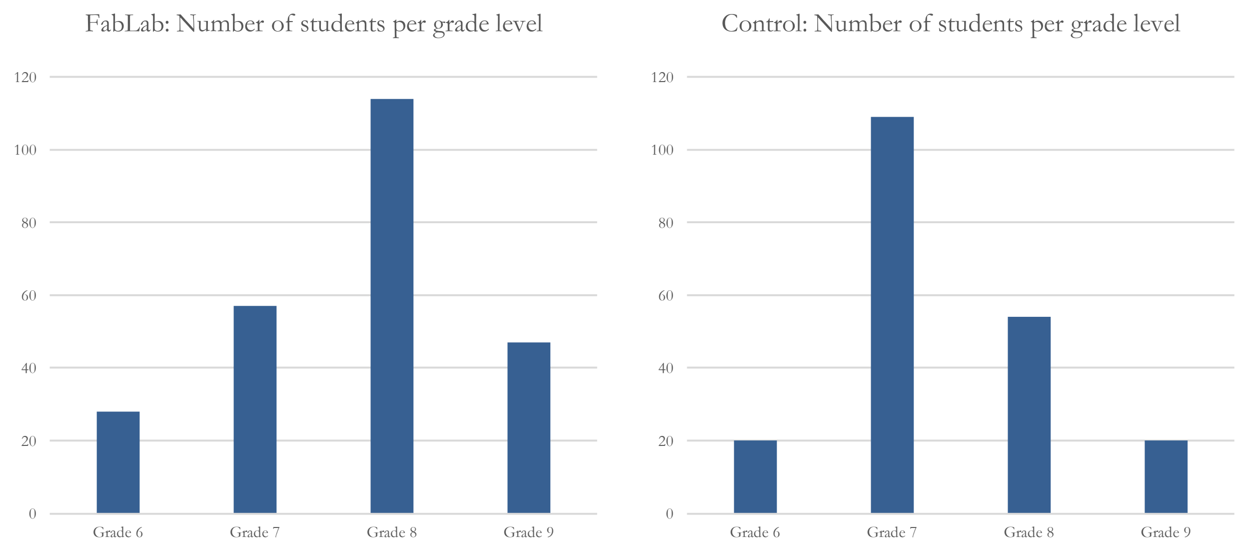

Figure 1: Number of students at each grade level in the FabLab and control groups respectively.

As seen in Figure 1, students in the FabLab group were older on average than the students in the control group. There were two main reasons for this difference. The first was, that in school 16 (FabLab), the entire group of grade-nine students had participated equally in the FabLab activities and we therefore included all students from this grade, which gave us 46 responses. In the corresponding control school, however, there was only one class in grade nine, which gave us 20 responses. Furthermore, we failed to find a willing control school that could match school 12. Thus, the 41 responses for grade eight students from this school are unmatched in the control group. Number of students in each grade level in the 2014 survey is listed in Figure 2.

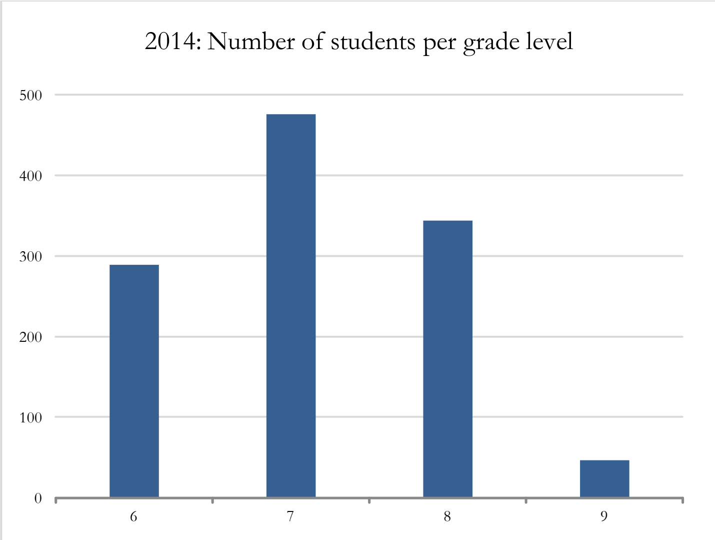

Figure 2: Number of students at each grade level in the 2014 baseline survey.

The students in the 2014 survey (see Figure 2) were on average younger than those in the 2016 survey. We did not try to control the grade level of participating classes in the 2016 survey, since the most important selection criterion in the FabLab group was to survey the classes that had worked most with digital fabrication technologies. The most important selection criterion for the control schools was to match FabLab schools as well as possible.

3.8. Data treatment

The data was downloaded from SurveyXact as a Microsoft Excel file. The original data file contained 551 entries. Responses that did not fit the criteria mentioned below were deleted, and the final number of responses in the FabLab and control datasets combined ended up at 449.

3.8.1. Blanks

If someone started a questionnaire without filling in anything at all, an entry was created. Such a case was counted as a blank. It is very probable that we created most of these ourselves, since every time we tested whether the server was running, a blank entry was created. 72 blanks were deleted from the dataset.

3.8.2. Duplicate entries

Due to technical problems, several students needed to start over on the survey, thus creating duplicate entries. In each case, the entry with the most answers was kept in the data set, and the others were deleted. Four records of duplicate entries were deleted.

3.8.3. Age range

In this survey we were researching 11-15 year olds, and therefore any entries outside this range were deleted. Nine responses were deleted because the respondents had put something unrelated to age in the age field, or had stated an age which was out of bounds.

3.8.4. Completion

It was decided to only keep only responses in which the respondent had completed the entire questionnaire. For this reason, 17 entries with uncompleted questionnaires were deleted.

3.1. Notes on statistical analysis

All statistical analysis was carried out in R (RStudio Team, 2016). As is customary, we applied a p-value of 0.05 in our statistical tests. In other words, whenever there is a less than five percent chance that an effect could have arisen randomly, we accepted this effect as significant. However, as has been pointed out (Field, Miles, & Field, 2012), when 100 different parameters are tested with an accepted p-value of 0.05, five of these will show significant effect by chance even if there are no effects (corresponding to the five percent chance of random effects). This is known as familywise error. Since we often included more than one question in a family of questions, we have used the Holm-Bonferroni correction to adjust p-values within batteries of questions. The Holm-Bonferroni method is a relatively conservative way of dealing with family-wise errors, and we do run the risk of getting false negatives – that is of reporting no effects, when in reality there were effects (Gelman & Hill, 2007). Because of this risk, in some cases we will discuss the descriptive differences but add that the effects were not significant.

As explained later, in most batteries of questions, it could be argued, that schools should be treated as random effects. Since we only had surveyed students taught by one teacher in each school, the effect of schools included the effect of the teachers. That is, if we wanted to find effects that were independent of the difference made by teachers and schools, we needed to take the effect of schools into account by using them as random effects in our models. However, since we did not have the opportunity to control schools' choices of technologies or implementations, such analysis rarely rendered any effects significant. The effect of teachers' differing implementations of different technologies in many cases did not yield results that could be generalized to all teachers in all schools in the area. In some cases below, we discuss results both with and without treating schools as random effects.

4. Digital fabrication in schools

In the FabLab@School.dk project, students worked with a range of different digital fabrication technologies. In this section we describe students' responses to questions regarding their use of such technologies, their knowledge of them, and whether or not, they had learned to use the selected technologies in school. We asked these questions in order to gauge students' "abilities to use, master and understand digital technologies."

4.1. Exposure to digital fabrication technologies

In the questionnaire students were asked which technologies they had worked with, and whether they had used them to work with their own ideas or whether they had followed a set of instructions. Because the FabLab@School.dk project was centered on introducing FabLab technologies to students in schools, we expected students in the FabLab group to have worked with more technologies than students in the control group.

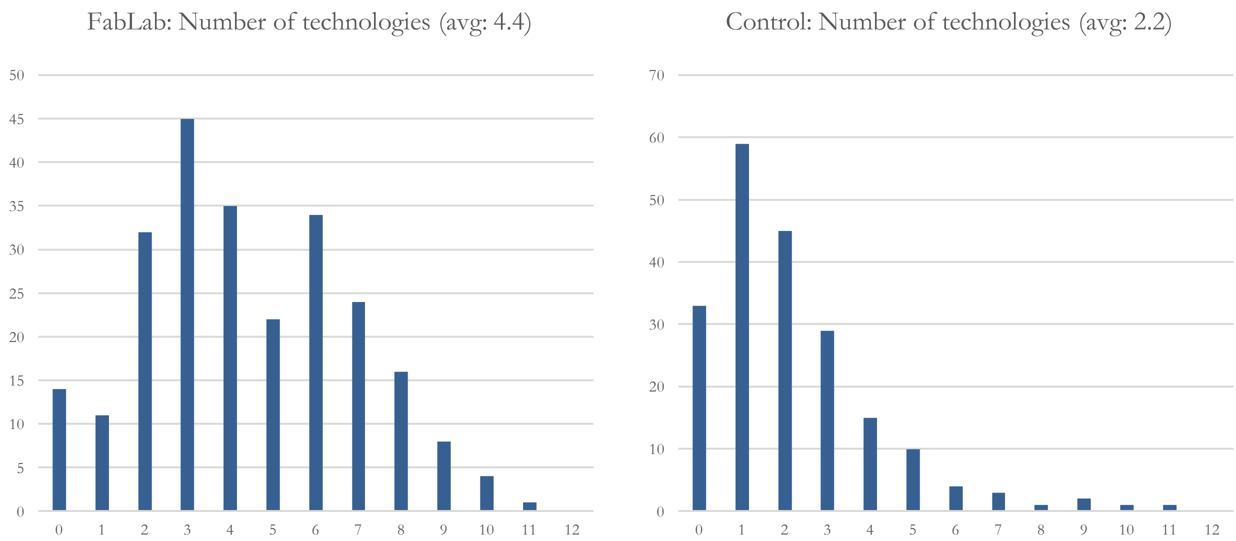

Figure 3: Average number of technologies used by FabLab and Control groups respectively. Answers in the category "other FabLab technologies" were excluded from these charts (as explained in text).

As seen in Figure 3, FabLab group students had on average been exposed to more digital fabrication technologies (4.4 technologies per student on average), than students in the control group (Average: 2.2). We were, however, surprised, both by how many students from the control group had worked with digital fabrication technologies and by the broad range of digital fabrication technologies the control group students had worked with (see below).

4.2. Exposure to different kinds of digital fabrication technologies

Figure 4 and Figure 5 show the percentages of students in the FabLab group that had been exposed to each selected technology.

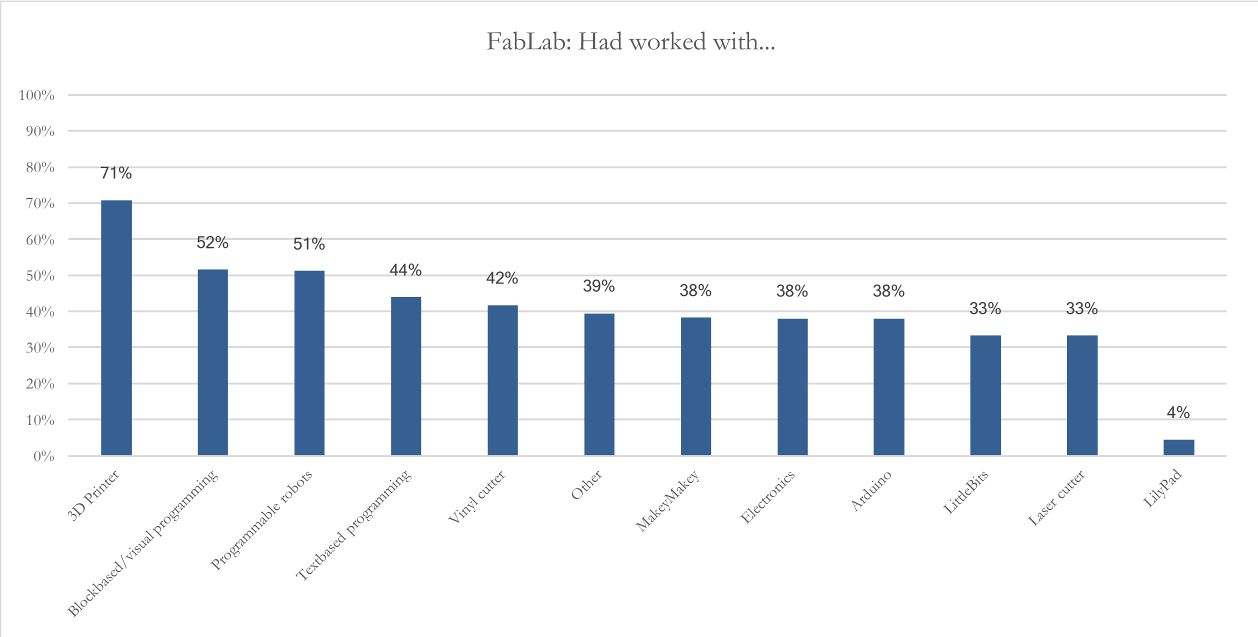

Figure 4: Percentage of students from the FabLab group, who reported to have used the listed technologies.

As seen in Figure 4, seventy-one percent of the students in the FabLab group reported that they had worked with 3D printers. At the other end of the scale, fewer than five percent of the students reported, that they had used the LilyPad Arduino. In the literature surrounding the development of the LilyPad it is often claimed that because it is meant to be used with textiles, the LilyPad appeals to girls more than other technologies (Buechley, Eisenberg, Catchen, & Crockett, 2008). Thus it is perhaps surprising that more schools had not chosen to introduce the LilyPad in their FabLab activities in order to engage the girls. On the spectrum between the LilyPad and the 3D printers, was a range of technologies which between 33 and 52 percent of the students reported having worked with. These technologies included Blockbased/visual programming (52 percent), Programmable robots (51 percent), Textbased programming (44 percent), and vinyl cutters (42 percent). Further, more than one third of the students from FabLab schools had worked with MakeyMakey (38 percent), Electronics (38 percent), Arduino (38 percent), LittleBits (33,3 percent), and Laser cutters (33,3 percent). Only schools that had worked with some digital fabrication technology or technologies were selected for the survey. Among these schools, however, there was a large variation in the technologies, each school was using (see section 4.4).

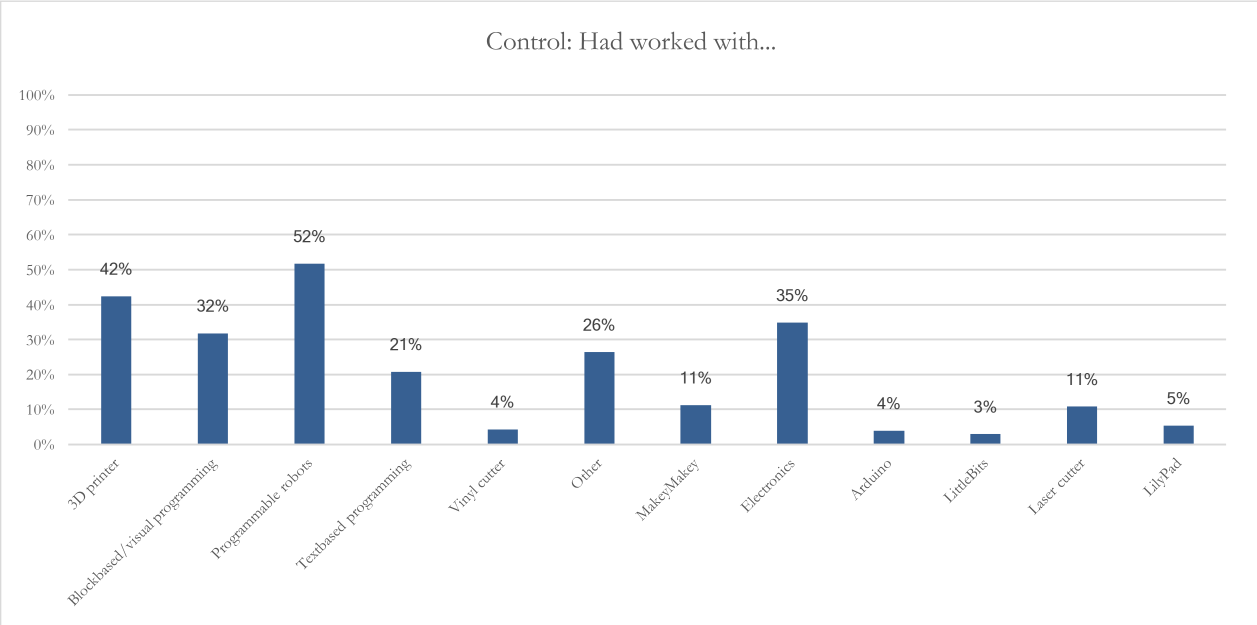

Figure 5: Percentage of students from the control group, who reported to have used the listed technologies.

As depicted in Figure 5, students from the control group reported working with a range of technologies, among which the most common were programmable robots (52 percent), 3D printers (42 percent), and electronics (35 percent). Thirty-two percent reported that they had used block-based or visual programming, while 21 percent had worked with text-based programming. Some students reported that they had worked with MakeyMakey (11 percent) and laser cutter (11 percent), while few students had worked with LilyPad (5 percent), vinyl cutter (4 percent), Arduino (4 percent), and LittleBits (3 percent). Twenty-six percent reported that they had worked with other digital fabrication technologies. When these students were asked to state which other digital fabrication technologies they had worked with, however, they all mentioned either technologies that did not fit our definition (e.g. iPads, computing in general) or technologies that were already included (e.g. LEGO Mindstorms).

Comparison of the charts reveals that a higher percentage of students from the FabLab group than the control group had worked with most technologies. The only exceptions were programmable robots and LilyPads. However, many students from the control group claimed to have worked with digital fabrication technologies. For example, more than 40 percent of students in the control group claimed to have used a 3D printer. Two schools in particular seemed to have worked with 3D printers: only six out of 51 students from school seven and four out of 17 students from school three reported that they had never used a 3D printer. That so many of the students from our control group had worked with digital fabrication technologies highlights the difficulties of working quantitatively with real schools in real-world settings: we had no authority to demand that control schools did not use 3D printers or other digital fabrication tools, and thus we did not compare the FabLab group to a group of students that had not been working with digital fabrication technologies. Therefore, effects sizes measured by comparing FabLab to control schools, were lessened by the control groups' exposure to digital fabrication.

There were visible differences between FabLab (Figure 4) and control group (Figure 5) students' self-reported work with all the listed technologies except LilyPads, robots, and electronics. However, when testing whether or not these differences between the control group and the FabLab group are statistically significant, the schools, students came from, should be taken into account. Since different teachers in different schools teach in different ways to different groups of students, any comparison of effects on groups of students needs to check, that differences between effects on different groups of students are not only created because of differences between schools. In statistical jargon, this means that the school, students come from, should be treated as a so-called random variable. That is, if we wanted to show an effect that was true irrespective of which school digital fabrication technologies were introduced to, we would have to factor out the importance of school, teacher, and implementation. Treating school as a random variable did not allow us to conclude, that the differences, which we had observed in the charts, were statistically significant – with two exceptions: students within the FabLab project had used both Arduinos and vinyl cutters to a statistically significant greater extent than those in the control group. As already noted, we were not able to choose, which technologies each school implemented in either FabLab or control groups. In subsequent sections of the report, we treat the differences between groups of schools in more depth.

4.3. Comparing groups of schools

As described above, we found large variations between schools within the FabLab group. This variation meant, that comparisons between the FabLab group, the control group, and the group from the 2014 survey did not produce the insights, we had expected. Below, we have explored the variation within the FabLab group by dividing this group into groups of archetypical categories. As described in section 3.5, we conducted interviews with eleven groups of students in eight FabLab schools. In each school, teachers were asked to identify and select two or more students who had benefitted the most from working with digital fabrication. Thus in these eight schools we gained qualitative insights into the highest outcomes from the teaching done there. In a subsequent analysis of student interviews, the responses were clustered into four types of schools using an affinity diagramming approach (Beyer & Holtzblatt, 1999). In the end, schools were placed in four archetypical categories based on students' recollection of projects with digital fabrication within four different perspectives: (1) the number of technologies applied from the teacher's and school's repertoire, (2) the degree to which the work with digital fabrication technologies had been framed as explorative design processes, (3) the degree to which the students had worked systematically with complex problem-solving, and (4) the degree to which the work with digital fabrication technologies was seen as an integrated part of school work in general. We then used the four archetypical categories to analyze the survey data in order to look for trends within the FabLab group. The four archetypes are characterized in Table 4. Each of the groups have been given a color in order for the purpose of clarity.

	Use of digital materials	Combination of digital fabrication and design processes	Systematic work with complex problem solving	Digital fabrication and design integration in school curriculum
Group 1: Green	Used a large repertoire of digital technologies	Used design process models to scaffold digital fabrication processes	Systematically worked with complex problem solving through several projects with digital fabrication	High degree of integration between digital fabrication, design processes and other school activities
Group 2: Orange	Used a large repertoire of digital technologies	Used design process models to scaffold digital fabrication processes	Worked with a technology focus or with tame school problems.	Had to some degree integrated digital fabrication and design with other school activities.
Group 3: Purple	Used a large or medium-sized repertoire of digital technologies	To small or some degree used design process models to scaffold digital fabrication processes	Primarily worked with digital fabrication technologies in confined school tasks without relation to problem solving.	Had to small or some degree integrated digital fabrication and design with other school activities.
Group 4: Red	Used a small repertoire of digital technologies	To some or small degree used design process models to scaffold digital fabrication processes	Primarily worked with digital fabrication technologies in confined school tasks without relation to problem solving.	Had to small or some degree integrated digital fabrication and design with other school activities.

Table 4: Groups of schools created on a basis of interviews with students from the included schools.

Group 1 consisted of students from one school in which interviews indicated, that students had a high degree of ownership for the FabLab projects, that they rated the importance of the process highly, and that they saw a connection between design and technology as a process directed towards societal development and change. These students were able to reflect on how design and technology were changing the way we live, and they saw connections between what they did in the FabLab and society, their identity, and their own lives. Group 1's expected average result on national exams (as a socioeconomic reference) was 7.5, which was well above the average of 7.0 of the FabLab group.

The students who were interviewed from group 2 were very tech-savvy. They worked with the technologies outside of school as well as in school. They were able to creatively think with different materials. They had a high self-confidence with regards to technology, and they had a high degree of ownership for the FabLab projects. They were mainly concerned with the technology and with what they could use the technology to produce in the fabrication phase of designing. They were less concerned with the design process as an approach to working with technology and complex problems. They engaged with tinkering, experimenting and iterating with the technologies. Students from group 2 had an expected average examination result of 7.8, which was the highest in the FabLab group.

The students interviewed from group 3 were a bit less uniform. Some of them had a basal knowledge of digital fabrication while others had a low knowledge of the included technologies. Some students stated, that they had been introduced to the technologies, but that they had not experienced the chance to actually work with them. Others responded that they had tried many different technologies, but that the technologies were always changing, in line with the activities, which they described as introductory activities such as creating keychains, stickers, and driving a Sphero robot on a track. Most of these students saw some kind of potential in the technologies, but they lacked interest, knowledge, or reasons to identify themselves with digital fabrication in order to engage with the projects. Some students did not understand, how these technologies were relevant to personal lives or their future careers. The boys in this group seemed to be motivated by performing well in school, as the driver for their engagement in the FabLab@School projects. Most of the students in this group had some knowledge of design processes, but lacked experience or motivation of how this could be applied in other projects or subjects. The schools in this group recruited students with an average expected exam score of 7.5, which was at the same level as group 1 and which was well above the total average in the FabLab group.

Students in group 4 in general had some basal knowledge of a few digital fabrication technologies. Some had worked with either LittleBits or Arduino, others had seen how the laser cutter or 3D printer worked and perhaps printed a logo sticker or a key-chain. They were not self-confident with regards to their knowledge of the technologies. They had worked with few, stand-alone projects, but they generally found it difficult to remember, what they had done. In general, they lacked interest in FabLab and found it somewhat boring. They described work with digital fabrication in school as too much talk by the teacher and only few student-driven projects. The students in this group lacked a vocabulary for talking about, what they had done both technologically and with regards to the design process. Students from this group on average had an expected examination average of 6.1. This was low compared to the FabLab average of 7.0 and very low compared to the schools in other archetypical categories. In the following sections, the four groups of FabLab schools described in Table 4 will be used to look for trends in the responses by students from each group.

4.4. Exposure to technology in group comparisons

One noticeable difference between the groups was the average amount of different types of technologies, they had used. There were of course several different strategies for using digital fabrication technologies: in one of the schools in group three, for example, new technologies were introduced frequently but more or less randomly according to the students interviewed. Other schools may have focused on using a few technologies to achieve an understanding of these in more depth, but it seems probable that the number of technologies to some degree reflected the emphasis placed on FabLab@School. Figure 6 depicts the average number of technologies used by students in each school group.

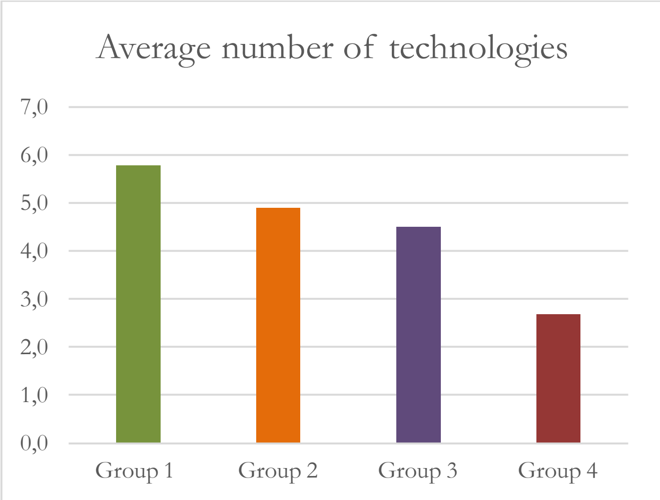

Figure 6: Number of technologies used in the different school groups.

As seen on Figure 6, there were large differences between groups one (5.8 technologies on average) and four (avg: 2.8). This is consistent with the group four students' descriptions of relatively sporadic FabLab-projects as compared to group one's consistent focus on FabLab throughout the entire FabLab@School.dk project period. Students from both group two and group three had used between four and five different technologies on average. However, the students interviewed from group two had talked about doing interesting projects with the technologies, whereas those from group three had talked about being introduced to technologies more at random. In the next section, this difference will be investigated through survey answers.

Within groups of schools, there were great variations in the number of technologies, each student reported using. Figure 7 shows the number of students from Group 1, who claimed to have worked with each possible number of technologies.

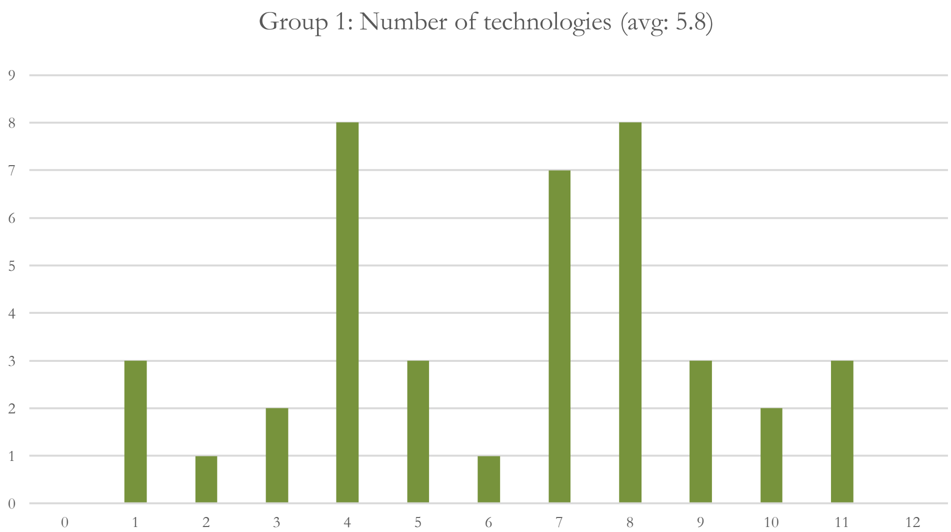

Figure 7: Number students in Group 1 that claimed to have used each possible number of technologies.

Group 1 consisted of only one school, and even within this one school, the number of used technologies varied greatly. While some of this variation may to be due to students not reporting correctly and some of it may be due to students having used technologies outside of school, the variation could also point to a project-oriented approach in which digital technologies were tailored to the individual project.

4.5. Approaches to working with digital fabrication technologies

It is often emphasized in the FabLab@School.dk project (see, e.g., the project focus in section 3) that digital fabrication technologies should be introduced to schools with the purpose of giving the students a chance to be creative with them. Therefore, our hypothesis was that schools taking part in the FabLab@School.dk project would use digital fabrication technologies more frequently to work with students' own ideas. In the survey we therefore asked students to rate their experiences with maker technologies according to whether they had been following instructions or developing their own ideas. Responses are summarized in Figure 8 and Figure 9.

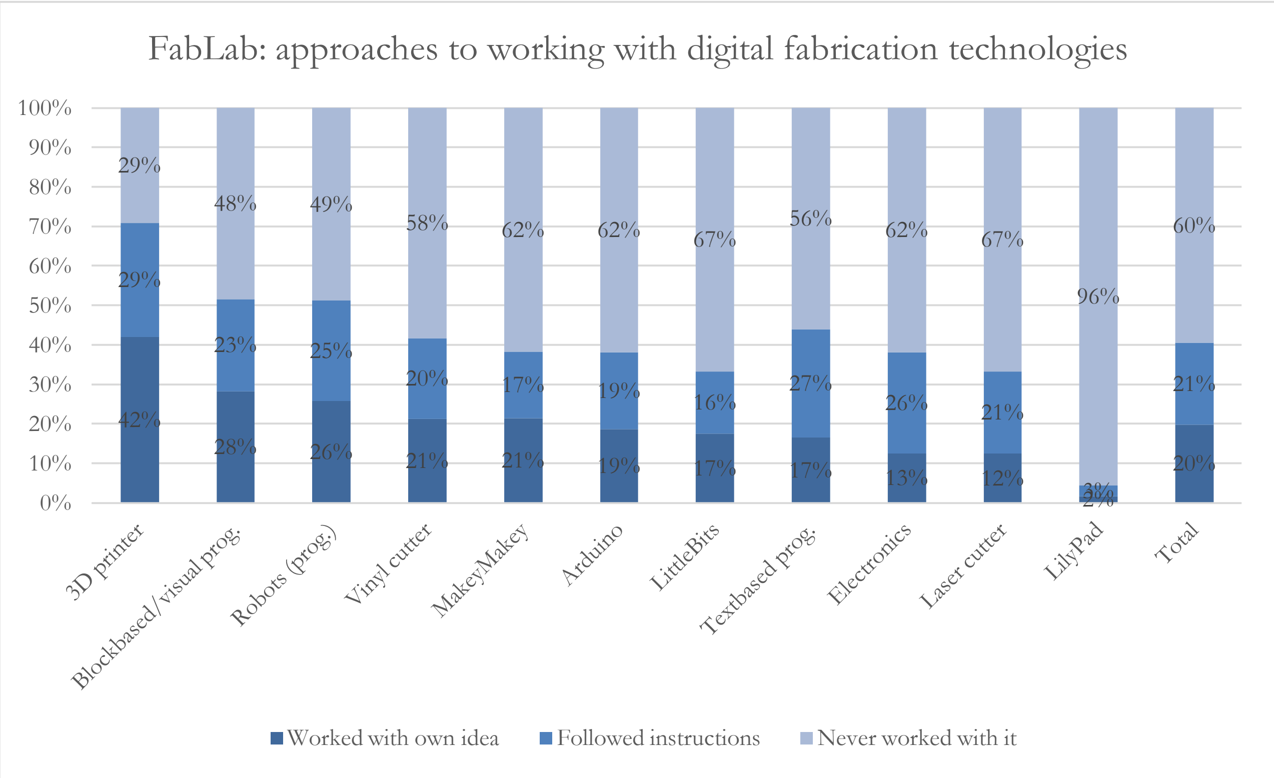

Figure 8: Approaches to working with the technologies in the FabLab group. Students' responses to questions of whether they had used the technologies to work on their own projects, or whether that had followed instructions. Ordered by "Worked with own idea". Last column displays the overall percentages.

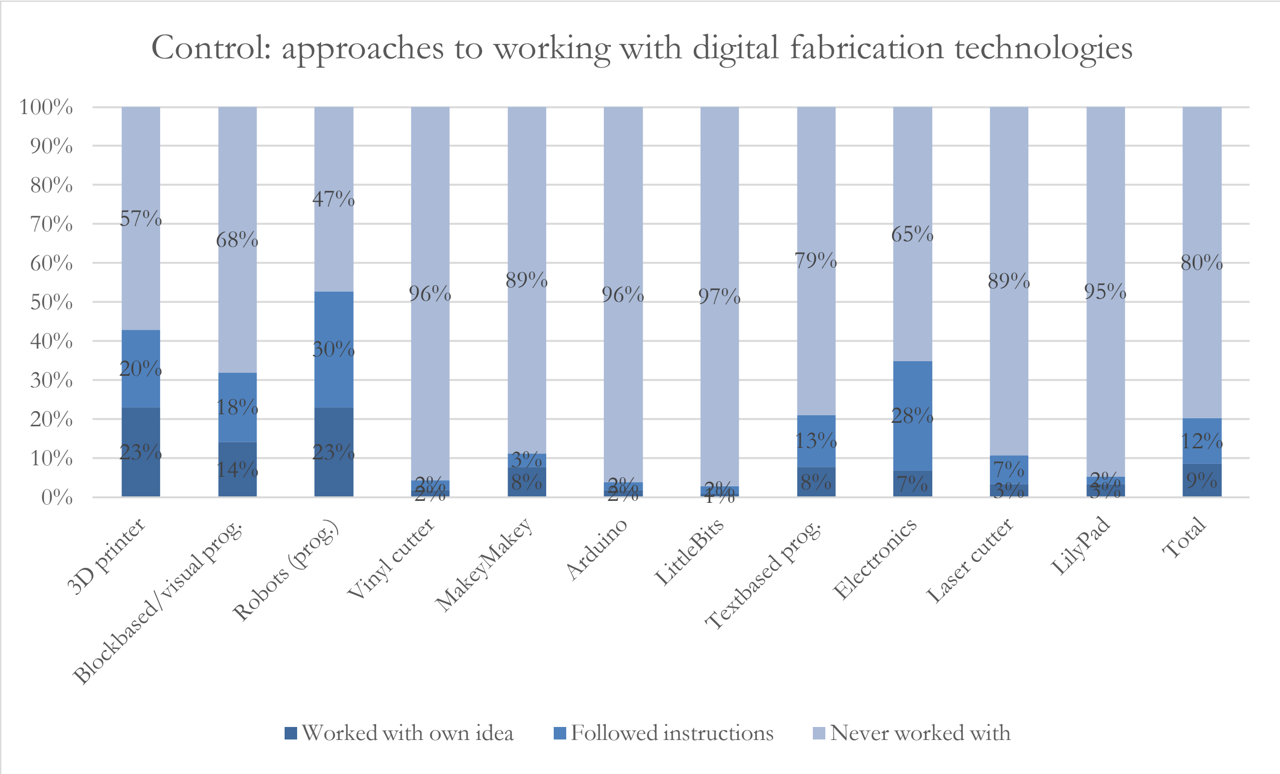

Figure 9: Approaches to working with the technologies in the control group. Students' responses to questions of whether they had used the technologies to work on their own projects, or whether that had followed instructions. Ordered to match the ordering of the corresponding chart for the FabLab group. Last column displays the overall percentages.

As seen in Figure 8 and Figure 9, there were visible differences in the approaches between FabLab and control groups on some technologies. For example, in the control group seven percent of the students reported that they had used electronics and soldering to work on their own ideas, while 28 percent reported that they had used electronics while following instructions. This amounted to a ratio of 1:4. In the FabLab group, 13 percent had worked with their own ideas and 26 percent had followed instructions, which amounted to the ratio 1:2. Such differences were, however, not statistically significant. Furthermore, these differences in approach for each technology were scattered. Another way to look at the data in Figure 9 and Figure 9 was by looking at the total number of technologies each student claimed to have used for working with their own ideas and for following instructions respectively. In particular the average number of technologies used for working with their own ideas by students in each group would be valuable in order to gauge their experience with problem-solving. These are shown in Figure 10.

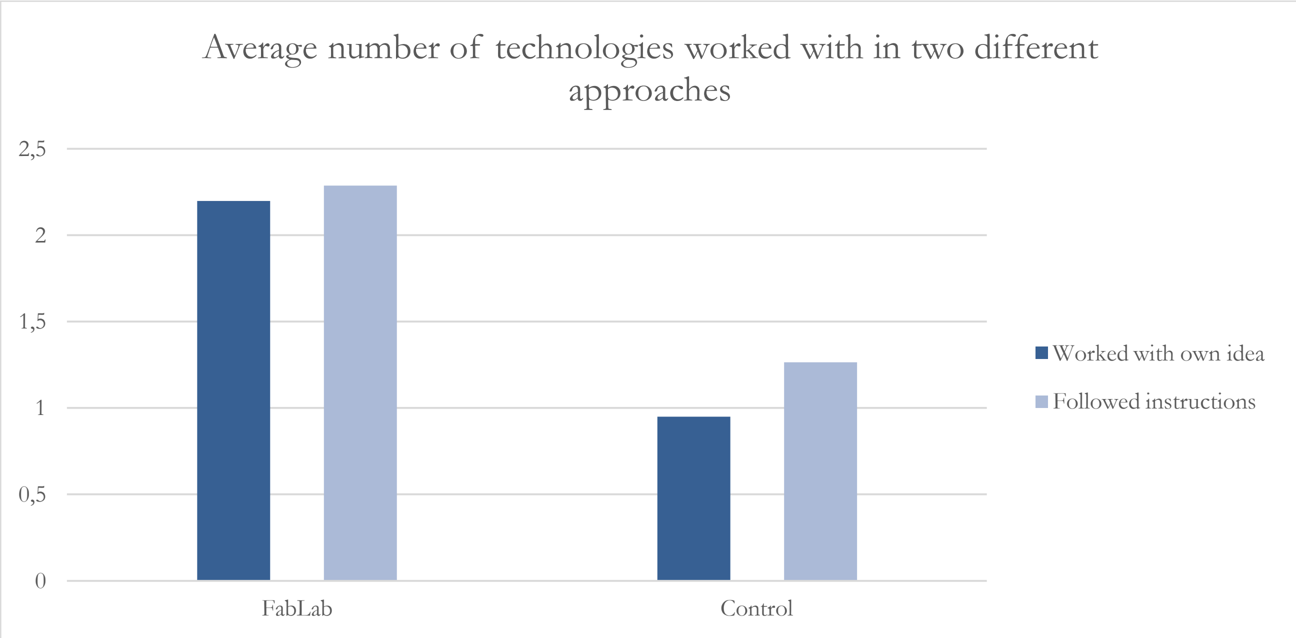

Figure 10: Average number of technologies used in the FabLab and control groups with the two different approaches of either following instructions or working with own ideas.

As depicted in Figure 10, the FabLab group students on average claimed they had been using approximately the same number of the listed technologies to work with their own ideas (2.4 technologies on average) and in following instructions (2.5 technologies on average). On average, control group students reported that they had used 1.0 technologies for working with their own idea and 1.3 technologies in following instructions. There were, however, large variations between students within both the FabLab and the control groups. These variations are explored further in Figure 11 and Figure 12.

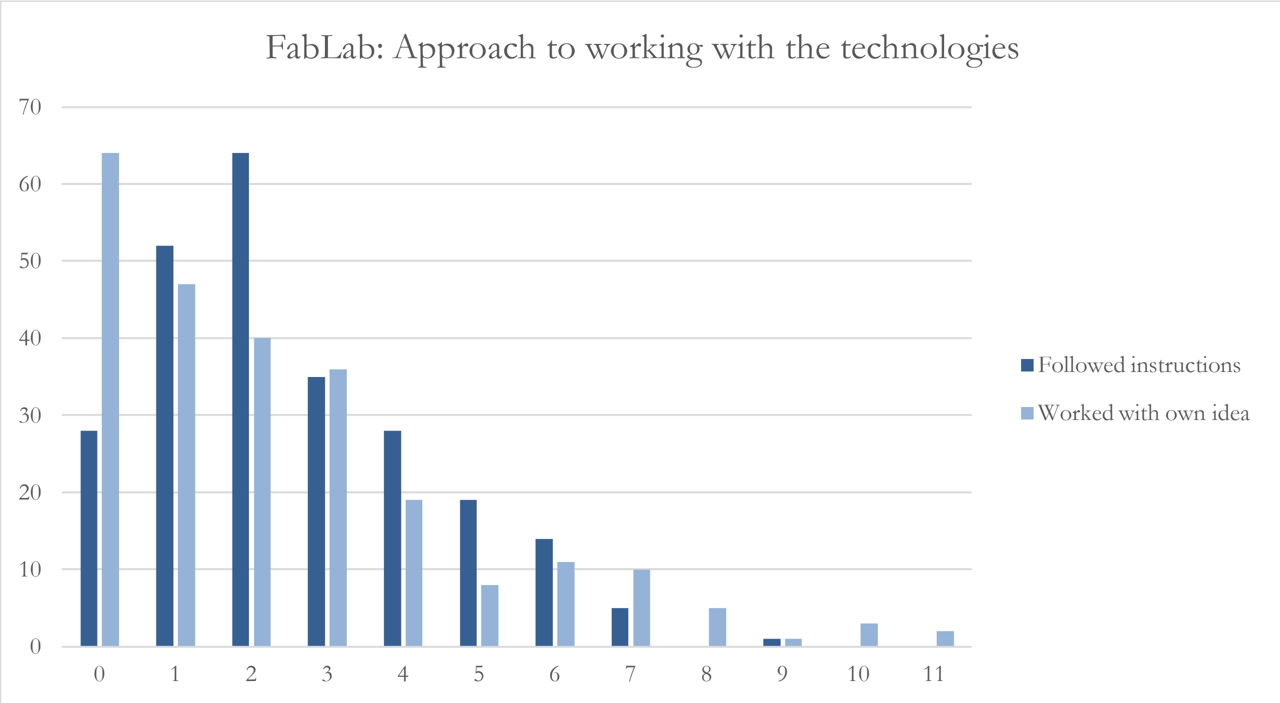

Figure 11: Average number of technologies used in the FabLab group with the two different approaches of either following instructions or working with own ideas.

As shown in Figure 11, Sixty-four students from the FabLab group (26 percent) claimed that they had never used the listed technologies to work with their own ideas, whereas 40 students (16 percent) had used five or more technologies for working with their own ideas. Thus, there were large variations within the FabLab group, and a fourth of the students reported, that they had never tried to use a digital fabrication technology to work on their own idea.

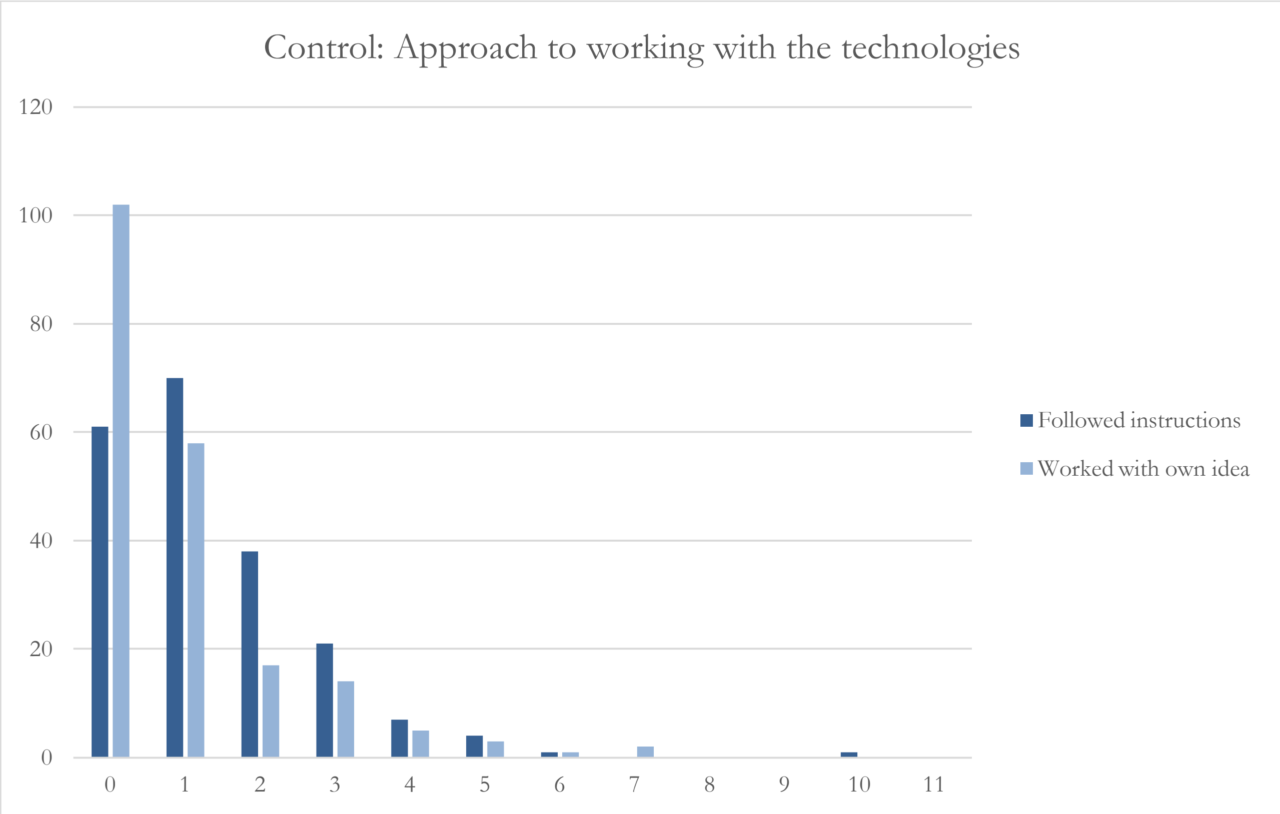

Figure 12: Average number of technologies used in the FabLab group with the two different approaches of either following instructions or working with own ideas.

As shown in Figure 12, 102 students (50 percent) in the control group claimed they had not used any of the listed technologies to work on their own ideas and only six students (3 percent) had used five or more of the technologies for this. Thus, while there was also some variation in the control group, this variation was centred around whether or not these students had been working with any digital fabrication technologies. The ratios between approaches were different in the two groups: in 48 percent of the instances in which FabLab students reported using one of the listed technologies, they reported that they had done so while working with their own ideas. This was true for 41 percent of the control group students. In conclusion, then, the FabLab students had both experienced a higher ratio of working with their own ideas and had been working with their own ideas across a much wider range of technologies.

4.5.1. Differences between schools within the FabLab group

As was the case with the total number of technologies used, there was a large variation between schools with regards to whether they used technologies by working with students' own ideas or in following instructions. In Figure 13 we have depicted approaches for each technology between groups one to four.

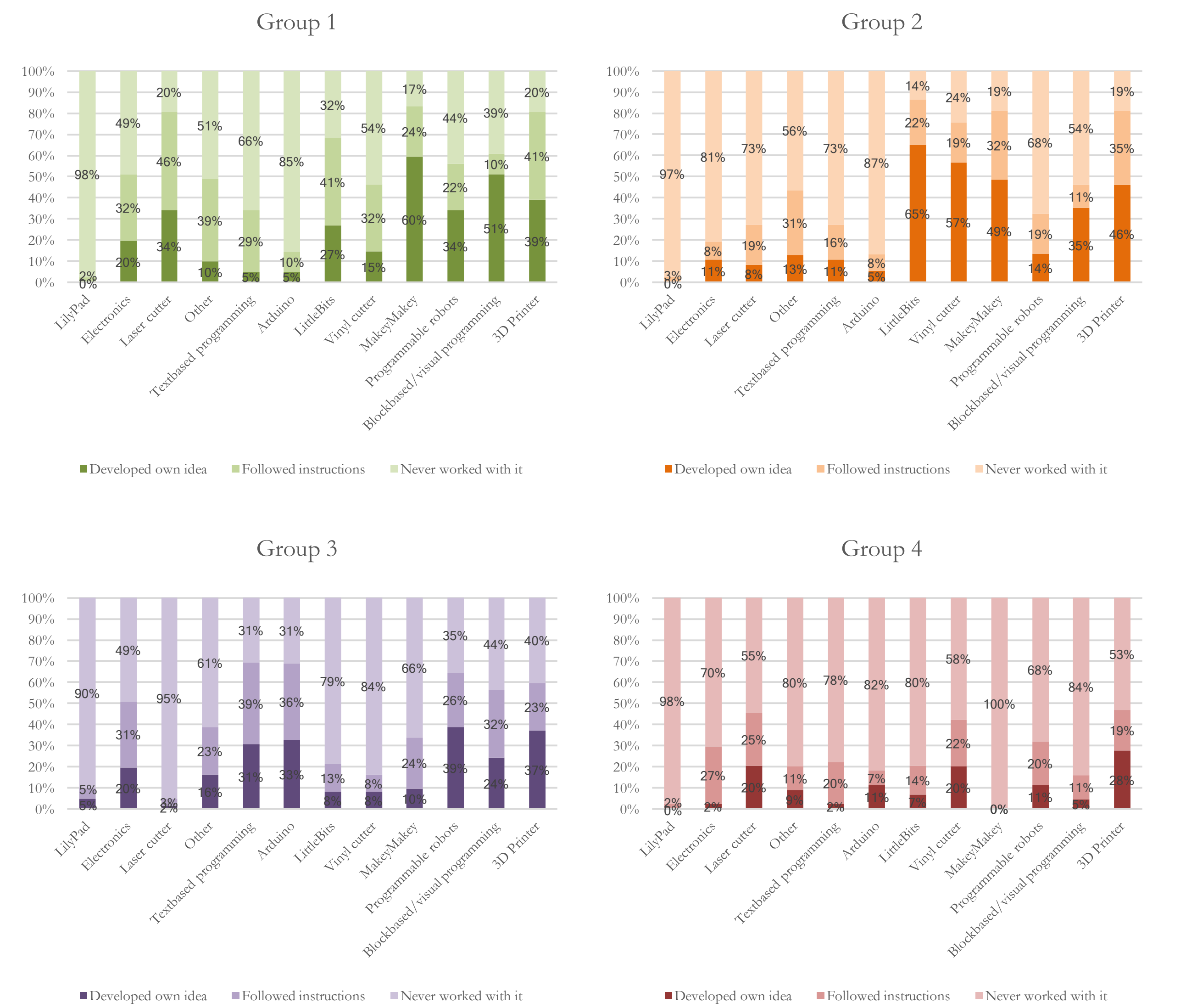

Figure 13: Approaches to working with digital fabrication technologies in the four groups. Expressed as percentages of students in a group, who claimed using the technology in a given approach.

Figure 13 shows variation between the ways in which students from different groups of schools had worked with each technology. Because teachers from each school could choose how to use the technologies, there were large variations among schools in terms of which of two teaching approaches they had used. For example, of the students in groups one, two, three, and four, 83, 81, 34, and zero percent respectively reported using the MakeyMakey. Out of these students, 71 percent from the group 1 claimed using the MakeyMakey for working on their own ideas, whereas the same was true for 60 percent of the students from group 2 and 29 percent of the students from group 3. The use of LittleBits appeared to reverse this trend: Of the 68 percent of students in group 1 who claimed using LittleBits, 39 percent claimed using it to work on their own ideas. The same was true for 75, 38, and 33 percent of the students in groups 2, 3, and 4 respectively. The trend in regard to uses of LittleBits to a degree contradicts the corresponding trend in using MakeyMakey. Thus, there were large variations between school groups in regard to which technologies teachers chose to implement in either of the two approaches. Figure 15 displays the number of students in each group, who claimed using a given number of technologies for working with own ideas and in following instructions respectively.

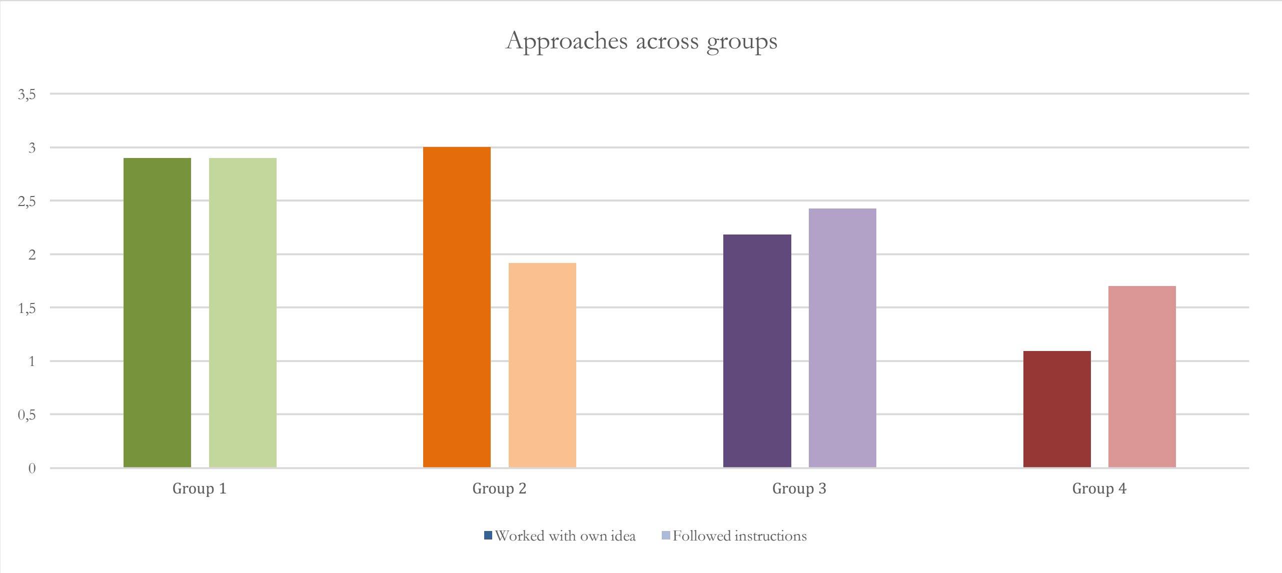

Figure 14: Number of technologies used to work with own ideas (darker bars) and in following instructions (lighter bars) across groups.

As shown in Figure 14, there were large differences between the approaches of some of the groups. In group two, more technologies had according to students' responses been used to work with students' own ideas than had been used in following instructions (61 percent). In groups one and three, approximately equal number of technologies had been used in the two approaches (50 percent and 47 percent respectively), whereas in group 4, students claimed they had used more technologies to follow instructions than they had to work with their own ideas (39 percent). Since this pattern to a certain extent follows the number of technologies used, it could be that the more technologies are used by students in a school, the more they will be allowed to use them for their own projects. However, in this trend, group two stood out. Here, students answered that almost two-thirds of the technologies they had used, had been used for working on their own ideas. Whether teachers teach by letting students follow instructions or by letting them work creatively on their own ideas is obviously a matter of teacher style, student group, and parents' expectations, among other influential factors. Thus, while there was a trend towards working more with own ideas in the groups who had worked with a larger number of technologies, this trend needs further investigation.

In Figure 15 we explore the extent to which there were variations between students in regard to the number of technologies they had worked with in the two approaches.

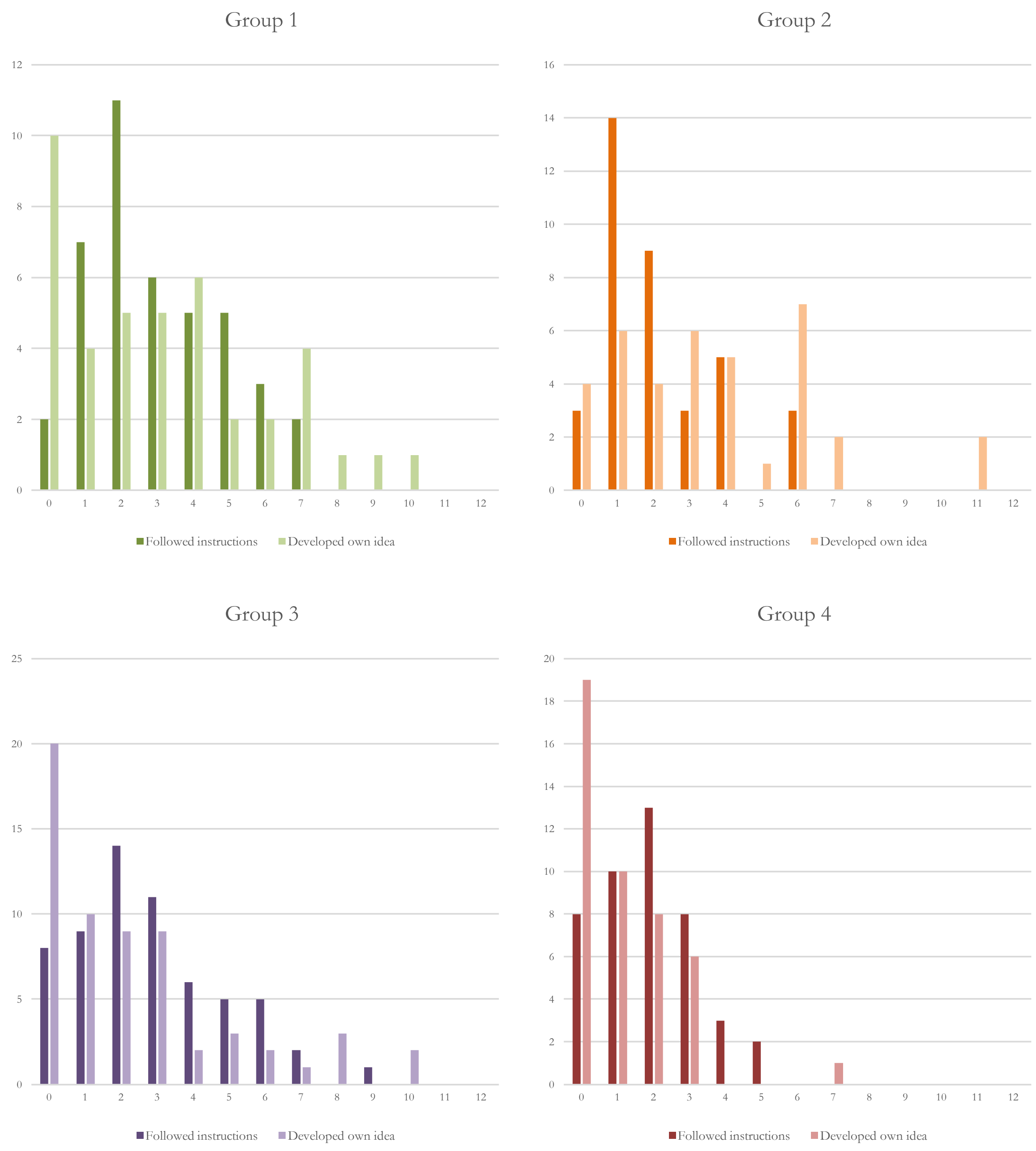

Figure 15: Frequency of students who had worked with a given number of technologies by following instructions and developing own ideas in groups one, two, three, and four.

As shown in Figure 15, students' responses with regards to how many technologies they had used to work with their own ideas did not follow a normal distribution (bell curve) for groups 1 and 2. Rather, there were large differences between students within the same group. In group 2, two outliers claimed to have used all 11 technologies to work on their own ideas. These outliers have a large impact on the average for group 2 (37 in total). Without the two outliers, students from group 2 had on average used

2.4 technologies to work with their own ideas, which follows the trend of a correlation between the total number of technologies used and the number of technologies used to work on own project. From their responses to other items in the questionnaire, the two outliers did, however, seem to take the survey seriously, and so we do not propose, that they should be removed. Rather, we wish to use the calculation to point to the possibility, that when teachers become more experienced in working with digital fabrication technologies, their tendency to let students work with own ideas increases. In group 1, ten students responded, that they had not used any of the technologies to work with own ideas, whereas nine students had used six or more technologies to work with own ideas, according to their responses. Since these students all came from the same school (there was only one school in group 1), the variation could suggest, that this school worked with digital fabrication technologies in a project-based approach, in which there was a great differentiation between the groups with respect to how they used the technologies. Overall, the conclusion is, that even within schools and groups of schools, there were great variations in student responses in regard to the number of technologies used to work with own ideas.

4.6. Knowledge of the technologies

In both the 2014 and the 2016 surveys, students were asked to rate their knowledge of technologies on a scale of 1 (I know nothing about it) to 6 (I could teach others about it). In Figure 16, Figure 17, and Figure 18 below, it can be seen that the FabLab group students on average rated themselves higher than both the 2014 group and the control group.

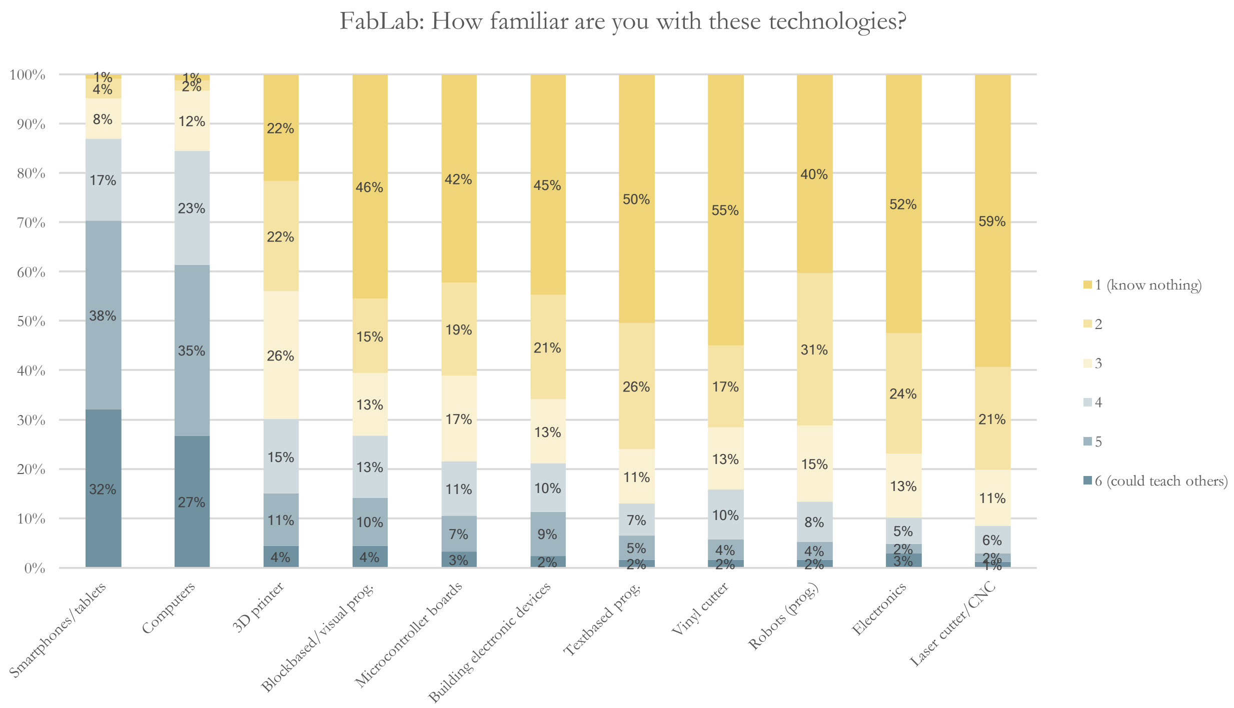

Figure 16: FabLab group students' responses on self-perceived knowledge of technologies. Ordered by the sum of percentages of students in categories 5 and 6.

2014: How familiar are you with...

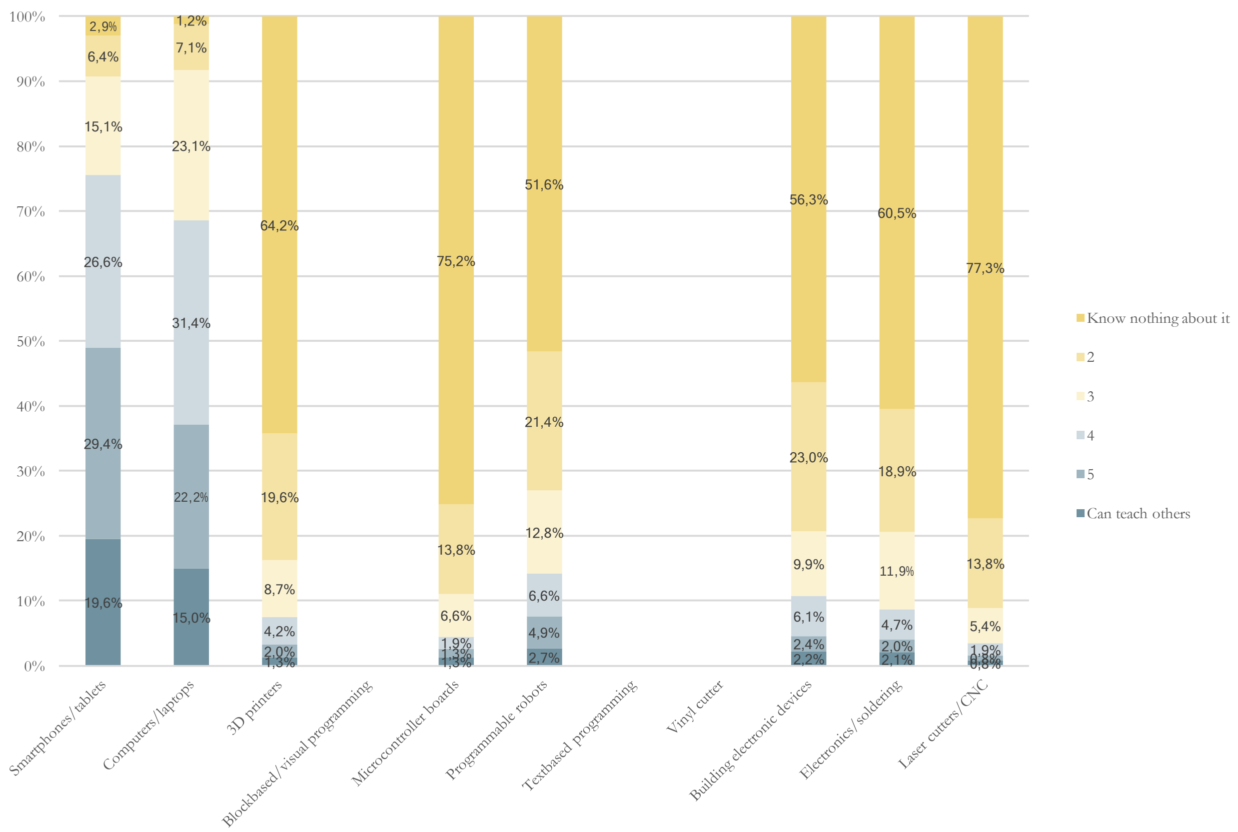

Figure 17: Students from 2014 baseline survey's self-perceived knowledge of a range of technologies used in school FabLabs. On the original survey, there were separate questions for smartphones and tablets. Here, the average of responses on these two questions is reported as Smartphones/tablets for the sake of comparison with the 2016 survey. Further, neither of the programming questions nor the vinyl cutter question were parts of the 2014 survey. Arranged in the same order as Figure 16.

Comparing Figure 16 and Figure 17 reveals, that the FabLab group had significantly higher self-reported knowledge of all digital fabrication technologies than did the students from the 2014 survey. The only technology surveyed in both 2014 and 2016 that the FabLab group did not report being more knowledgeable about than the 2014 group was electronics and soldering. Since the test for significance was done carried out both using a Holm-Bonferroni correction of p-values and treating schools as random variables (see section 3.1), this result was robust. Thus, we conclude, that students in the FabLab@School.dk project on average perceived of themselves as more knowledgeable about digital fabrication technologies than they would have in 2014 at the beginning of the FabLab@School.dk project. This effect could be due to the FabLab@School.dk project, or it could be, that it is an effect in society at large. After all, the technological landscape of the society had changed a lot since 2014. It is for this reason that we included a control group in our endline survey.

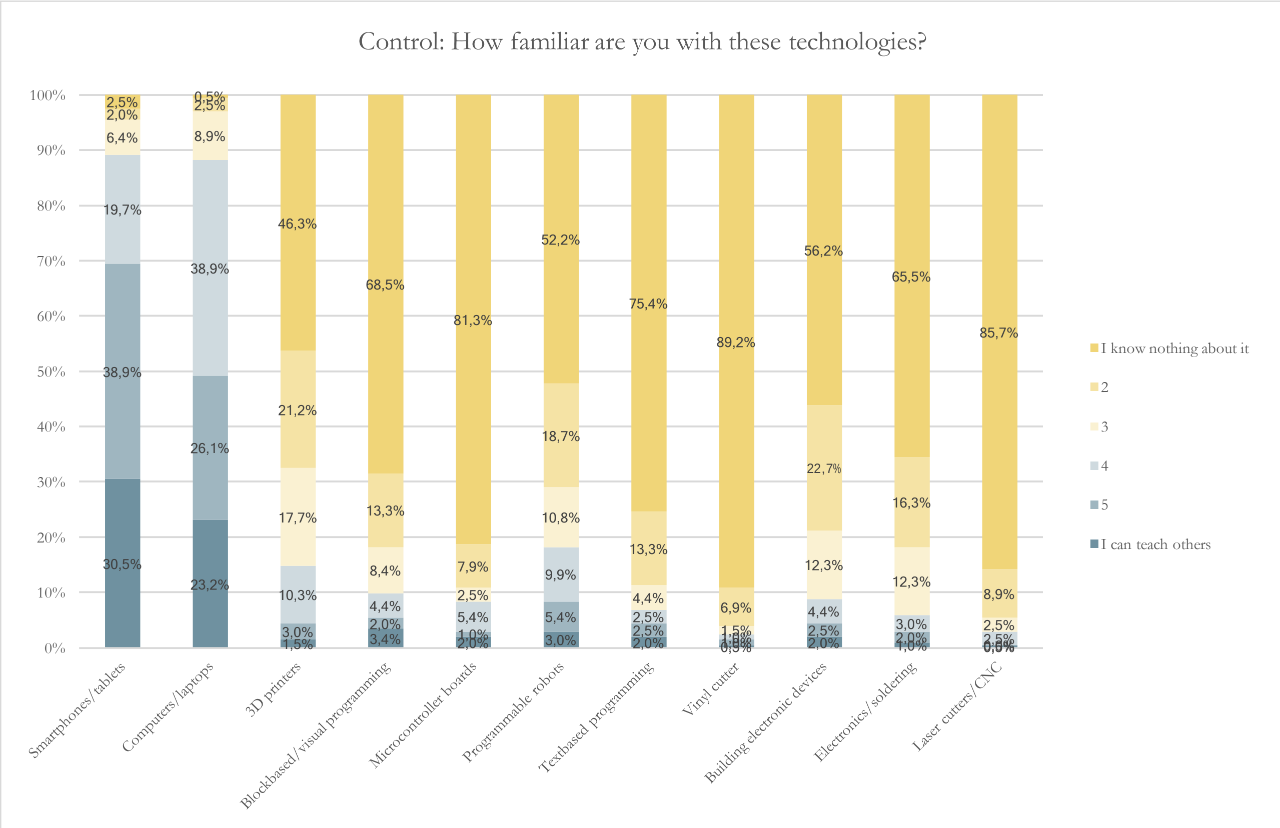

Figure 18: Control group students' responses self-perceived knowledge of technologies. Arranged in the same order as Figure 16.

For all of the technologies in Figure 16 and Figure 18, the trend is that students from the FabLab group on average rated themselves higher than did students from the control group. When comparing the two groups on each technology without taking the variation between schools into account, this difference was statistically significant for 3D printers, Laser cutters, Microcontroller boards, textbased programming, vinyl cutters, and block-based/visual programming. This result was to be expected since these technologies were and are integral parts of the FabLab@School.dk project. However, when using school as a random variable in our statistical model, and thus when taking the variation between schools within each group into account (see section 3.1), we cannot conclude, that the difference is statistically significant. That is, we cannot conclude, that the results did not happen by chance. The only exception is 3D printers. Here the average weighted score of the control group students was 2.1, whereas on average, FabLab group students rated themselves as 2.8 on the scale of 1 to 6 of how familiar they were with the 3D printer. This difference was statistically significant. Thus, we conclude that regardless of the school, digital fabrication was introduced to, students did on average attain higher levels of self-perceived knowledge of 3D printers than they would have if their schools had not been part of the project.

4.6.1. Differences between schools within the FabLab group

As depicted in Figure 19, student responses to the question of how familiar they were with the different technologies showed large variations between the four groups of schools (see section 4.3). For example, 42 percent of the students from group one were above the average score (3.5) on 3D printers. For group 2, the number was 46 percent, for group 3 it was 20 percent, and for group 4 it was 19 percent. Thus groups 1 and 2 fared better in students' self-perceived knowledge of the 3D printer than did groups 3 and 4. The overall trends are better viewed when comparing the (weighted) averages of student responses on each technology.

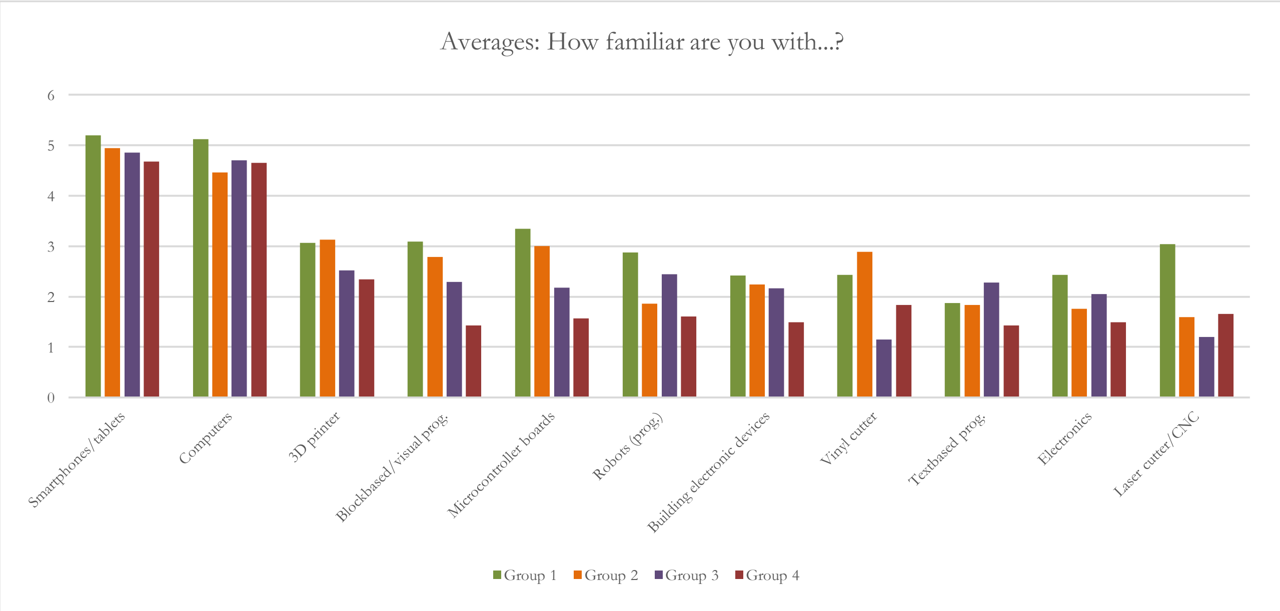

Figure 19: Averages of groups' self-perceived knowledge of technologies.

For all technologies except text-based programming, 3D printers and vinyl cutters, students from group one rated themselves more highly than students from the other groups. By contrast, students from group four rated themselves lower than students from all other groups on all digital fabrication technologies except laser and vinyl cutters. However, this group did not rate themselves lower than the other groups in regards to computers in general, which suggests that their lack of self-perceived knowledge of digital fabrication technologies was not just due to self-perceived lack of understanding of IT in general or low self-esteem. Students from group two on average rated themselves more highly than the other groups on vinyl cutters and 3D printers, whereas students from group three on average had the highest self-perceived knowledge of text-based programming and the second-highest self-perceived knowledge of building electronic devices from scratch, and of electronics and soldering in general.

4.7. Where did the students learn to use digital fabrication technologies?

We were surprised that so many of the students in the control group had worked with digital fabrication technologies. In Figure 20 and Figure 21, we compare responses from the FabLab and control groups with regards to where the students had learned to use the different technologies.

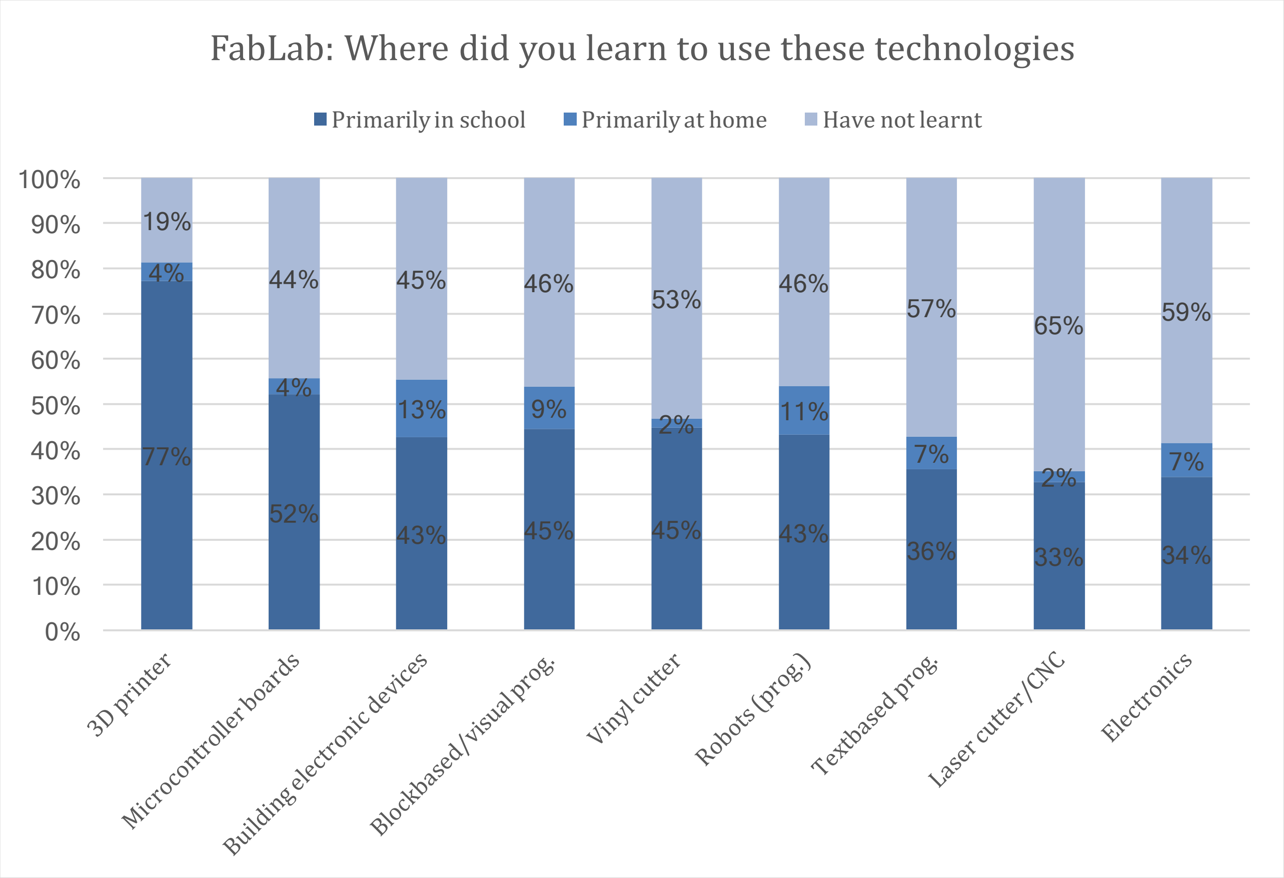

Figure 20: FabLab students' responses to the question of where they learned to use the given technologies. Ordered by "Primarily in school".

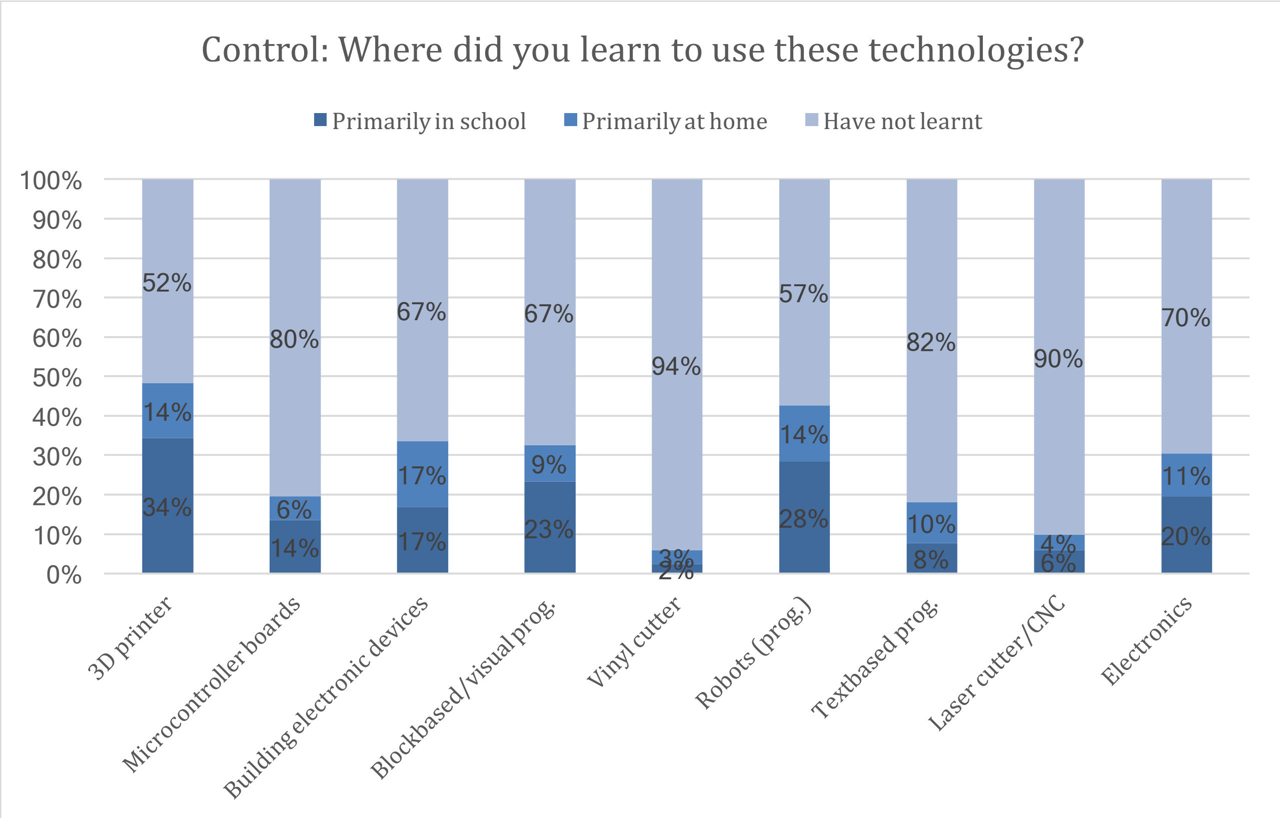

Figure 21: control group students' responses to the question of where they learned to use the given technologies. Arranged in the same order as Figure 20.

Figure 20 and Figure 21 show that it was more common for the control group students than the FabLab students to have learned to use the included technologies at home. Thus one reason the control group students had used more digital fabrication technologies than we had expected, could be because some of them had been able to use them in out-of-school contexts. However, 34 percent of the control group students still reported that they learned to use 3D printers in school. According to their answers, 28 percent of the control group students learned to use programmable robots in school, 23 percent learned to use block-based or visual programming, and 20 percent learned about electronics and soldering, while 17 percent learned to build electronic devices from scratch and 14 percent learned to use microcontroller boards. In conclusion, students from the control group had worked quite a bit with the technologies that were included in the FabLab@School.dk project, and it seems plausible that this is one of the reasons why we did not see statistically significant differences in answers between FabLab and control groups on a range of the questions where we had expected to see such differences. When comparing the FabLab and control groups on where they had learned to use the technologies, however, it was more common for FabLab students to report that they had learned to use the technologies in school. This difference was statistically significant for 3D printers, laser cutters and vinyl cutters, text-based programming, microcontroller boards, and building electronic devices from scratch. In conclusion, according to their answers students from the FabLab group had learned to use digital fabrication technologies in school more frequently than students from the control group. The only exceptions were programmable robots, electronics and soldering, and blockbased/visual programming.

In earlier sections of this report, we have showed how large variations between groups of FabLab schools made comparisons between the FabLab and the control groups difficult. If there would also be large differences between where students within the FabLab group learned to use the technologies, the variations between groups of schools could be caused by students in some schools spending more time with the technologies outside of school than students from other groups. Figure 22 displays the differences between groups one, two, three, and four in regard to where students claimed to have learned the involved technologies.

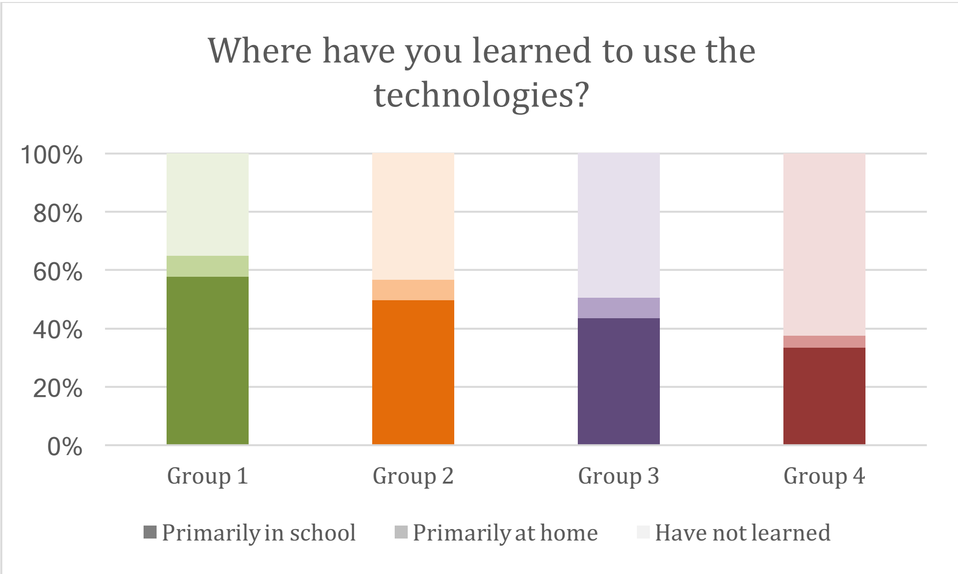

Figure 22: Percentage of the responses in which students in each group reported to have primarily learned to use a technology at school, in the home, or not at all.

As seen in Figure 22, the number of responses in which students claimed to have learned to use digital fabrication technologies at home was seven percent in groups one, two, and three, while it was four percent for group four. Thus in the cases of group one, two, and three, the variation in number of technologies used between schools was only due to more technologies being used in school in group one than group two in which more technologies were used than in group three. In group four fewer technologies were used both in and out of school.

4.8. Conclusion: Technologies, implementation and knowledge

Compared to the 2014 group, the FabLab group on average had an increase in self-perceived knowledge of 3D printers, laser cutters, vinyl cutters, building electronic devices, microcontroller boards, programmable robots, text-based programming, and blockbased/visual programming. Thus FabLab students improved their understandings of digital fabrication technologies.

Students in the Fablab group had been exposed to more digital fabrication technologies, than was the case in the control group. Further, the FabLab students had more experience in using the technologies to work on own ideas, and they had to a higher degree worked with the technologies in school settings.

Thus FabLab students gained experience with a range of digital fabrication technologies. Compared to the control group, students from the FabLab group to a higher degree reported that they had primarly gained knowledge about 3D printers, laser cutters, vinyl cutters, text-based programming, microcontroller boards, and building electronic devices from scratch in school. Further, comparing FabLab and control groups revealed that students in the FabLab group on average reported a higher level of knowledge of 3D printers.

The survey reported here, was designed as a comparison between an experimental group (FabLab group), a control group, and corresponding data from a 2014 survey. However, these comparisons were difficult to make for two reasons. First, the control group students had to an unexpectedly large extent been exposed to digital fabrication. Second, there were very large variations in the implementations of digital fabrication within the FabLab group. Both comparisons between the FabLab, control, and 2014 groups, and the variations within the FabLab group in regard to the use and knowledge of technologies were explored throughout chapter 4. There is no central strategy in the FabLab@School.dk project with regards to how many and which technologies to implement and how to implement them. We see this as the main reason for the large amount of variation that we found within the FabLab group in regard to which technologies and how many technologies, the schools used.

The data discussed in chapter 4, suggested a correspondence between the number of technologies used, the number of technologies used to work with own ideas, and the self-perceived knowledge of these technologies.

5. Students' design knowledge

In this chapter, we explore how students reported in answer to questions regarding design, design processes, and a designerly stance towards inquiry.

5.1. Designerly stance towards inquiry

As stated in the introduction the survey consisted of several different types of questions. More specifically, the questions ranged from items with Likert-type scales asking about opinions or self-perceived abilities, through multiple-choice tasks, to open-ended problems. One such problem was the task of how to prevent seniors with dementia getting lost (and sometimes dying before they were found) from their care homes. This was an example of a design problem, a so-called *wicked problem* (Buchanan, 1992). It is a characteristic of wicked problems that they are indeterminate. That is, they do not have one true solution. Thus, by definition, suggesting a solution to a wicked problem requires judgment. According to the pragmatist design literature (e.g. (Löwgren & Stolterman, 2004)), this judgment is exercised on the basis of knowledge generated in an iterative design process, entailing inquiry into the problematic situation. As described by Cross (Cross, 2011), a designer would approach the wicked problem by means of an investigative (design) process. However, as evidenced in Hjorth et al. (Hjorth, Iversen, Smith, Christensen, & Blikstein, 2015), processual thinking and complex problem-solving were not part of the current Danish school reality in 2014. That is, the students were inclined to suggest solutions and invent ideas, rather than approaching the problem as a complex challenge in need of further investigation. In (Christensen, Hjorth, Iversen, & Blikstein, 2016), it is described how this question distinguishes between students suggesting a designerly stance towards inquiry and those suggesting a stance of technical rationality. Students with a stance of technical rationality tend to suggest finalized solutions based on their (lack of) existing knowledge rather than suggest paths for inquiry into the problematic situation. In the 2014 survey, fewer than 3 percent of the students suggested taking a designerly stance towards inquiry. Rather, students in the 2014 survey suggested finalized solutions such as better fencing, locks on the doors, more personnel, or tracking devices. In our 2016 survey (reported here), we included the same question with the same wording, with the aim of investigating whether more students would suggest a designerly stance towards inquiry this time. Students in the FabLab@School.dk project had in many cases been engaged in designing solutions to real-world problems, and had used the design process model developed in the Child–Computer Interaction Group at Aarhus University (see section 5.4, (Hjorth, Smith, Loi, Iversen, & Christensen, 2016; Smith et al., 2015)). Compared to most other design process models used in educational practices, this model places more emphasis on field studies—on inquiring into the problematic situation of real-world problems, as well as on argumentation and reflection, throughout the entire design process. The explicit focus on exploration and reflection in the context of real-world problems gave up hope that more students would take a designerly stance towards inquiry when faced with the wicked problem on the survey.

The dementia case was a real-world problem that was being discussed in the Danish media at the time of the 2014 survey.[2] The wording of the open-ended question translates from Danish to the following:

[2] The number of elderly refers to a Danish context (population approx. 5.7 million).

> At the beginning of the year 2014, nine grandparents disappeared from their care home because of their loss of memory (dementia). The problem for the care home is how to create security for these seniors without taking away their freedom.
>
> If you were asked to solve this problem, what would you do?[3]

Posing a good question that could probe the current state/understanding of *design*, *process*, and *inquiry* among the students in a valid way was difficult. We are aware that the framing of the question could have prompted respondents to come up with a solution rather than a process. Nevertheless, as described in (Christensen et al., 2016), a comparison of answers to this question with those of budding university-level designers did seem to significantly distinguish between stances of technical rationality and more designerly stances.

In our report on the 2014 survey, we wrote:

> ... it is our assumption that responses to similar questions, between the baseline survey and the endline survey, will reveal a shift in the number of students who have been exposed to design processes in FabLab@School activities. The assumption is, that it will be more frequent for the latter to suggest processual and investigative approaches to complex challenges. (Hjorth et al., 2015)

[3] Translated from Danish.

As can be seen in Figure 23 below, this was indeed the case, but only for a very small number of students.

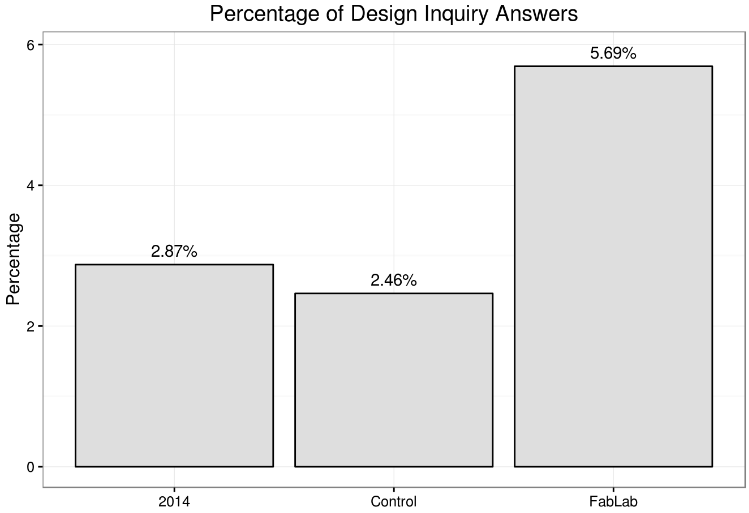

Figure 23: Percentage of students suggesting an inquiry while responding to the dementia problem. Numbers are shown for the 2014 survey, the control group, and the FabLab group.

As the Figure 23 shows, 5.69 percent of the FabLab group students suggested taking a more designerly stance towards inquiry. In the control group, the number was 2.46 percent. Since the percentage among the FabLab students is more than double that among the control group students, this could at first seem like a significant result. Once school was included as a random variable in order to control between-school variation, however, the difference was not statistically significant. Again, this points to a large variation between the schools. At the same time, fewer than 6 percent of the FabLab@School.dk students were suggesting an inquiry: the rest were coming up with finalized ideas such as fencing, tracking, or hiring more personnel (as in the 2014 survey). There was therefore insufficient data to compare the groups of schools. In the FabLab@School.dk project, inquiry and field studies have had a prominent position, and the teachers from all the schools had participated in conferences, workshops, or co-development of activities with the research group, which has emphasized inquiry and investigation. Teachers from six of the FabLab group schools had taken a master's course on design processes and digital fabrication, thus the idea of a designerly stance towards inquiry should not have been new to the teachers of the FabLab group students. However, the lack of a statistically significant difference between the control and the FabLab groups highlights that a designerly stance towards inquiry is perhaps not easily acquired.

5.2. Development of design literacy

It is one thing to know technology, another to be able to use it, and yet a third thing to understand how it was created, how it functions, and how it might influence our lives. These last questions are difficult to probe in a questionnaire—not least because they are difficult for 11–15 year olds to understand, with the associated result that it is also difficult to judge their knowledge on such complicated questions. However, since one of the aims of the FabLab@School.dk project was precisely to promote such understandings, we asked students from the FabLab group to reflect on to the degree to which the projects with digital fabrication technologies had helped them understand, reflect on, and work with technologies in a broader sense.

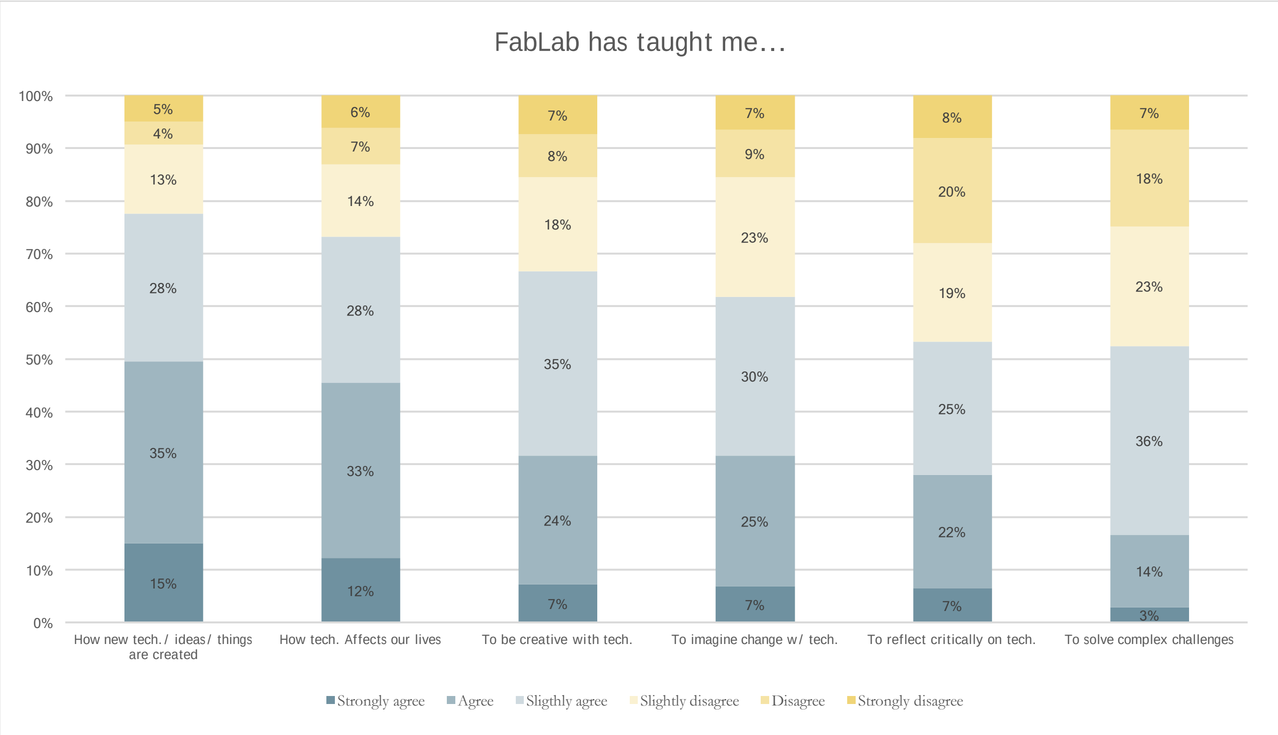

Figure 24: The degrees to which FabLab students agreed with proposed learning outcomes. Ordered by strongly agree.

As can be seen in

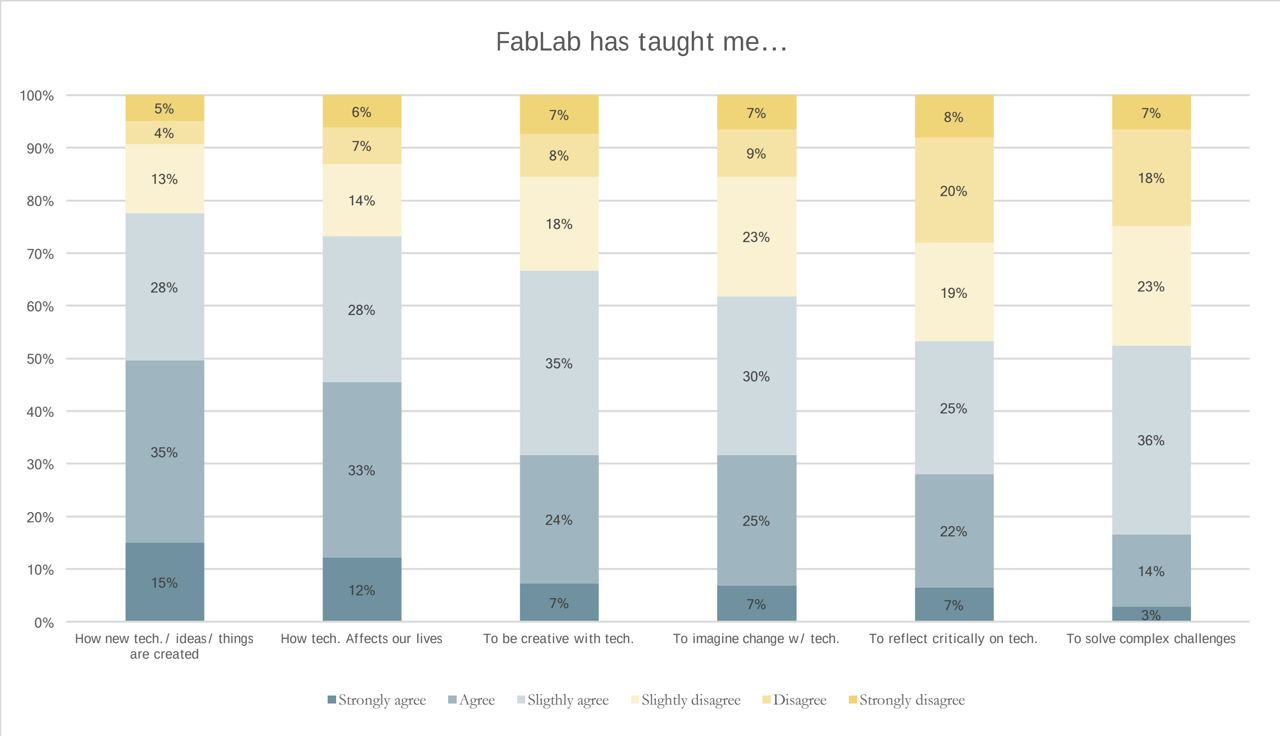

Figure 24, half of the students (50 percent) in the FabLab group either agreed or strongly agreed that the projects with digital fabrication technologies had helped them understand how new technologies are created; 9 percent disagreed or strongly disagreed, whereas 41 percent either agreed slightly or disagreed slightly. On average, the students in the FabLab group rated this question as 4.3 on a scale of 1 to 6 (the average being 3.5). On the question of whether or not projects with digital fabrication technologies had helped them to understand how technology is affecting the way we live, the average student score was 4.1. Thirteen percent of the students disagreed or strongly disagreed, whereas 46 percent agreed or strongly agreed. As in the question on understanding how technologies are created, 41 percent of the students either agreed or disagreed slightly. On average, students agreed that working with digital fabrication technologies had improved their ability to work creatively with technology (avg. 3.8), imagine how to create change with technology (avg. 3.8), and reflect critically on their own use of technology as well as that of others (avg. 3.5). More than half (52 percent) of the students in this FabLab group answered that working with digital fabrication technologies had to some degree helped them to solve difficult or complex challenges. However, most of these responses were in the slightly agree category (36 percent of the total responses). Only 14 percent of the students agreed, and 3 percent agreed strongly. Thus while students in the FabLab group on average reported that they had become better at understanding how technologies are created, how they affect our lives, how to work creatively and imagine change with technologies, and how to reflect critically on their use, these students on average did not see how this work had also strengthened their abilities to solve difficult and complex challenges in general. While we might have predicted that working in design processes with the aim of solving complex challenges would prepare students for future complex challenges in general, it is possible either that these students did not fully appreciate their own development, or that this development did not take place. In many schools, students had fewer projects with complex challenges than expected, and therefore if students' did not develop abilities to solve complex challenges, it could point to the possibility that the development of what we have elsewhere termed design literacy (Christensen et al., 2016; Smith et al., 2015) takes more time than was spent on such projects on average within the FabLab group. It could of course also point to missing qualities of the implementations of digital fabrication. The questionnaire did not yield any data to distinguish between types of implementation, but as reported above (se section 4.3), interviews with students pointed to four archetypes of implementation. Based on these four types, school were divided into four groups. In the next section, we will compare the responses of students from these groups.

5.3. Development of design literacy among groups of schools

As can be seen in

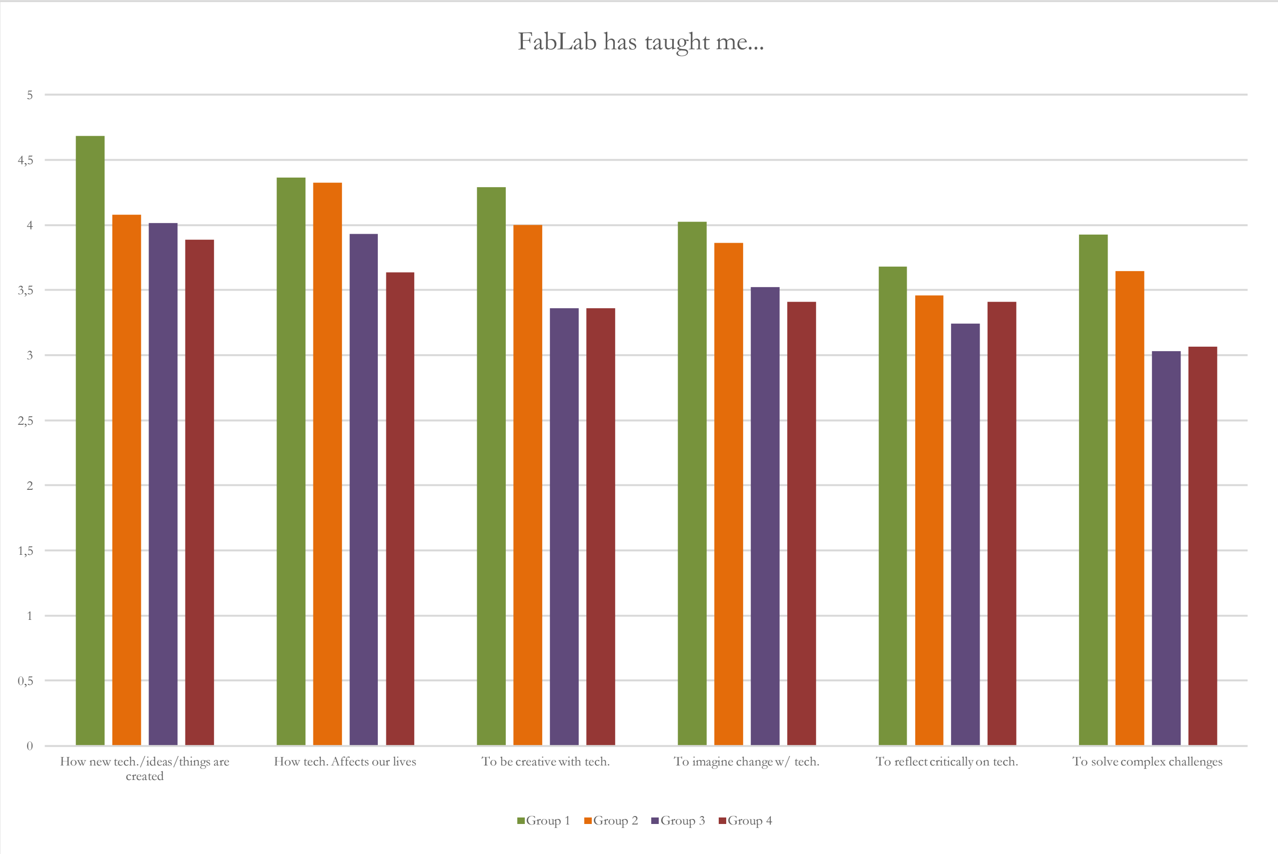

Figure 25, there were large differences between the groups of schools in regard to students' self-perceived outcomes of their work with digital fabrication. Further, these differences followed one of the trends described above—that students from group one seemed to have benefited the most from work with digital fabrication technologies, whereas group four seemed overall to have benefited the least. Groups two and three were placed between groups 1 and 4 on most questions.

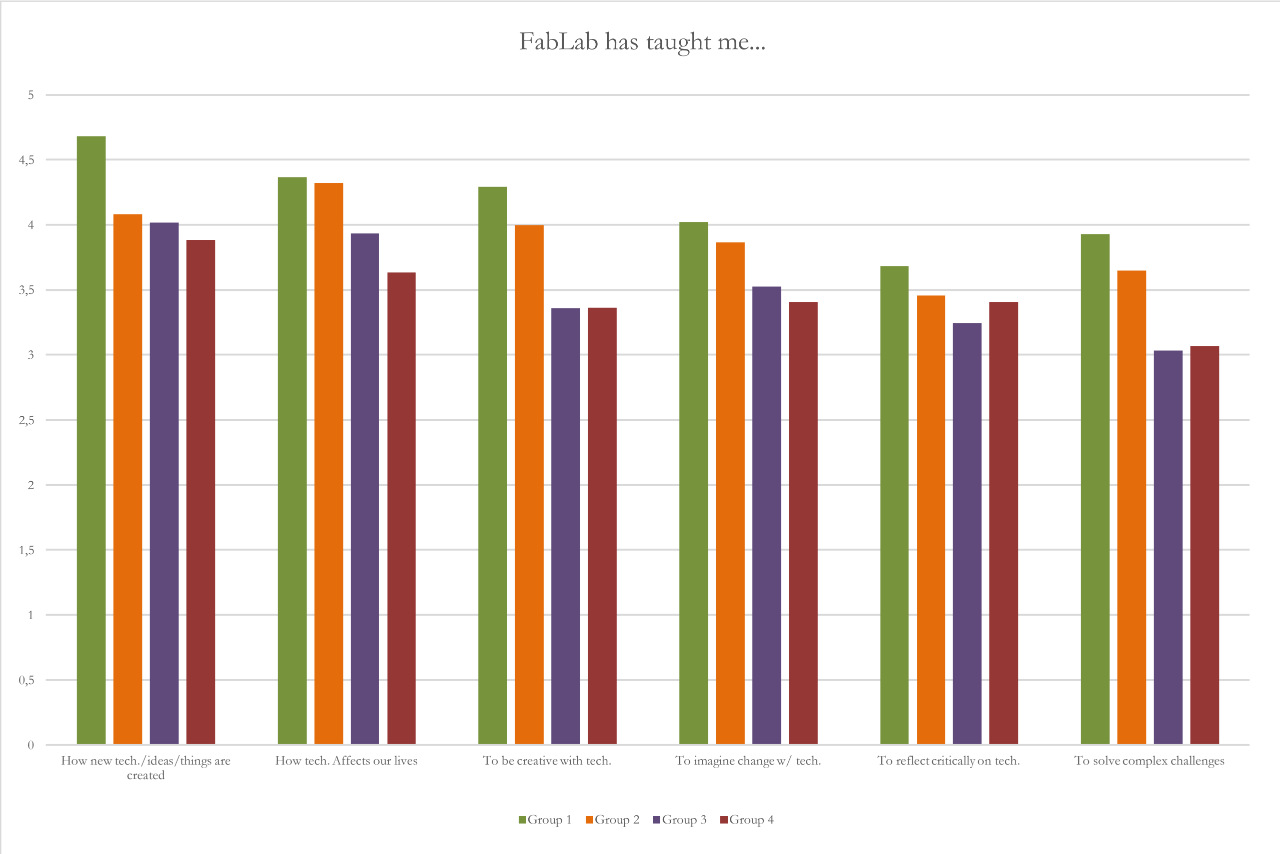

Figure 25: Average responses from students within groups 1 through 4 on questions regarding their outcome of work with digital fabrication technologies in school. Note, that the average of the scale (which was from 1 to 6) is 3.5. Ordered by average score for the entire FabLab group.

On all of the questions reported in Figure 25, more than 50 percent of the students in the overall FabLab group answered that they did to some extent agree. As reported above, however, the average response on whether or not work with digital fabrication technologies had helped the students to solve difficult or complex challenges was below the 3.5 average. As can be seen here, only group one and two students on average scored the question above 3.5. Thus only in these schools did students on average agree that working with digital fabrication technologies had prepared them for taking on complex challenges. If the development of skills for taking on these kinds of challenges is a priority of work with digital fabrication technologies, it therefore seems important that these technologies be used in ways that mirror the approaches taken by school groups one and two rather than three and four. The responses followed the same pattern on the question of whether or not work with digital fabrication technologies had helped the students to work creatively with technology. One might therefore suggest that working creatively with technologies is a prerequisite if working with digital fabrication technologies is to further students' abilities to take on difficult or complex challenges. All groups on average agreed that working with digital fabrication technologies had helped them better understand how technologies, ideas, and things were created. However, group one stood out, with a very high average of 4.7. On average, students from all groups agreed that working with digital fabrication technologies had helped them understand how technology was affecting their lives, but only students from group one on average responded that they had become better at critically reflecting on their own and others' use of technologies. Being able to imagine how to create change with technology was something on which students from group one, two, and three on average responded they become better at (4.0 and 3.9, and 3.5 respectively), whereas students from group four did not (3.4).

In sum, students from all four groups on average reported that working with digital fabrication technologies had helped them to better understand how technologies, ideas, and things are created, as well as how technology is affecting our lives. Further, the data suggests that in groups where students on average reported that they had become better at working creatively with technology and at solving complex challenges, these gains were greater.

5.4. Structuring the design processes with the design process model

As part of the FabLab@School.dk, the Child–Computer Interaction Group at Aarhus University developed the AU design process model depicted in Figure 26 (Hjorth et al., 2016; Smith et al., 2015).

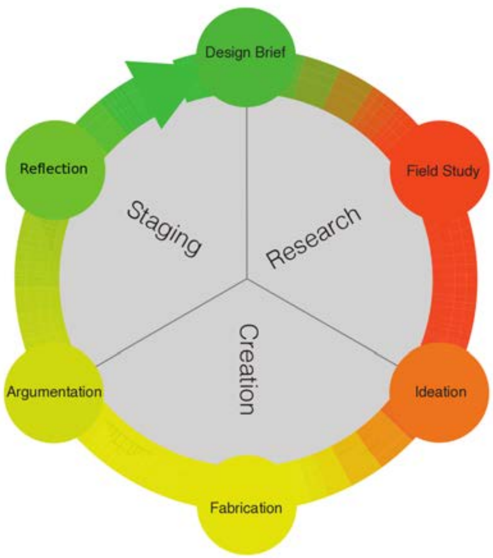

Figure 26: The AU design process model.

This process model differs significantly from other design process models used in educational practices (see (O'Brien, 2016) for an account of different design process in education) in its enhanced focus on field studies, a feature that corresponds with teaching material, which was developed by AU, and which was used by most teachers in the FabLab@School.dk project. It was up to the teachers whether or not they wished to use the design process model, but most schools have chosen to implement it in their teaching. In the FabLab group a total of 69 percent of the students reported that they used the model, 11 percent did not know, and 20 percent claimed they had not used it. Figure 27 explores students from the FabLab group's self-perceived knowledge of the different parts of the AU design process model.

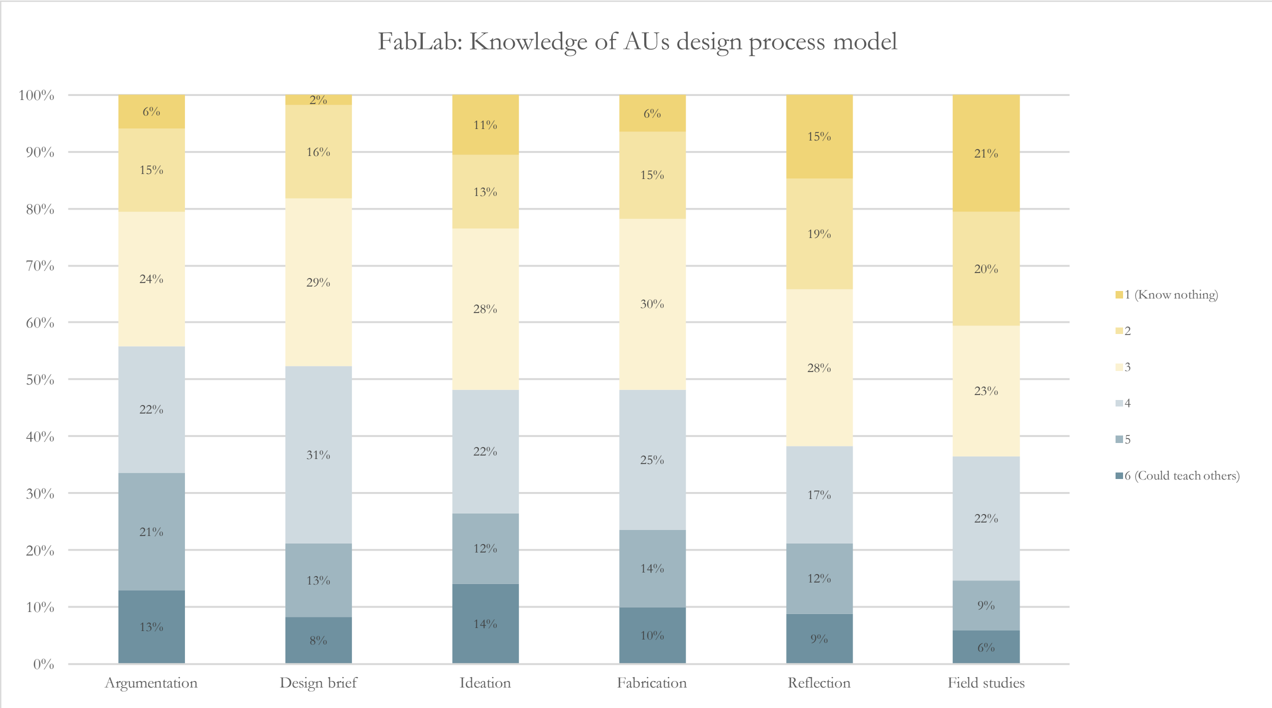

Figure 27: Students from the FabLab group's self-perceived knowledge of the various parts of the AU design process model. Students were asked to rate themselves on a scale of 1 (I know nothing about it) to 6 (I could teach others about it). Ordered by the sum of entries in categories 4, 5, and 6.

As depicted in Figure 27, more than 50 percent of the students in the FabLab group perceived of themselves as belonging to category four, five, or six in regard to the argumentation (56 percent) and design brief (52 percent) parts of the process. Between 40 and 50 percent of students placed themselves in this category in regard to ideation (48 percent) and fabrication (48 percent), whereas below 40 percent reported this for reflection (38 percent) and field studies (37 percent). Thus the data suggests that students on average found field studies and reflection to be the most difficult parts of the process or that there had been less emphasis on teaching these phases of the process.

5.5. Use and knowledge of the design process model in groups of schools

Only students who reported that they had used the design process model were asked how well they knew the different parts of the model. There were, however, variations between the groups of schools in regard to the degree to which they had used the design process model. These variations are depicted in Figure 28 and Figure 29.

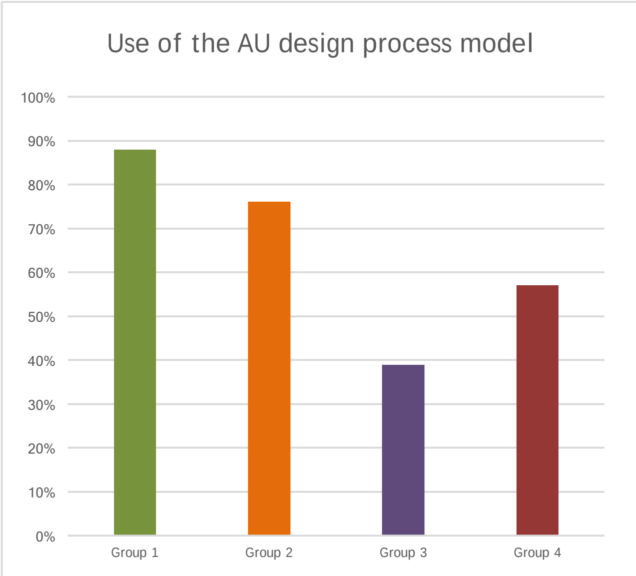

Figure 28: Percentages of students from each school group that reported using the design proces model.

As can be seen in Figure 28 there were large variations between the groups in regard to their reported use of the AU design process model. Eighty-eight percent of students from group one reported that they had used the model. The same was true for 76 percent of the students in group two. In group three, only 39 percent of the students reported that they had used the design process model. Fifty-seven percent of the students in group four reported that they had used the model. Students from groups three and four were more heterogeneous in their responses to whether or not they had used the model in school. Students' self-perceived knowledge of the various parts of the AU design process are shown in Figure 29.

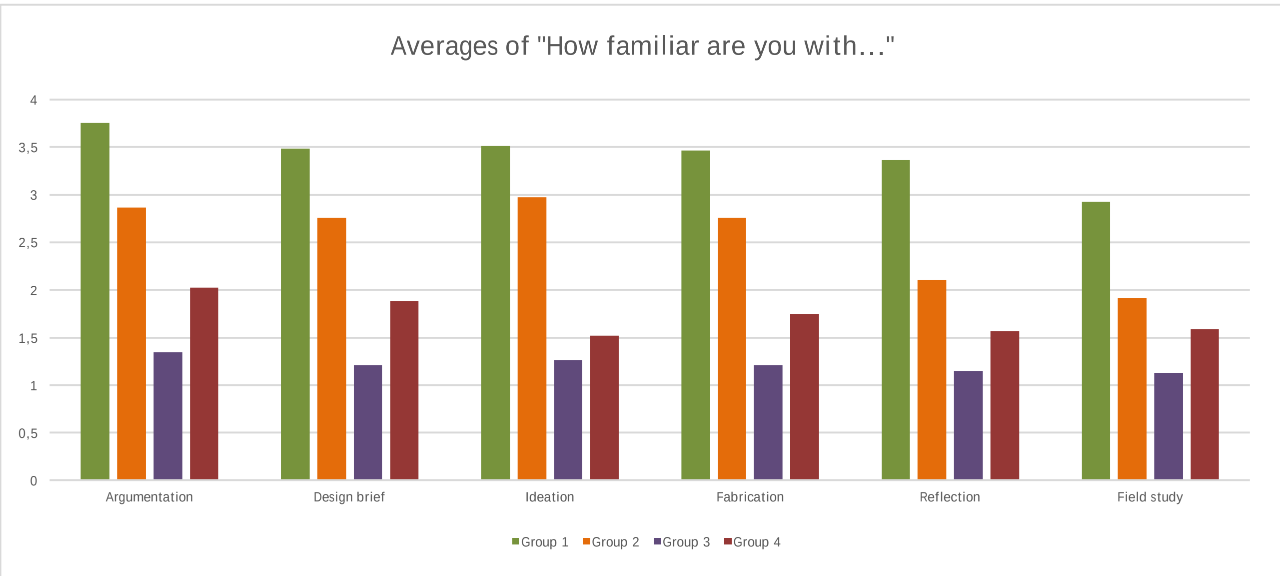

Figure 29: Group averages of the question of how familiar students are with the different parts of the design process model. Ordered by student averages in the FabLab group in total

When looking at the averages of self-perceived knowledge of the different parts of the design process model within the different groups depicted in Figure 29, students from group one on average rated themselves higher than students from all other groups on all items. Second on all parts of the model were students from group two. The students from group three who had responded that they had used the design process model rated themselves below all other groups on average. Students from group four on average rated themselves between students from groups two and three. The data suggests that teachers from group one had used the design process model more than teachers from groups two, four, and three. In sum, the data suggests a correspondence between the number of students from a given group that reported using the model and the self-evaluated level of these students. When the number of students who responded they had used the model and the self-perceived knowledge of these students both follow the same pattern, it seems plausible to us that this has to do with the emphasis placed on the design process model or the amount of time spent on projects structured around this model. This leads us to conclude that the data suggests that students from group one had worked more on projects structured around the AU design process model, than had students from group two, who in turn had worked more on such projects than students from group four. Finally, the data suggests that students from group three had worked the least on projects structured around the AU design process model.

When comparing the use of the AU design process model to students' self-perceived outcomes of the work with digital fabrication, the data suggests that the more students work in processes structured around the design process model, the more they had been taught to solve complex challenges and reflect critically on the use of technology (as measured by self-evaluation). Further, group three and four scored themselves at equal levels in regard to the degree to which work with digital fabrication had helped to work creatively with technology. Since students from group four had worked with fewer technologies and had used fewer technologies to work on own ideas than students from group three, it seemed plausible, that students from group 3 should have been gained more in respect to being creative with technology from working with digital fabrication. It seems, however, that not structuring the work with digital fabrication around the design process model, hindered students from group three in getting the outcome that would have been expected. Thus our data suggests that students gain more in regard to complex problem solving, critical reflection on the use of technology, and the ability to work creatively with technology, when their work with digital fabrication is structured around a design process model which is both systematic and iterative.

5.6. Conclusion: Towards design literacy

In conclusion, we do see some steps towards design literacy among some students from some schools, but the results highlight that this is a very difficult goal for teachers and students to work towards. In our interpretation, the data suggests that scaffolding and structuring the work with digital fabrication in schools around a design process model like that developed within the FabLab@School.dk project furthers the development of design literacy.

As reported above, there were large differences between the school groups. In groups one and two, students on average reported that they had become better at solving difficult or complex challenges. When looking at the use of the design process model as evidenced by student responses to questions on whether they had used the model and the degree to which they knew the different parts of the model, our data suggests that students gain more in regard to complex problem solving, critical reflection on the use of technology, and the ability to work creatively with technology, when their work with digital fabrication is structured around a design process model. We therefore find it plausible to suggest that in schools where the design process had to a high degree been structured and scaffolded by the use of a design process model, students came to feel more secure about thinking and acting innovatively (with technology) on societal challenges. However, more research is needed in order to substantiate this claim.

We asked the students to evaluate their outcome of work with digital fabrication in school, and on average, students from the FabLab group reported that work with digital fabrication had helped them to understand how new technologies, ideas, and things were created, to imagine how they could create change with technology, and to be creative with technology. In our interpretation, this translates to the conclusion that according to the students themselves, as a result of the FabLab@School.dk project they had become better at *thinking and acting innovatively with technology*.

Further, the students on average agreed that as a result of working with digital fabrication they had become better at understanding how technologies affect our lives and at critically reflecting on their own and others' use of technology. However, they did not on average agree that they had become better at solving difficult or complex challenges. In our interpretation, this translates into the conclusion that contrary to students from the groups 1 and 2, students in the FabLab group did not on average agree that they had developed better abilities for using the technology "on societal challenges." This discrepancy emphasizes the variation between implementations among groups of schools. Thus many students did not experience the long-term commitment to working with complex problems in design processes.

As mentioned previously, within the FabLab@School.dk project, we viewed students' "abilities to think and act innovatively (with technology) on societal challenges" as a key goal of education in the twenty-first century. We hypothesized that the project had the potential to further such abilities. In line with this, we have elsewhere (Smith et al. 2015, Christensen et al. 2016) used the term "design literacy" to denote those parts of design competence to take on complex or wicked problems which are relevant to all students in the twenty-first century. In our investigations of what it means to be design-literate, we have singled out a designerly stance towards inquiry as an important aspect. In the survey reported here, we used the DeL tool (Christensen et al., 2016) to gauge the students' stances towards inquiry. This did not however allow us to conclude that students had changed their stances because of the FabLab@School.dk project. Our lack of ability to show a statistically significant increase in the number of students taking a designerly stance towards inquiry highlights that such a stance and thus design literacy does not appear of its own accord when digital fabrication technologies are introduced into the classroom. Rather, the development of design literacy seems to require long-term commitment to systematic work with complex problem solving scaffolded by an iterative design process model.

6. Student motivation in the FabLab

In the literature on digital fabrication in education, the motivational aspects have often been pointed to as a primary objective for implementing work with these technologies (see e.g. (Martinez & Stager, 2013)). In the survey reported here, we wanted to investigate if students in the formal educational settings of FabLab@School.dk would likewise evaluate work with digital fabrication in education favorably.

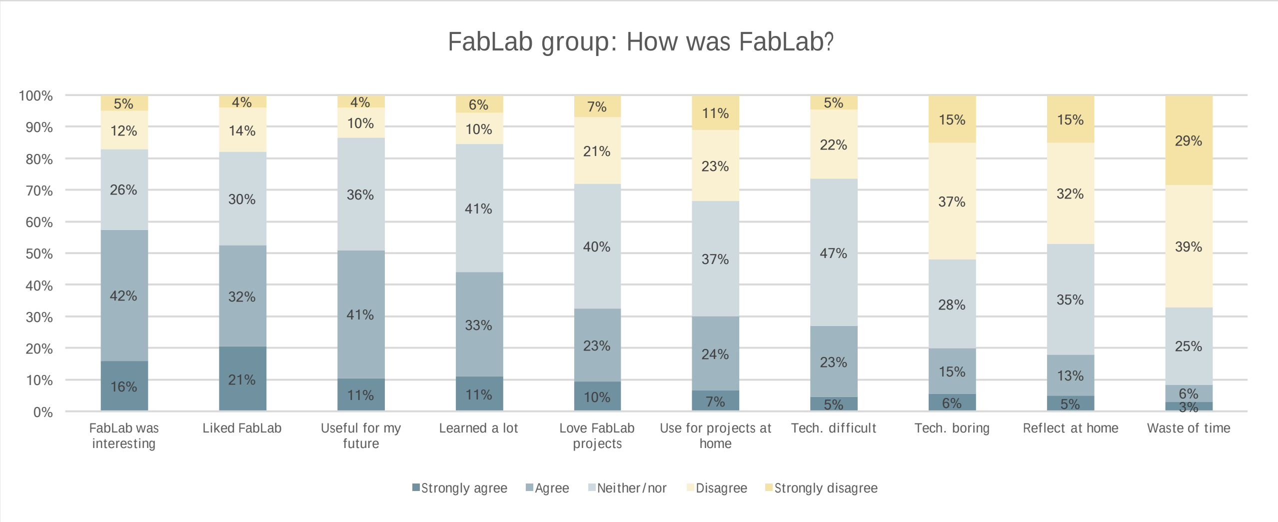

Figure 30: Responses from the FabLab group on the degree to which they agreed with statements about motivational aspects of the work with digital fabrication. Ordered by the sum of strongly agree and agree

Fifty-eight percent of the students from the FabLab group agreed (42 percent) or strongly agreed (16 percent) that they found the work in the schools' FabLab or makerspace interesting. Fifty-three percent agreed (32 percent) or strongly agreed (21 percent) that they had liked the work. Fifty-two percent of the FabLab students agreed (41 percent) or strongly agreed (11 percent) that the work with digital fabrication technologies in school would be useful for them in the future. Forty-four percent agreed (33 percent) or strongly agreed (11 percent) that they learned a lot from working in their school's FabLab or makerspace. Further, 33 percent of the students did to some extent agree that they loved doing projects with digital fabrication technologies (23 percent agreed, 10 percent strongly agreed). Thus, on average, students from the FabLab group found work with digital fabrication interesting (3.5) and useful (3.4). They liked (3.5) and even loved (3.1) projects in the FabLab or makerspace, and according to the students, they learned a lot (3.3).[4]

On average, the students reported that they did not find FabLab to be a waste of time (2.2) and they did not find the technologies boring (2.6). They did not report that they reflected on what they learned about digital fabrication technologies when they were at home (2.6), and they did not on average report that

[4] In order to calculate an average, the categories were assigned values which ranged from 1 (Strongly disagree) to 5 (Strongly agree). Such calculations entail the assumption that there are equal intervals between the different points on the scale. The mid-point of the scale is 3.0 and averages above 3.0 thus mean that students on average agree.

they would like to use the technologies for projects outside school (2.9), though 31 percent agreed or strongly agreed that they would. Approximately an equal number of students to some extent agreed (28 percent) or disagreed (27 percent) that the technologies were difficult. Overall, students from the FabLab group had positive experiences with working with digital fabrication and they found the work relevant. As with most of the other questions, however, there were noticeable differences between the school groups.

6.1. Comparing school groups on student motivation

Figure 31 compares student experiences with digital fabrication between the four groups of schools within the FabLab group.

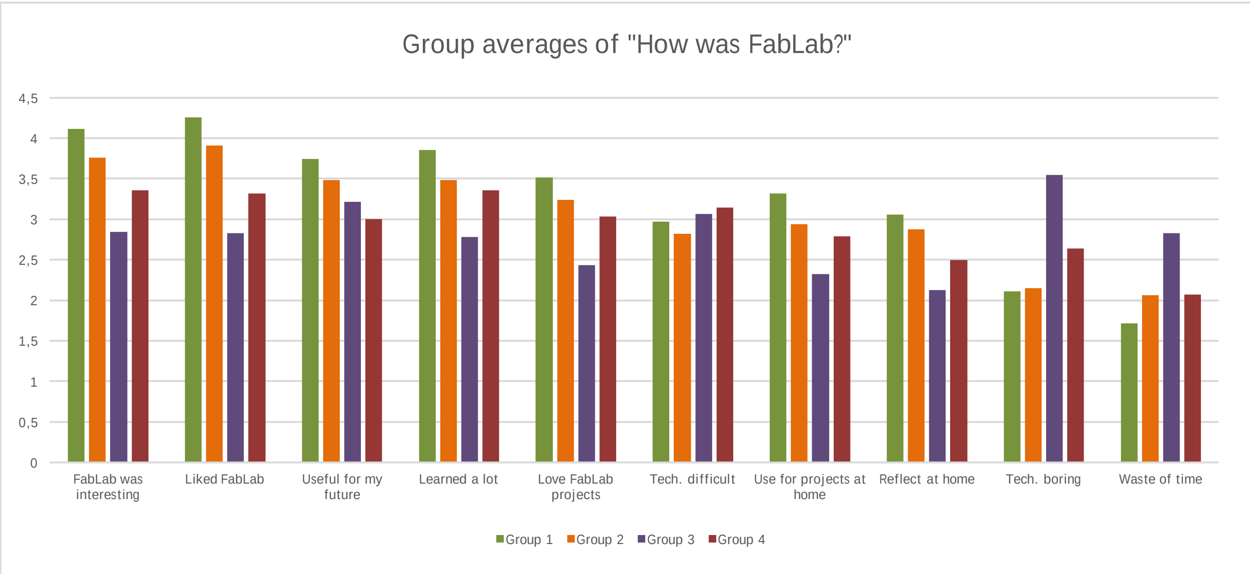

Figure 31: Group averages of answers on to which degree students from the groups agreed with the statements. Averages are calculated by assigning values of 1 (Strongly disagree) to 5 (Strongly agree). This entails the assumption, that intervals between the different categories are equal. Ordered by averages for the entire FabLab group.

As shown in Figure 31, students from group one and two were very positive about their experiences with digital fabrication in school. No students from group two and only 6 percent of the students in group one disagreed or strongly disagreed with liking the work in the FabLab or makerspace at their school, while only 3 and 6 percent from group one disagreed or strongly disagreed respectively with the statement “I learned a lot in FabLab/makerspace” (Not depicted here). Group one really stood out in the extreme answer categories: 49 percent of the students strongly agreed with liking being in their school’s FabLab/makerspace, and 51 percent strongly disagreed that this was boring.

Comparing the average scores given by students from the various groups, the picture of students in groups one and two as the most positive is confirmed. On average, students from these two groups reported that they found being in their school’s FabLab/makerspace interesting (4.1 and 3.8 respectively), that they liked being in the FabLab/makerspace (4.3 and 3.9), that what they learned about digital fabrication technologies would be useful for their futures (3.7 and 3.5), that they learned a lot in the

FabLab/makerspace (3.9 and 3.5), and that they loved doing projects with digital fabrication technologies (3.5 and 3.2).[5] The least motivated students were those in group three. These students on average did find the technologies useful for their futures (3.2), but they did not find FabLab/makerspace interesting (2.8), they did not on average like being in their school's FabLab/makerspace (2.8), they did not find they had learned a lot (2.8), and they did not love projects with digital fabrication technologies (2.4). They did, however, find the technologies boring (3.5).

In sum, the students from groups one and two were the most positive about their work with digital fabrication. Again, group one stood out. Students from this group were the most motivated with regard to their work with digital fabrication in school. Students from group three on the other hand stood out as the least motivated. These students were also the ones, who had to the least degree worked with real-world problems, and whose work had to the least degree been structured around the AU design process model. While the degree to which such work was structured by a design model could correlate to student motivation, more research is needed in order confirm or reject this hypothesis.

[5] As before, in order to calculate an average, the categories were assigned values which ranged from 1 (Strongly disagree) to 5 (Strongly agree). Such calculations entail the assumption that there are equal intervals between the different points on the scale. The mid-point of the scale is 3.0 and averages above 3.0 thus mean that students on average agree.

7. Conclusion

In this report, we discuss a range of survey items, developed to gauge students' abilities to use, master and understand digital technologies, as well as their abilities to think and act innovatively with technology on societal challenges. In the report, we compare a group of students, who have worked with digital fabrication technologies as part of the FabLab@School.dk project in the period from 2014 to 2016 (FabLab group) with a group of students, who have not been a part of the project (control group), as well as to responses from our 2014 survey. Findings from these comparisons are discussed in section 7.1. One main finding was that there were large variations between schools within the FabLab group across a range of items discussed below. These variations have been investigated through comparisons of groups of schools within the FabLab group. Based on group interviews with students from eight FabLab schools, we divided these schools into four groups characterized by their answers within four categories of (1) the number of technologies applied from the teacher's and school's repertoire, (2) the degree to which the work with digital fabrication technologies had been framed as explorative design processes, (3) the degree to which the students had worked systematically with complex problem-solving, and (4) the degree to which the work with digital fabrication technologies was seen as an integrated part of school work in general. Findings from comparisons between groups of schools within the FabLab group are discussed in section 7.2.

7.1. FabLab group, control group, and the 2014 survey

As a group, the FabLab students had been exposed to more technologies than the control students and had more experience in using them to work on their own ideas. From the data (see Figure 3) it was clear that students in the FabLab group had on average been exposed to more digital fabrication technologies (4.4 technologies per student on average) than those in the control group (average: 2.2). Further, as shown in the figure, the FabLab students had tried to work with their own ideas with a wider range of technologies (see Figure 10). This suggests that FabLab students had more experiences in working with their own ideas using digital fabrication technologies than students from the control group. However, students from the control group had worked with more digital fabrication technologies than expected (see Figure 5. According to their answers (see Figure 20), students from the FabLab group had learned to use a larger number of digital fabrication technologies in school than students from the control group had (see Figure 21). The control group students to a greater extent had to gain experience with digital fabrication in out-of-school contexts, but their answers demonstrate that advanced technologies such as 3D printers and robotics are becoming more common both in schools and in society in general.

Compared to the 2014 group (see Figure 17), the FabLab group had significantly higher self-perceived knowledge of all digital fabrication technologies except electronics and soldering. This suggests that students in the FabLab@School.dk project on average perceived of themselves as more knowledgeable about digital fabrication technologies than they would have at the beginning of the project.

Stances towards inquiry are difficult to change. In the FabLab@School.dk project, inquiry, field studies, and a designerly stance towards inquiry had been emphasized. However, there was no statistically significant difference between the 2014, control and FabLab groups in regard to students' stances towards inquiry, and this highlights that a designerly stance towards inquiry is not easily acquired and require a long-term commitment to working with real-world problems.

7.2. Comparing groups of schools

In this section, we present Figure 32 to compare groups of schools across a range of the topics discussed in the present report. Here, the number of technologies used by students in school groups and the number of technologies used to work with students' own ideas are depicted in the same chart as combined scores on items of motivation, knowledge of technologies and the design process model, and students' self-perceived outcomes. It is important to note, however, that the various items are not all measured on the same scale. The number of technologies is measured as a simple count, while knowledge of the design process model and digital fabrication technologies as well as students' outcomes are measured on 6-point Likert scales with a median of 3.5. The motivational score is measured on a 5-point Likert scale with a median of 3.

7.2.1. Calculations of the combined scores

Scores in Figure 32 below were calculated as follows. The number of total technologies used by a school group and the number of technologies used to work on own ideas are average counts of technologies within the group. The scores for knowledge of the design process model and the scores for knowledge of digital fabrication technologies are simple averages across included items and students in the group. In order to create a single score for student motivation, we averaged scores on the first five items and the inverted scores on the last two items in Figure 31. The last three scores in Figure 32 are all made from data depicted in Figure 25: Creativity with technology is the average of scores on "To be creative with technology", "To Imagine change with technology", and "How new technology, ideas, and things are created." Critical reflection with technology is the average of "To reflect critically on technology" and "How technologies affect our lives." The score for complex problems is made of the same values as "To solve complex challenges."

Figure 32: Combined scores for different parts of the questionnaire. Scores are averages of scores reported above. The design process model and Technologies scores are the group average scores on all items within their respective sections. The other scores are made up of only some of the scores from their respective sections. The different items are calculated differently and with different scales, and therefore they cannot be compared directly.

As depicted on Figure 32, there were large variations within the FabLab group in regard to the number of technologies encountered, design process structuring, student motivation, and the students' self-perceived knowledge and outcomes. There was no centralized strategy in the FabLab@School.dk project in regard to how many technologies to use, which technologies to use, and how to implement the technologies. Rather, the implementation was left to the individual teachers' preferences and competences, as well as the availability of technologies at each school. We expect this to be the main factor accounting for the large amount of variation. The variations between groups of schools within the FabLab group were:

- There was a large degree of between-group variation on the average number of technologies students had worked with. On average, students from group 1 reported that they had worked with 5.8 of the digital fabrication technologies, students from group 2 that they had worked with 4.9, students from group 3 that they had worked with 4.5, and students from group 4 that they had worked with 2.7 digital fabrication technologies. There were also large variations in which technologies students from the different groups reported having worked with. Further, there were large variations in the number of technologies students in the four groups had used to work with their own ideas. Here, school group 2 stood out with the highest average number of technologies used in this way (3.6) – to a large degree helped by two outliers claiming to have used all or nearly all technologies to work on their own idea. The other groups of schools followed the trend from the total number of technologies used, in that students from group 1 had used the highest number of technologies to work with their own ideas (3.2), followed by group 3 (2.3), and group 4 (1.2).
- There were large between-group variations in the *use of AU's design process model* and in the students' self-perceived knowledge of its parts. All interventions, workshops, and teacher training done by

Aarhus University's Child–Computer Interaction Group as part of the FabLab@School project were centered on the design process model developed here. Students from group 1 stood out by on average evaluating their knowledge of the parts of the design process model highest of all the groups. Students from group three on average evaluated their knowledge lower than students from the other groups.

- Additionally, there was a large between-group variation in *student motivation* and in their perception of their experiences working with digital fabrication technologies. Students from group one and two were the most positive in regard to their work with digital fabrication. Again, group one stood out: group one students on average evaluated their work with digital fabrication in school more positively than any of the other groups. Group three students evaluated their experiences with digital fabrication negatively compared to the other groups.
- There was a large between-group variation in students' *knowledge of digital fabrication technologies* at the end of the two-year project period. As stated above, students from the FabLab@School.dk project had on average evaluated their knowledge of digital fabrication technologies more highly than the average of students in the 2014 survey. There was, however, a large variation between the responses from groups of schools. According to the responses, students from group 1 were on average more knowledgeable about the surveyed digital fabrication technologies than the average of students from group 2, who were more knowledgeable than the average of students from group 3, who were in turn on average more knowledgeable than the average of students in group four.
- There was a large between-group variation in the *learning outcomes* of working with digital fabrication technologies. The general trend with regard to the different types of learning outcomes was that students from groups 1 and 2 evaluated their learning outcomes more highly than students from groups 3 and 4. Especially students from group 1 perceived that they had had large gains in their abilities to produce with digital fabrication technology (thinking and acting innovatively with technology), to critically reflect on the use of technology, and to solve complex problems.

The data suggests a correspondence between number of technologies, use of a design process model, motivation, and learning outcomes: looking at the use of the design process model as evidenced by student responses to questions on whether they had used the model and the degree to which they knew its different parts, we find it plausible to suggest that in schools where the design process had been structured and scaffolded by the use of a design process model, students came to feel more secure about taking on complex problems. However, more research is needed in order to substantiate this claim. In the project reported here, we have introduced an experiment into the existing public school system, which is currently directed by a long list of common goals. It will be interesting to follow the continued efforts to create a place for design-based work with complex problems in digital fabrication within this system.

We did see small steps leading in the direction of design literacy, but the results highlight that it is challenging for both teachers and students to work towards this goal, which is not yet clearly defined. In our interpretation, the data suggests that scaffolding and structuring the work with digital fabrication in schools around a design process model like the one developed within the FabLab@School.dk project furthers the development of design literacy. However, with the large variation between schools and in the absence of central strategies and goals, it is very much up to chance what education in digital fabrication and design processes the students get.

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Appendix A: Full translations of questions

Heading	Question	Categories	Abbreviated question
	PERSONAL INFORMATION		
First, we would like to know a little about you and your school	How old are you?	Open question	Age
	What is the name of your school?	Open question	School
	What is your gender?	Boy	Gender
		Girl	
	Which grade are you in?	6, 7, 8, or 9	Grade level
	TECHNOLOGIES		
Here, we ask you about specific technologies that you might have worked with in school	In what way have you worked with the following technologies		
	3D printer	I have never worked with this technology	3D printer
		I have followed instruction to make something with this technolgy	
		I have used this technology to work on my own idea	
	Laser cutter	(same as above)	Laser cutter
	Vinyl cutter	(same as above)	Vinyl cutter
	MakeyMakey	(same as above)	MakeyMakey
	Arduino	(same as above)	Arduino
	LittleBits	(same as above)	LittleBits
	LilyPad	(same as above)	LilyPad
	Programmable robots (e.g. LEGO Mindstorms)	(same as above)	Robots (prog.)
	Electronics and soldering (LEDs and resistors)	(same as above)	Electronics

	Text-based programming (e.g. HTML, Processing, Arduino, Sonic Pi, or Python)	(same as above)	Textbased prog.
	Blockbased or visual programming (e.g. LEGO Mindstorms, Scratch, ArduBlock, or Weedoo)	(same as above)	Blockbased/visual prog.
	Other digital fabrication technologies	(same as above)	Other
	List the technologies, you have worked with. Describe what the technologies were used for.	Open question	What other technologies have you work with, and how?
How familiar are you with the following technologies?	Evaluate yourself on a scale of 1 (I know nothing about it) to 6 (I could teach others about it).		
	Computers/laptops	1, 2, 3, 4, 5, or 6	Computers
	Smartphones/tablets/iPads	1, 2, 3, 4, 5, or 6	Smartphones/tablets
	Laser cutter/CNC router	1, 2, 3, 4, 5, or 6	Laser cutter/CNC
	Vinyl cutter	1, 2, 3, 4, 5, or 6	Vinyl cutter
	3D printer	1, 2, 3, 4, 5, or 6	3D printer
	Building electronic devices or simple machines from scratch	1, 2, 3, 4, 5, or 6	Building electronic devices
	Microcontroller boards (e.g. MakeyMakey og Arduino)	1, 2, 3, 4, 5, or 6	Microcontroller boards
	Building programmable robots (e.g. Lego Mindstorms)	1, 2, 3, 4, 5, or 6	Robots (prog.)
	Electronis and soldering (LEDs and resistors)	1, 2, 3, 4, 5, or 6	Electronics
	TExt-based programming (e.g. HTML, Processing, Arduino, Sonic Pi, or Python)	1, 2, 3, 4, 5, or 6	Textbased prog.
	Blockbased or visual programming (e.g. LEGO Mindstorms, Scratch, ArduBlock, or Weedoo)	1, 2, 3, 4, 5, or 6	Blockbased/visual prog.
	Where did you learn this?		
	Laser cutters or CNC routers	Primarily in school	Laser cutter/CNC
		Primarily at home	
		Have not learned	

	Vinyl cutter	(same as above)	Vinyl cutter
	3D printer	(same as above)	3D printer
	Building electronic devices or simple machines from scratch	(same as above)	Building electronic devices
	Microcontroller boards (e.g. MakeyMakey og Arduino)	(same as above)	Microcontroller boards
	Building programmable robots (e.g. Lego Mindstorms)	(same as above)	Robots (prog.)
	Electronics and soldering (LEDs and resistors)	(same as above)	Electronics
	TExt-based programming (e.g. HTML, Processing, Arduino, Sonic Pi, or Python)	(same as above)	Textbased prog.
	Blockbased or visual programming (e.g. LEGO Mindstorms, Scratch, ArduBlock, or Weedoo)	(same as above)	Blockbased/visual prog.
Has worked with digital fabrication in school	Have you ever worked with digital fabrication technologies, for example in a FabLab or workshop, in school? Digital fabrication technology can for example be MakeyMakey, Arduino, vinyl cutter, and 3-D printer.	Yes / no	
What did you make, and with what technology?	Briefly describe what you made, which technology you used, and what you used the technology to do?		
	1. project	open question	
	2. project	open question	
Here, we ask you how you liked working with digital fabrication technologies in school. In som schools, there is a space called a FabLab or a Makerspace, where you can	How did you like working with digital fabrication in school/FabLab?		

work with these technologies			
	The technologies were difficult	Strongly disagree	Tech. difficult
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	Working with the technologies was boring	(same as above)	Tech. boring
	I like being in the school's FabLab/Makerspace	(same as above)	Liked FabLab
	Being in the school's FabLab/Makerspace is interesting	(same as above)	FabLab is interesting
	Being in the school's FabLab/Makerspace is boring	(same as above)	Waste of time
	I want to use the technologies for my own projects out of school	(same as above)	Use for projects at home
	The things we learn about digital fabrication technologies will be useful for me in the future.	(same as above)	Useful for my future
	I love working on digital fabrication projects.	(same as above)	Love FabLab projects
	I learn a lot in the school's FabLab/makerspace	(same as above)	Learned alot
	When I am home, I think about what we learned about digital fabrication technologies	(same as above)	Reflect at home
To what extent do you agree? Use the scale of 1 to 6, where 1 means "Strongly disagree", while 6	Digital fabrication in school has		

means "Strongly agree"			
	taught me how to work creatively with technology	Strongly disagree	To be creative with tech.
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	taught me how to solve complex challenges	(same as above)	To solve complex challenges
	helped me relate to societal issues	(same as above)	To relate to societal challenges
	helped me to imagine how I can change things (e.g. with technology)	(same as above)	To imagine change w/ tech.
	helped me become better at cooperating with people with different backgroups and abilities	(same as above)	To cooperate in heterogeneous groups
	taught me how technology is affecting the way we live	(same as above)	How tech. Affects our lives
	taught me how new ideas, things, and technologies are created.	(same as above)	How new tech./ideas/things are created
	helped me reflect critically to my own and others' use of technology (e.g. are we spending too much time on Facebook?, are our pictures safe on Snapchat?, are we creating too much e-Waste?).	(same as above)	To reflect critically on tech.
	helped me to communicate with various people on the internet.	(same as above)	To communicate on the Internet
	taught to work systematically with assignments (e.g. in Physics, Chemistry, or Science)	(same as above)	To work systematically
	has heightened my interest in completing a degree in higher education.	(same as above)	Interest in higher education

	has heightened my interest in wanting a creative or craftmanship education.	(same as above)	Interest in Crafts or creative education
	heightened my interest in starting my own company.	(same as above)	Interest in entrepreneurship
DESIGN AND CREATIVITY			
The next questions concern having novel ideas, working creatively, and creating new things with technolgy	How you ever worked with this design process model in your school?	Yes / no / don´t know	
How familiar are you with the various parts of the Design Process Model?	Evaluate yourself on a scale of 1 (I know nothing about it) to 6 (I could teach other about it).		
	Design brief	1, 2, 3, 4, 5, or 6	Design brief
	Field studies	1, 2, 3, 4, 5, or 6	Field studies
	Ideation	1, 2, 3, 4, 5, or 6	Ideation
	Fabrication	1, 2, 3, 4, 5, or 6	Fabrication
	Argumentation	1, 2, 3, 4, 5, or 6	Argumentation
	Reflection	1, 2, 3, 4, 5, or 6	Reflection
	How you ever had an idea for a new product or an invention?	Yes/no	How you ever had an idea for a product or an invention?
	Describe your idea (briefly)	Open question	Describe your idea (briefly)
	Did you create or build your idea?	Yes/no	Did you create your idea?
Design task: The challenge of the care home	In the beginning of the year 2014, 9 grandparents disappeared from their care home because of their loss of memory (dementia). The problem for the care home is to create security for the elderly without taking away their freedom.	Open question	If you were asked to solve this problem, what would you do?

	If you were asked to solve this problem, what would you do?		
How would you find the right solution to the problem of elderly demented disappearing?	Which parts of the process would be most important to you? Choose a number from 1 to 6 (1 = not important at all, 6 = very important)		
	I would create a detailed plan for the entire project	1, 2, 3, 4, 5, or 6	Create a detailed plan
	I would wait for a good idea to materialize	1, 2, 3, 4, 5, or 6	Wait for good idea
	I will visit a care home to study the problem further	1, 2, 3, 4, 5, or 6	Study nursing homes
	I would find out, how they handle this problem in other countries	1, 2, 3, 4, 5, or 6	Study other countries
	I will sketch possible solutions on paper	1, 2, 3, 4, 5, or 6	Sketch on paper
	I will build my idea using cardboard	1, 2, 3, 4, 5, or 6	Build cardboard mock-up
	I will test my cardboard model in a care home	1, 2, 3, 4, 5, or 6	Test cardboard mock-up
	I will repeat the tests with a new sketch or cardboard model	1, 2, 3, 4, 5, or 6	Iterate on mock-up or sketch
	I will test my solution together with elderly at the care home	1, 2, 3, 4, 5, or 6	Test solution with elderly
	I will arrange a meeting with staff and relatives to discuss my solution	1, 2, 3, 4, 5, or 6	Meet w/ staff/relatives
	I will make sure everybody agreed on the solution	1, 2, 3, 4, 5, or 6	All should agree
	I will use disagreements between individuals/groups to develop new ideas	1, 2, 3, 4, 5, or 6	Use disagreement fruitfully

	I will patent my idea	1, 2, 3, 4, 5, or 6	Patent the idea
	I will start a company to market my solution and make money	1, 2, 3, 4, 5, or 6	Market solution/make money
	As soon as my solution is finished, I will stop working on the the problem	1, 2, 3, 4, 5, or 6	Stop working when finished
	I will use knowledge gained in this project for future projects	1, 2, 3, 4, 5, or 6	Transfer knowledge to future projects
	Other things you would do? Describe them here.	Open question	Other
HACKING, DATA, AND TECHNOLOGY			
Here, we ask about your relationship to hacking and reparation of technology in your everyday life.	To what extent do you agree…		What is your relationship with technology?
	As long as they function properly, I don't care how my digital devices work	Strongly disagree	Don´t care how they work, as long as they work
		Disagree	
		Neither/nor	
		Agree	
		Strongly agree	
	I am interested in knowing how my devices work, and I often improve them	(same as above)	I want to know how they work and how to improve them
	When I notice something broken, I immediately think of a way to fix it	(same as above)	When things are broken, I think of ways to repair
	I know what is inside a phone and how it works	(same as above)	I know what is inside a phone/how it works
What do you do, if something doesn't work on e.g. Your computer or phone?	Choose three options		What do you do, if a device malfunctions?
	Call a friend	[check box]	Call a friend
	Read a manual	[check box]	Read a manual
	Ask one of my parents	[check box]	Ask a parent
	Call technical support	[check box]	Call technical support

	Search for (solutions to) the problem on the internet	[check box]	Search the Internet
	Seach for help on specific websites	[check box]	Search specific/relevant sites
	Start a thread/discussion - e.g. In a forum	[check box]	Start a thread/discussion
	Tinker with known commands, settings, etc.	[check box]	Tinker
	I do not know	[check box]	Do not know
	Other	[check box]	Other
	Please desribe…		Describe…
	Have you ever taken your phone or other digital devices apart?	Yes / no/do not know	How you ever taken your phone or other devices apart?
	Why did you open it? Was it e.g. To fix or improve something?	Open question	Why?
	Why Not?		
	Why would I?		
	I do not know how	[check box]	Why would I?
	I would void the warranty	[check box]	Does not know how
	I do not know	[check box]	Would void the warranty
	Other	[check box]	Do not know
	Please describe	[check box]	Other
			Describe
	To what extent do you agree with these statements about technology and data?		To what extent do you agree?
	Technology, data, and information should be open and available to all	Strongly disagree	Tech./data/info. should be free/open to everyone
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	National agencies should store everyones personal data and information	(same as above)	National agencies should store personal data

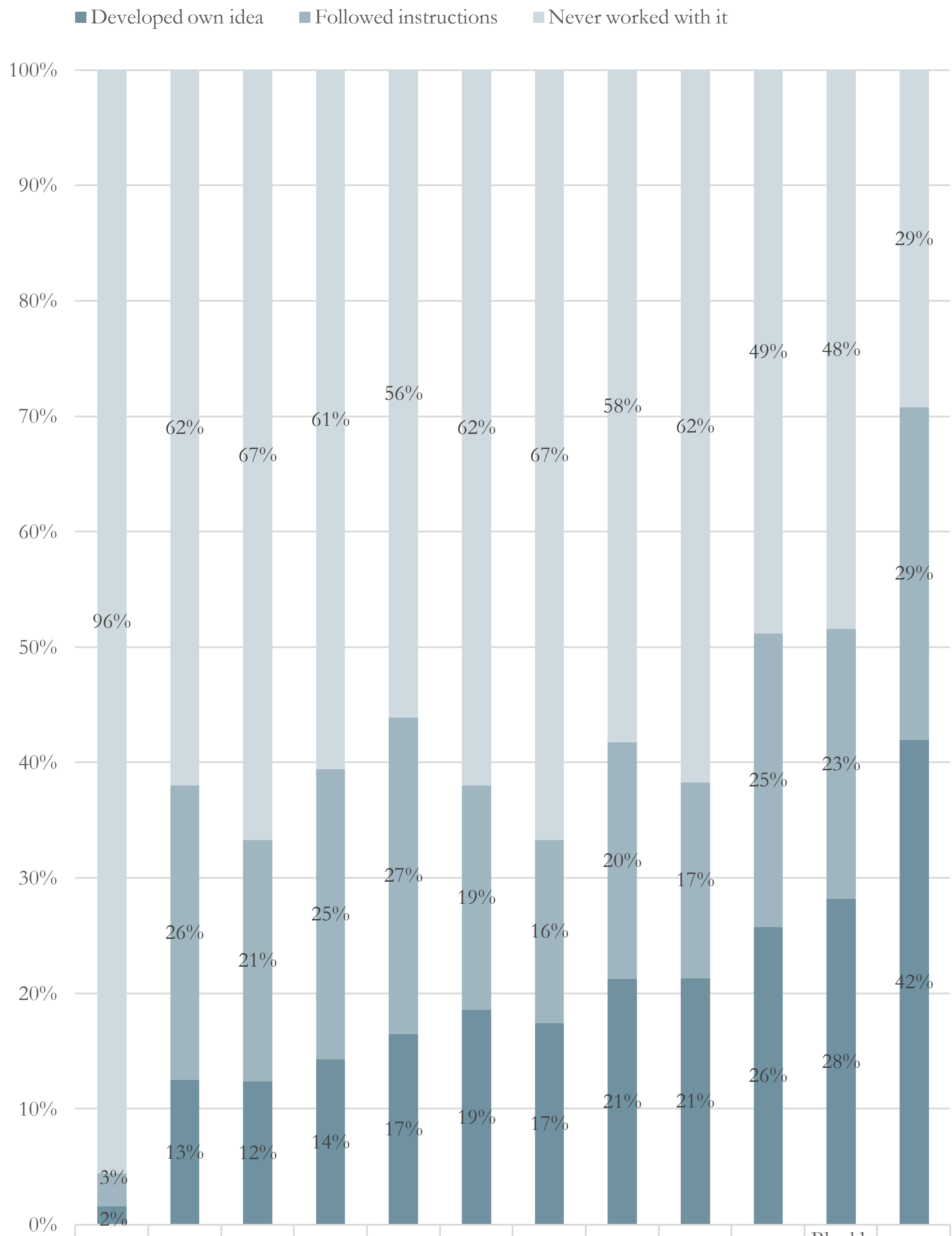
	It is important to me, who owns my data and informations, e.g. Photos and music	(same as above)	Important who owns data
	Hacking is only something criminals do on the internet	(same as above)	Hacking is done by criminals
	Hacking is something everyone does	(same as above)	Hacking is done by everyone
	Technology gives me freedom to express my interests	(same as above)	Technology gives me freedom to express my interests
	I can imagine how technology can be combined with other materials (e.g. Fabric, wood, or paper)	(same as above)	Technology can be combined with other materials
	Technology allows me to understand new contexts and opportunities	(same as above)	Technology allows me to understand new contexts and opportunities
YOUR FUTURE			
In the end, we would like to know if you would be interested in a career in technolgy, design, science, or in starting your own business. Further, we about the number of books in your home.	Here, we ask about your thoughts on the future. To what extent do you agree?		What are your thoughts on the future?
	I am interested in a career in technology and design	Strongly disagree	Future in digital design
		Disagree	
		Slightly disagree	
		Slightly agree	
		Agree	
		Strongly agree	
	I am interested in a career in engineering or science	(same as above)	Future in engineering/science
	I am interested in starting my own business	(same as above)	Start my own business

	Approximately how many books are there where you live? (You should not count magazines, newspapers, or school books)		Books at home
	0-10	[check box]	
	11-25	[check box]	
	26-100	[check box]	
	101-200	[check box]	
	More than 200	[check box]	

Appendix B: Responses from the FabLab group

This appendix features tables charts of the FabLab group's responses on quantitative items in the questionnaire.

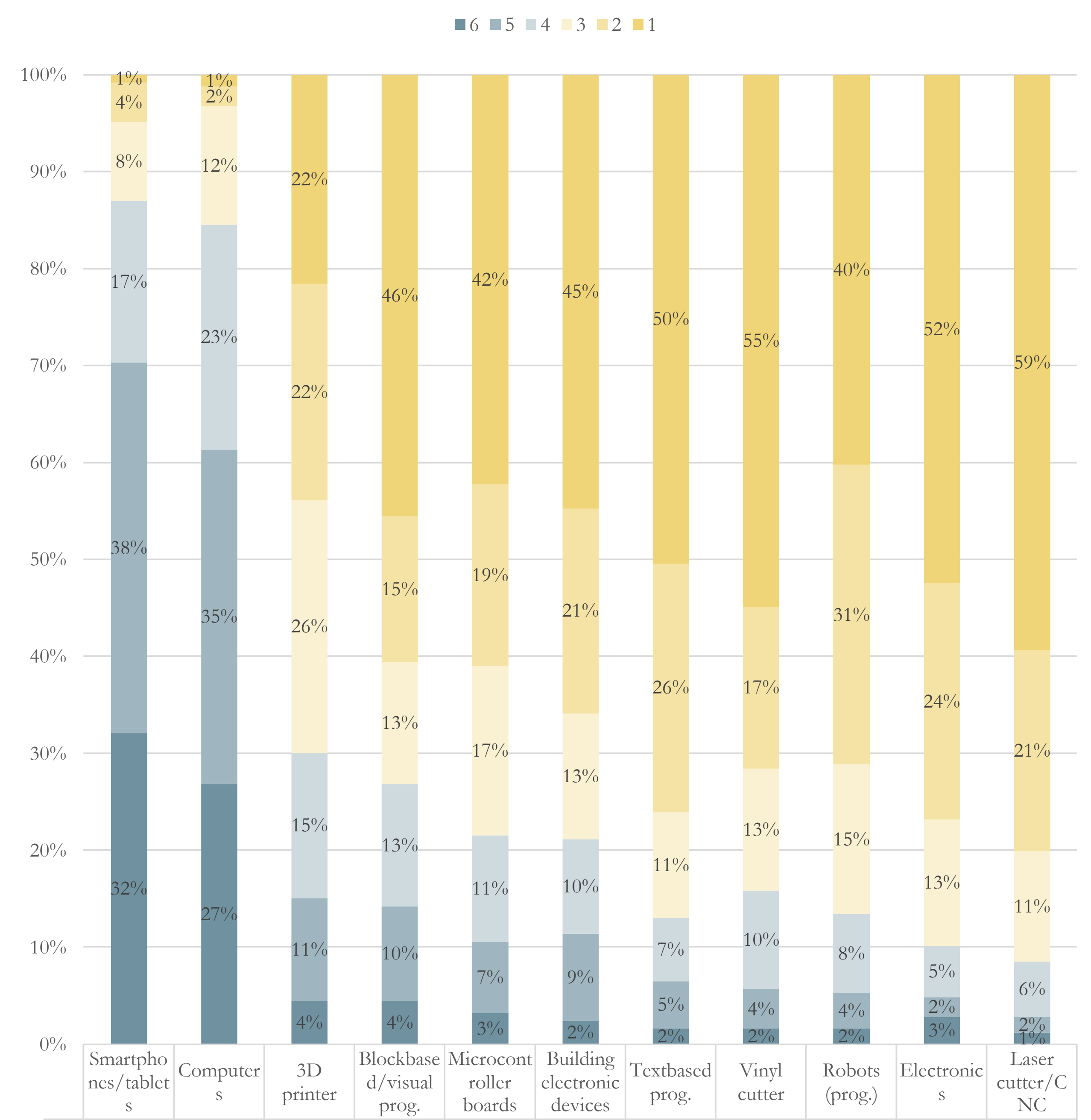
B.I: How did you work with the following technologies?



	LilyPad	Electronics	Laser cutter	Other	Textbased prog.	Arduino	LittleBits	Vinyl cutter	Makey Makey	Robots (prog.)	Blockbased/visual prog.	3D printer
Never worked with it	236	153	166	152	139	153	164	145	153	121	120	73
Followed instructions	7	63	52	63	68	48	39	51	42	63	58	72
Developed own idea	4	31	31	36	41	46	43	53	53	64	70	105

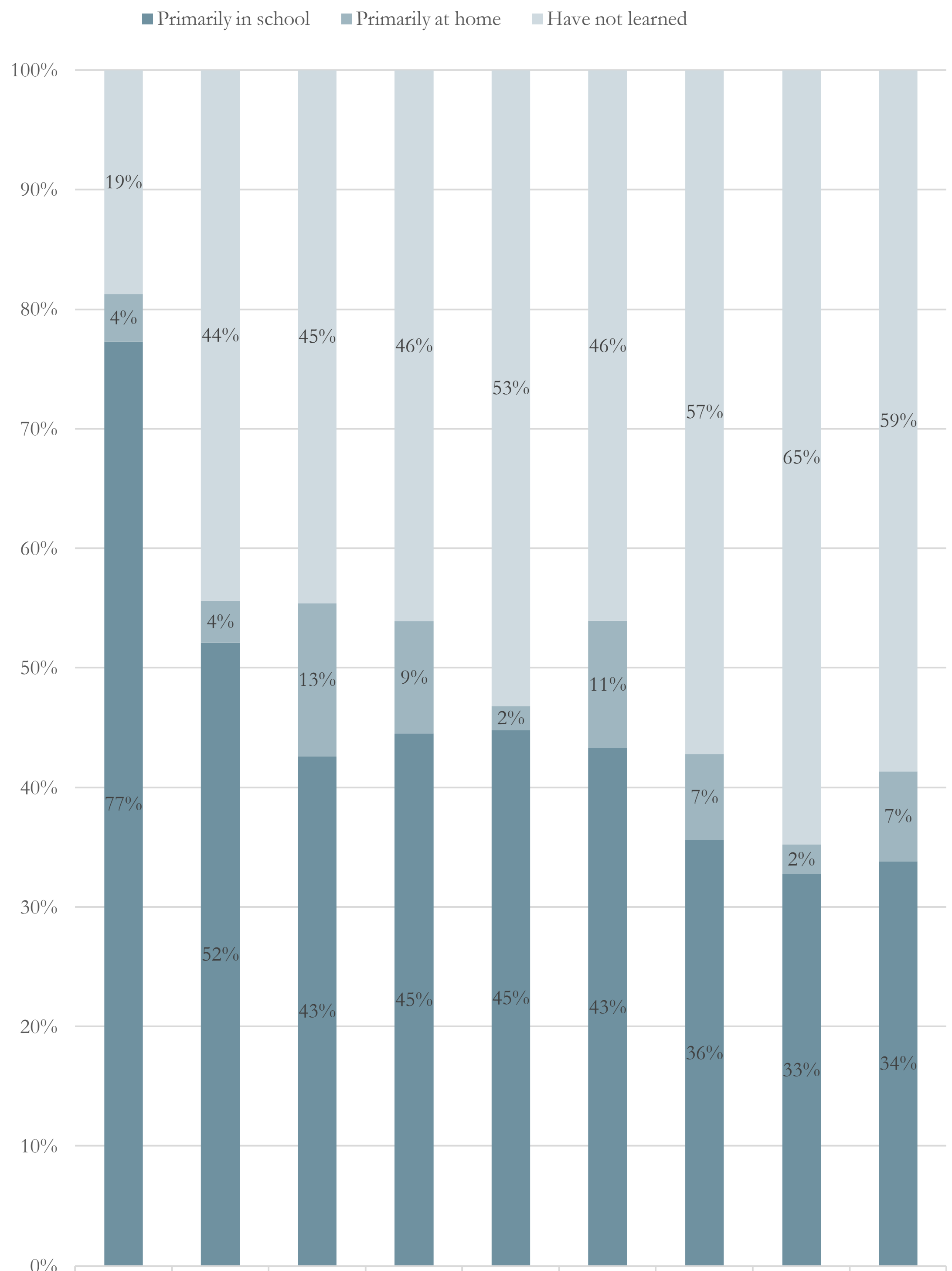
B.II: How familiar are you with these technologies?

Evaluate yourself on a scale from 1 to 6, where 1 is "I know nothing about it" and 6 is "I could teach others about it".



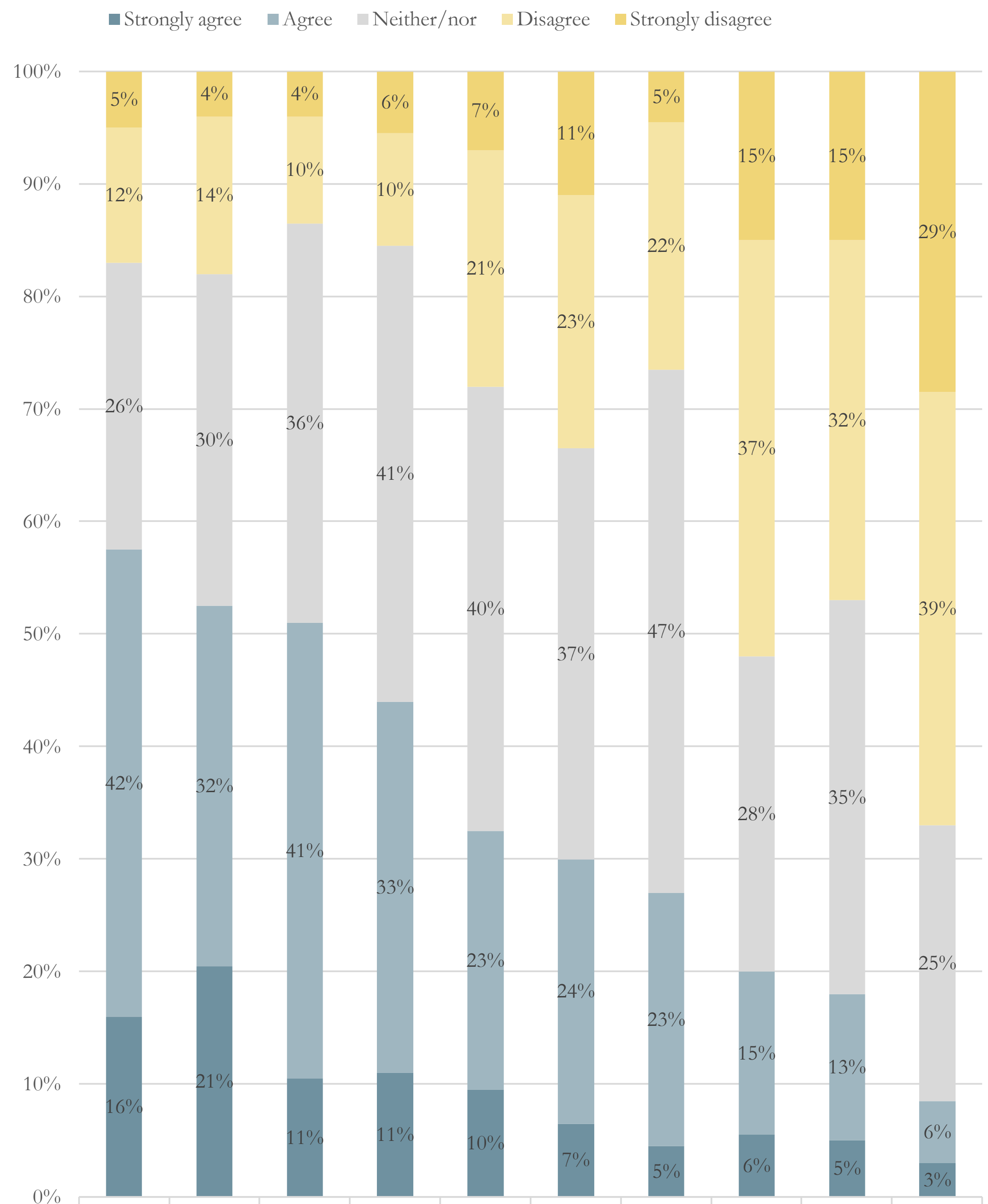
	Smartphones/tablets	Computers	3D printer	Blockbased/visual prog.	Microcontroller boards	Building electronic devices	Textbased prog.	Vinyl cutter	Robots (prog.)	Electronics	Laser cutter/CNC
1	2	3	53	112	104	110	124	135	99	129	146
2	10	5	55	37	46	52	63	41	76	60	51
3	20	30	64	31	43	32	27	31	38	32	28
4	41	57	37	31	27	24	16	25	20	13	14
5	94	85	26	24	18	22	12	10	9	5	4
6	79	66	11	11	8	6	4	4	4	7	3

B.III: Where did you learn to use these?



	3D printer	Microcont roller boards	Building electronic devices	Blockbase d/visual prog.	Vinyl cutter	Robots (prog.)	Textbased prog.	Laser cutter/CN C	Electronic s
Have not learned	47	114	115	118	133	117	143	160	149
Primarily at home	10	9	33	24	5	27	18	6	19
Primarily in school	194	134	110	114	112	110	89	81	86

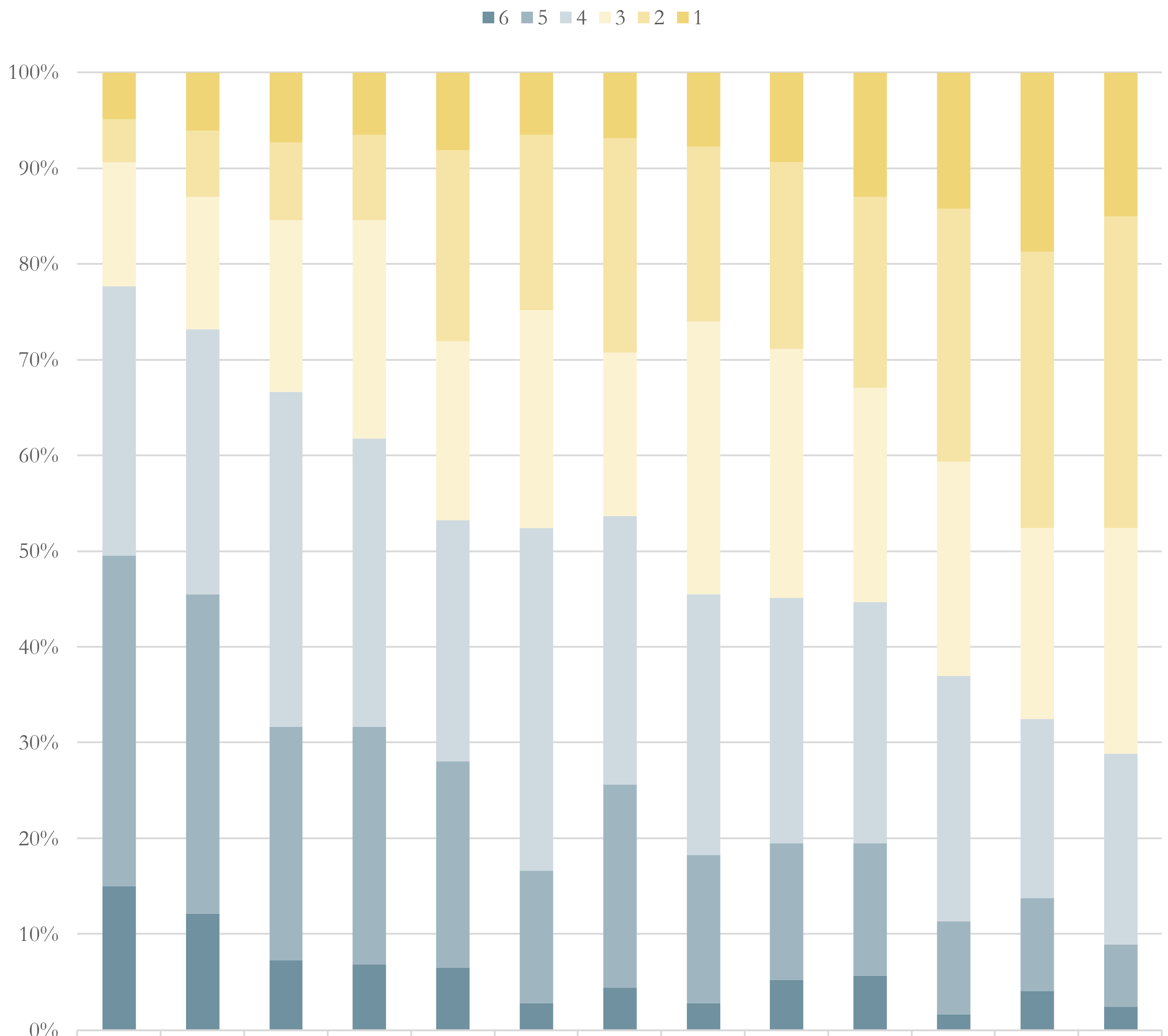
B.IV: How was working with digital fabrication in school/FabLab



	FabLab was interesting	Liked FabLab	Useful for my future	Learned a lot	Love FabLab projects	Use for projects at home	Tech. difficult	Tech. boring	Reflect at home	Waste of time
Strongly disagree	10	8	8	11	14	22	9	30	30	57
Disagree	24	28	19	20	42	45	44	74	64	77
Neither/nor	51	59	71	81	79	73	93	56	70	49
Agree	83	64	81	66	46	47	45	29	26	11
Strongly agree	32	41	21	22	19	13	9	11	10	6

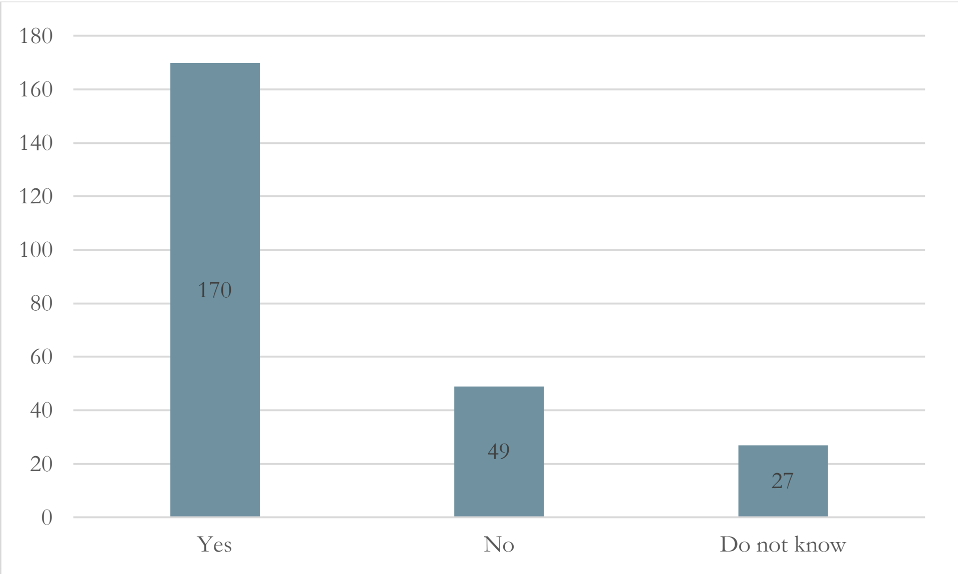
B.V: Learning outcomes

To which degree do you agree with the following statements? Work with digital fabrication in school has taught me…



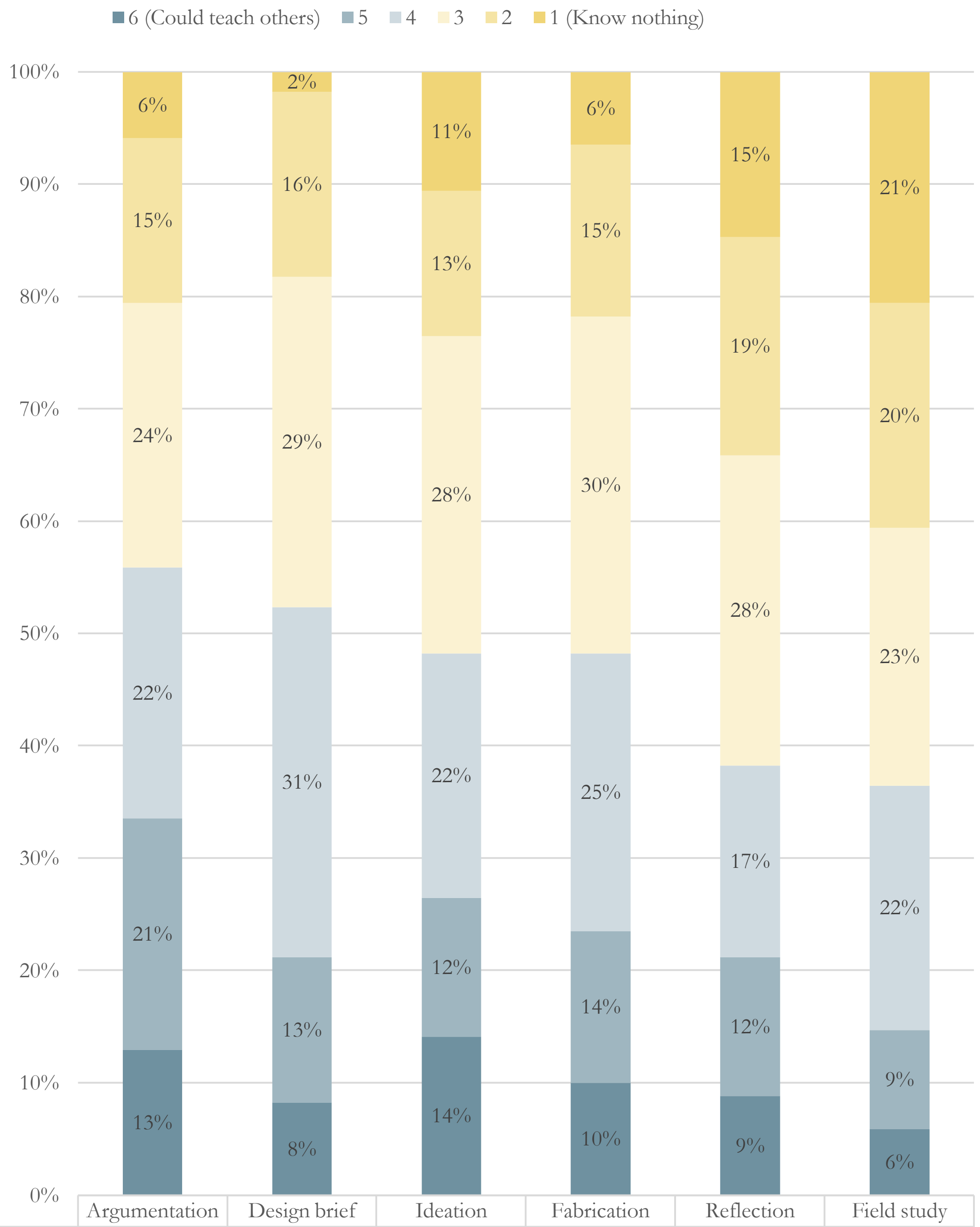
	How new tech./ ideas/ things are created	How tech. Affects our lives	To be creative with tech.	To imagine change w/ tech.	To reflect critically on tech.	To solve complex challenges	To cooperate in heterogeneous groups	To work systematically	To relate to societal challenges	to be interested in higher education	to be interested in crafts or creative education	To be interested in entrepreneurship	To communicate on the Internet
1	12	15	18	16	20	16	17	19	23	32	35	46	37
2	11	17	20	22	49	45	55	45	48	49	65	71	80
3	32	34	44	56	46	56	42	70	64	55	55	49	58
4	69	68	86	74	62	88	69	67	63	62	63	46	49
5	85	82	60	61	53	34	52	38	35	34	24	24	16
6	37	30	18	17	16	7	11	7	13	14	4	10	6

B.VI: Have you ever worked with this Design Process Model in school?



B.VII: How familiar are you with these parts of the Design Process Model?

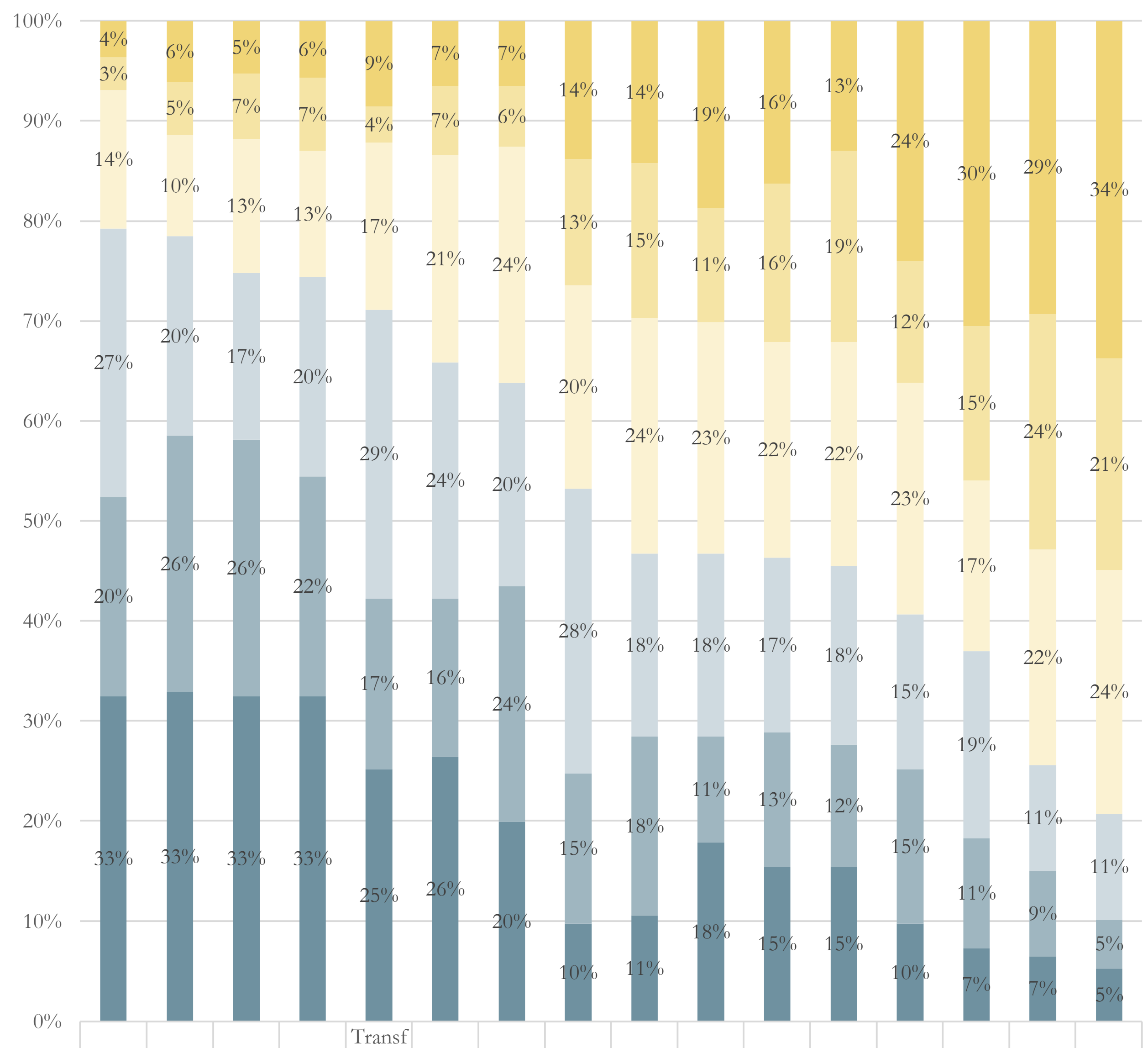
Evaluate yourself on a scale of 1 to 6, where 1 is "I know nothing about it" and 6 is "I could teach others about it".



	Argumentation	Design brief	Ideation	Fabrication	Reflection	Field study
1 (Know nothing)	10	3	18	11	25	35
2	25	28	22	26	33	34
3	40	50	48	51	47	39
4	38	53	37	42	29	37
5	35	22	21	23	21	15
6 (Could teach others)	22	14	24	17	15	10

B.VIII: Which parts of the process would be most important to you?

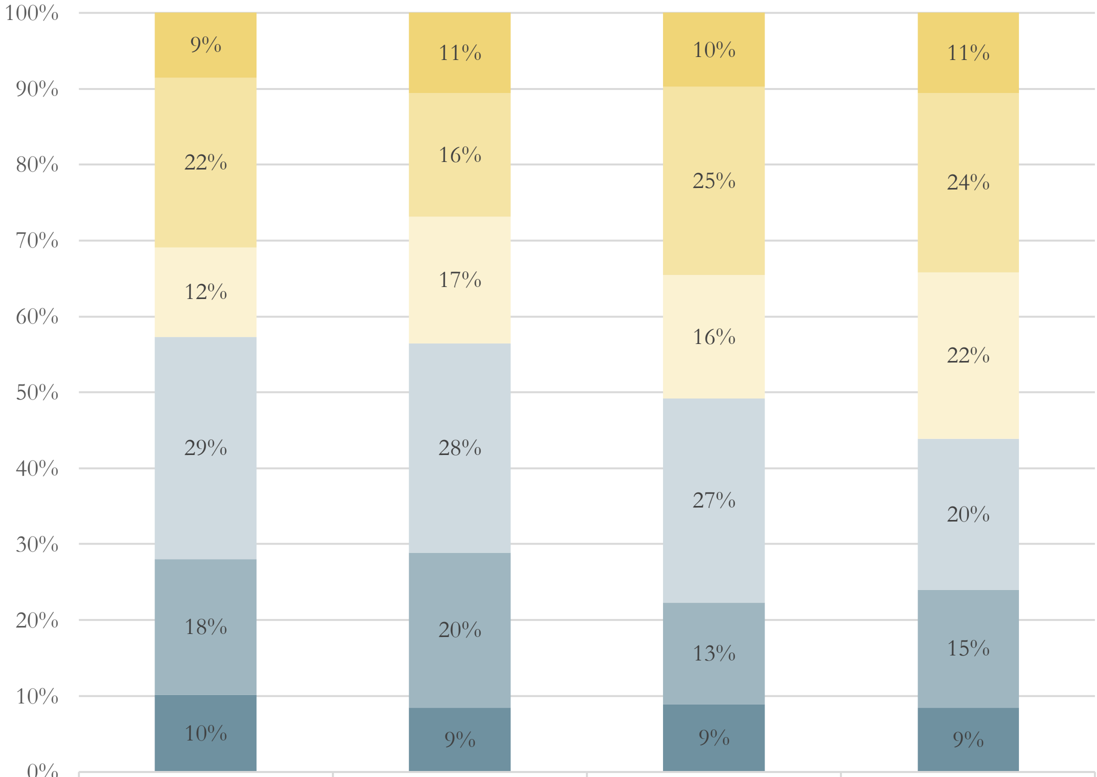
Choose a number between 1 and 6 (1 = not important at all, 6 = really important)



	All should agree	Meet w/ staff/relatives	Study nursing homes	Test solution with elderly	Transfer knowledge to future projects	Create a detailed plan	Use disagreement fruitfully	Study other countries	Sketch on paper	Patent the idea	Market solution/make money	Wait for good idea	Iterate on mock-up or sketch	Test cardboard mock-up	Stop working when finished	Build cardboard mock-up
1	9	15	13	14	21	16	16	34	35	46	40	32	59	75	72	83
2	8	13	16	18	9	17	15	31	38	28	39	47	30	38	58	52
3	34	25	33	31	41	51	58	50	58	57	53	55	57	42	53	60
4	66	49	41	49	71	58	50	70	45	45	43	44	38	46	26	26
5	49	63	63	54	42	39	58	37	44	26	33	30	38	27	21	12
6	80	81	80	80	62	65	49	24	26	44	38	38	24	18	16	13

B.IX: Relationship to hacking and reparation in everyday life

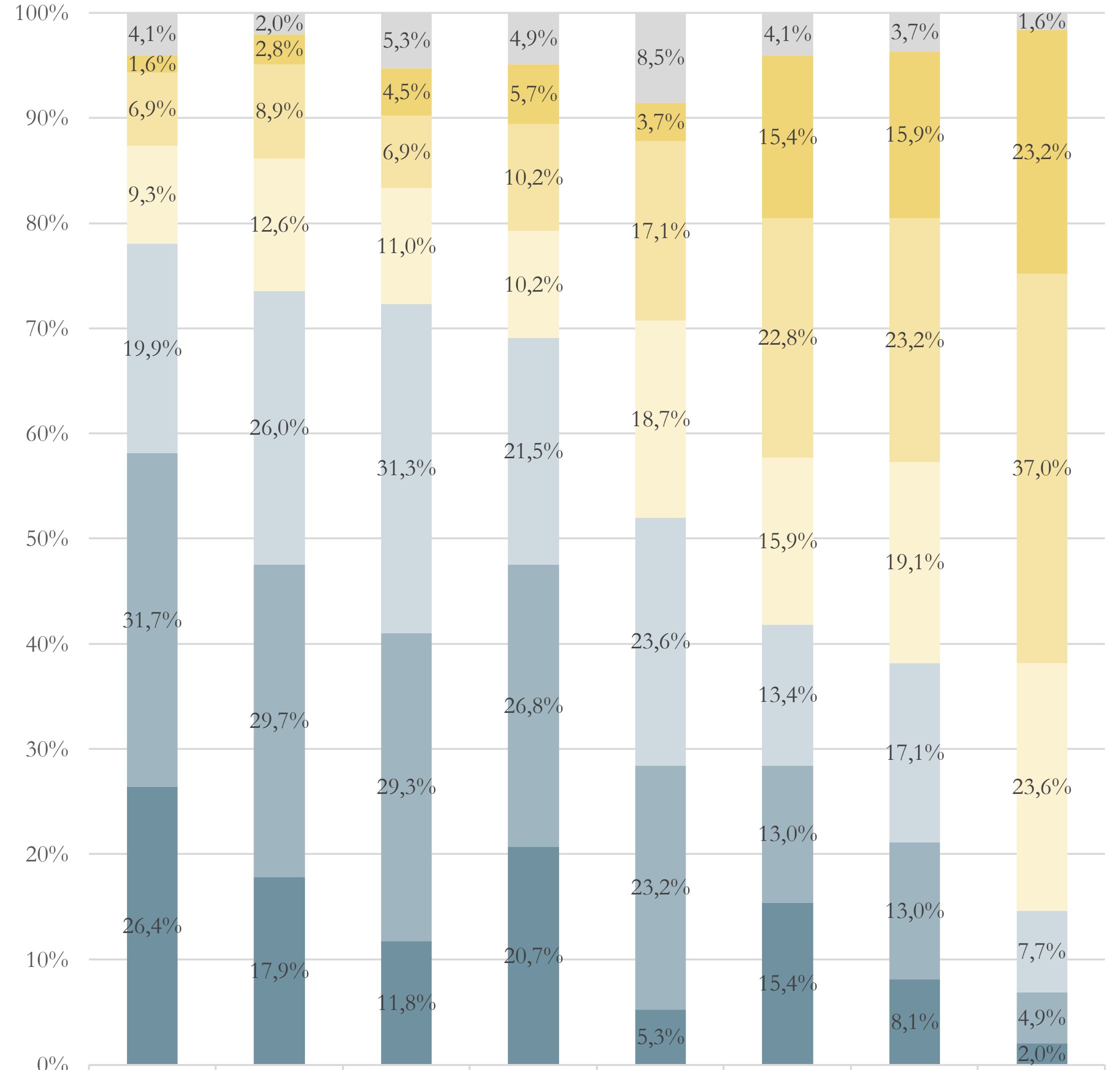
To what extent do you agree?...



	I know what is inside a phone/how it works	I want to know how they work and how to improve them	When things are broken, I think of ways to repair	Don´t how they work, as long as they work
Strongly disagree	21	26	24	26
Disagree	55	40	61	58
Slightly disagree	29	41	40	54
Slightly agree	72	68	66	49
Agree	44	50	33	38
Strongly agree	25	21	22	21

B.X: Technology and data

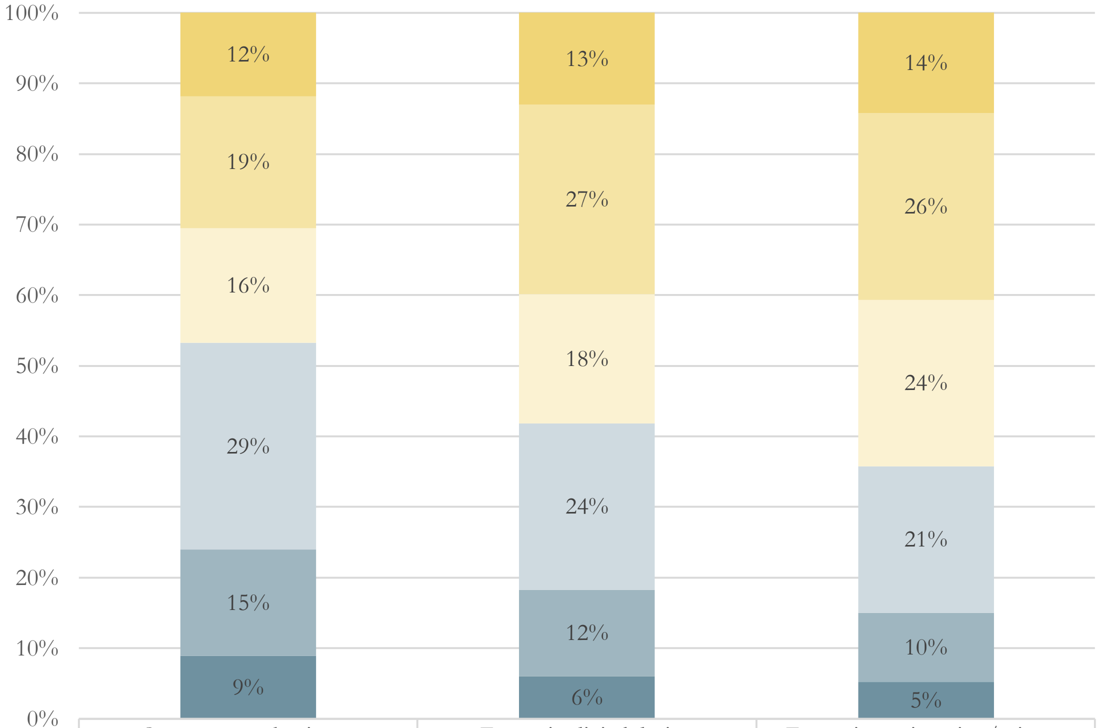
To what extent do you agree with these statements?



	Important who owns data	Technology gives me freedom to express my interests	Technology allows me to understand new contexts and opportunities	Tech./data/ info. should be free/open to everyone	Technology can be combined with other materials	National agencies should store personal data	Hacking is done by criminals	Hacking is done by everyone
Do not know	10	5	13	12	21	10	9	4
Strongly disagree	4	7	11	14	9	38	39	57
Disagree	17	22	17	25	42	56	57	91
Lightly disagree	23	31	27	25	46	39	47	58
Lightly agree	49	64	77	53	58	33	42	19
Agree	78	73	72	66	57	32	32	12
Strongly agree	65	44	29	51	13	38	20	5

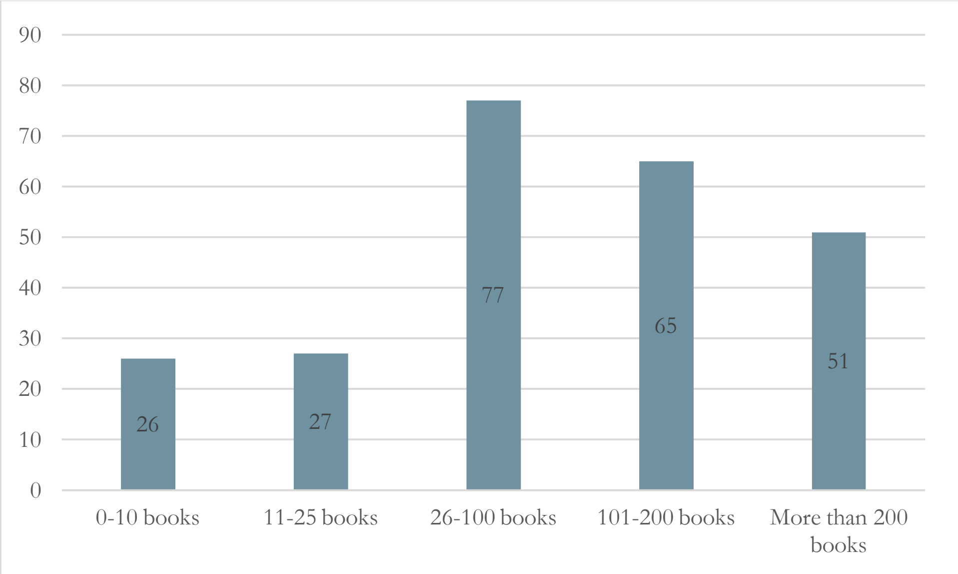
B.XI: Thoughts about the future

To what extent do you agree? I would like to/a…



	Start my own business	Future in digital design	Future in engineering/science
Strongly disagree	29	32	35
Disagree	46	66	65
Slightly disagree	40	45	58
Slightly agree	72	58	51
Agree	37	30	24
Strongly agree	22	15	13

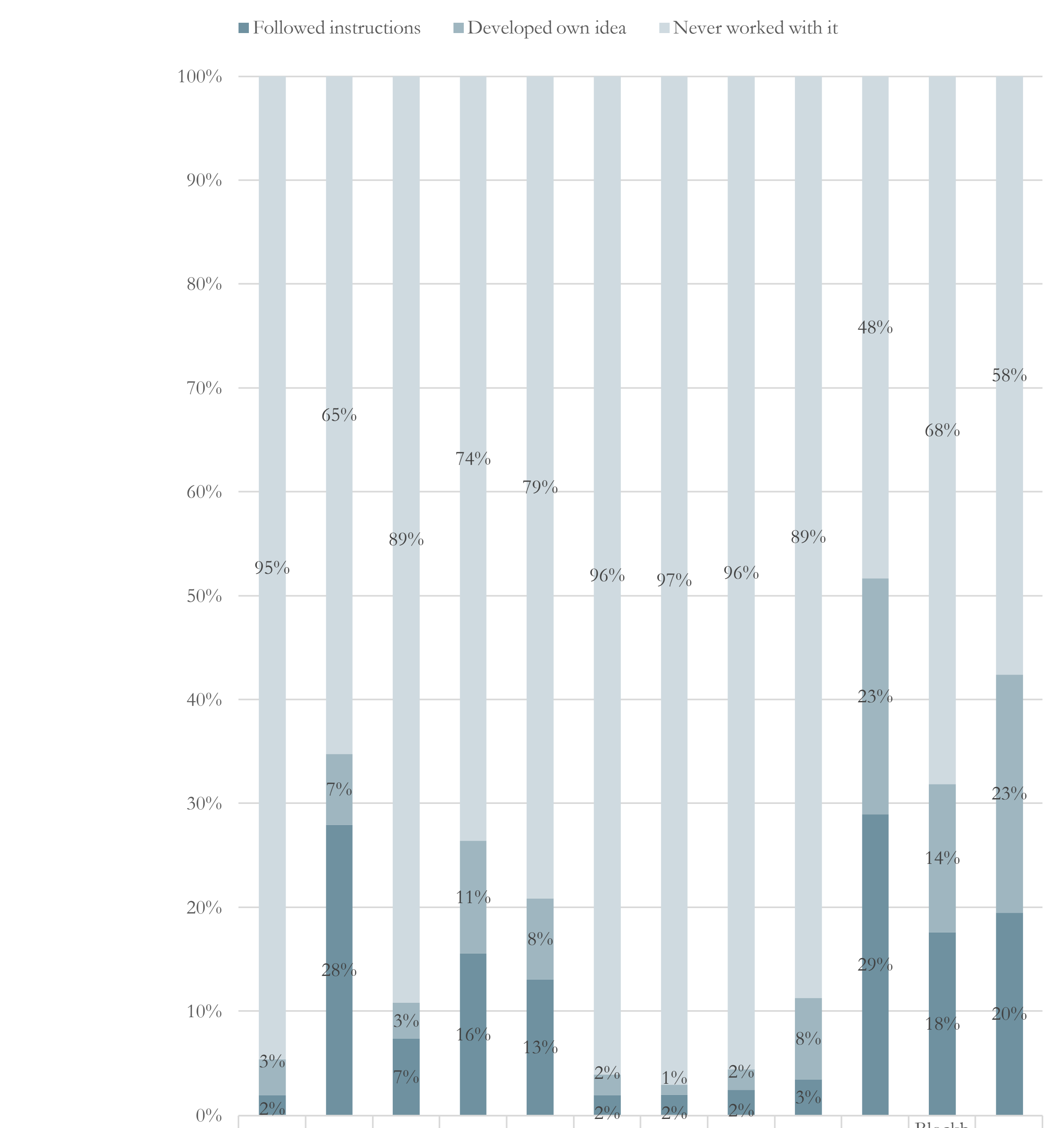
B.XII: How many books are in your home?



Appendix C: Responses from the control group

This appendix features tables charts of the FabLab group's responses on quantitative items in the questionnaire.

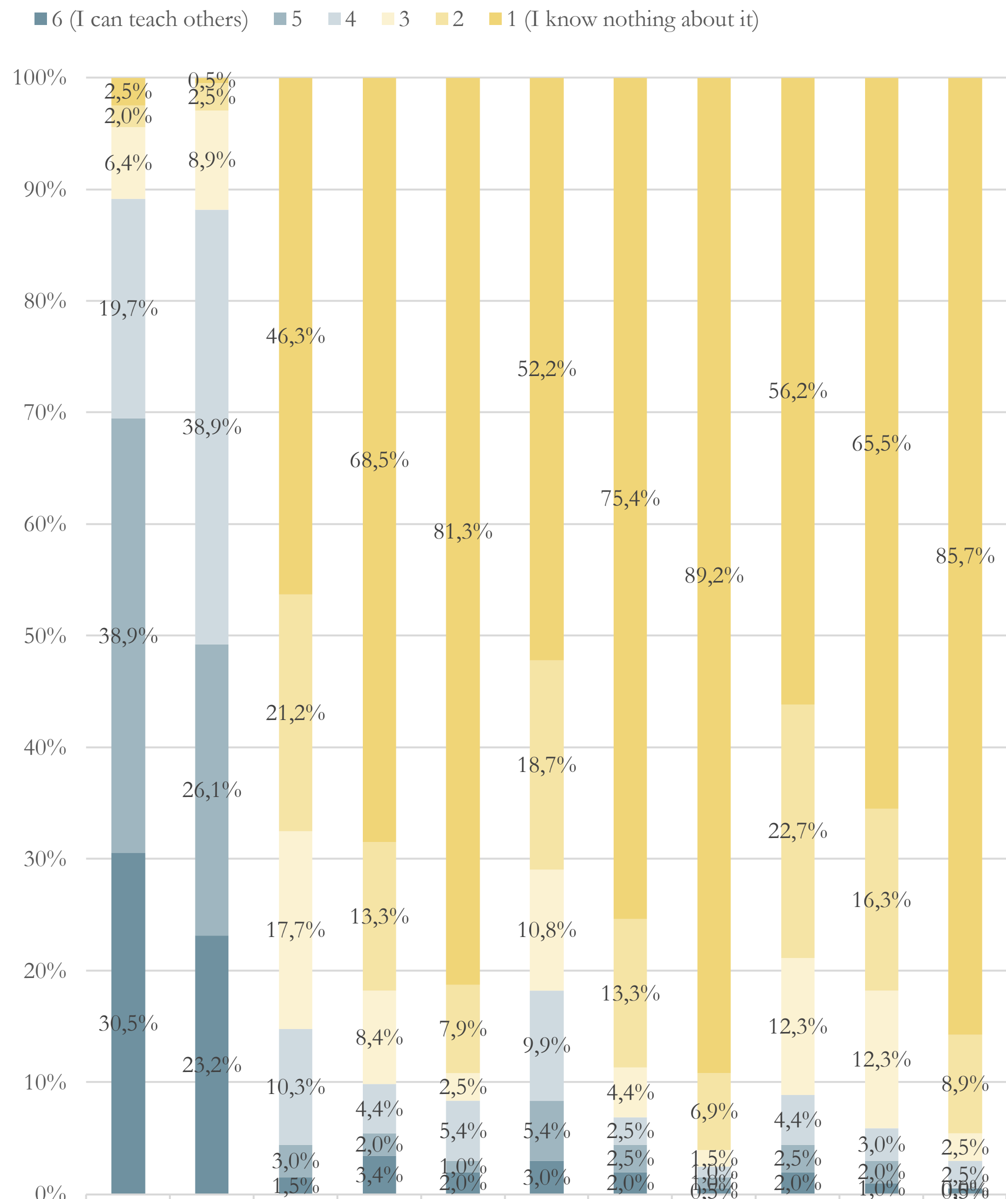
C.I: How did you work with the following technologies?



	LilyPad	Electronics	Laser cutter	Other	Textbased programming	Arduino	LittleBits	Vinyl cutter	Makey Makey	Programmable robots	Blockbased/visual programming	3D printer
Never worked with it	193	133	181	156	163	196	197	195	180	100	139	118
Developed own idea	7	14	7	23	16	4	2	4	16	47	29	47
Followed instructions	4	57	15	33	27	4	4	5	7	60	36	40

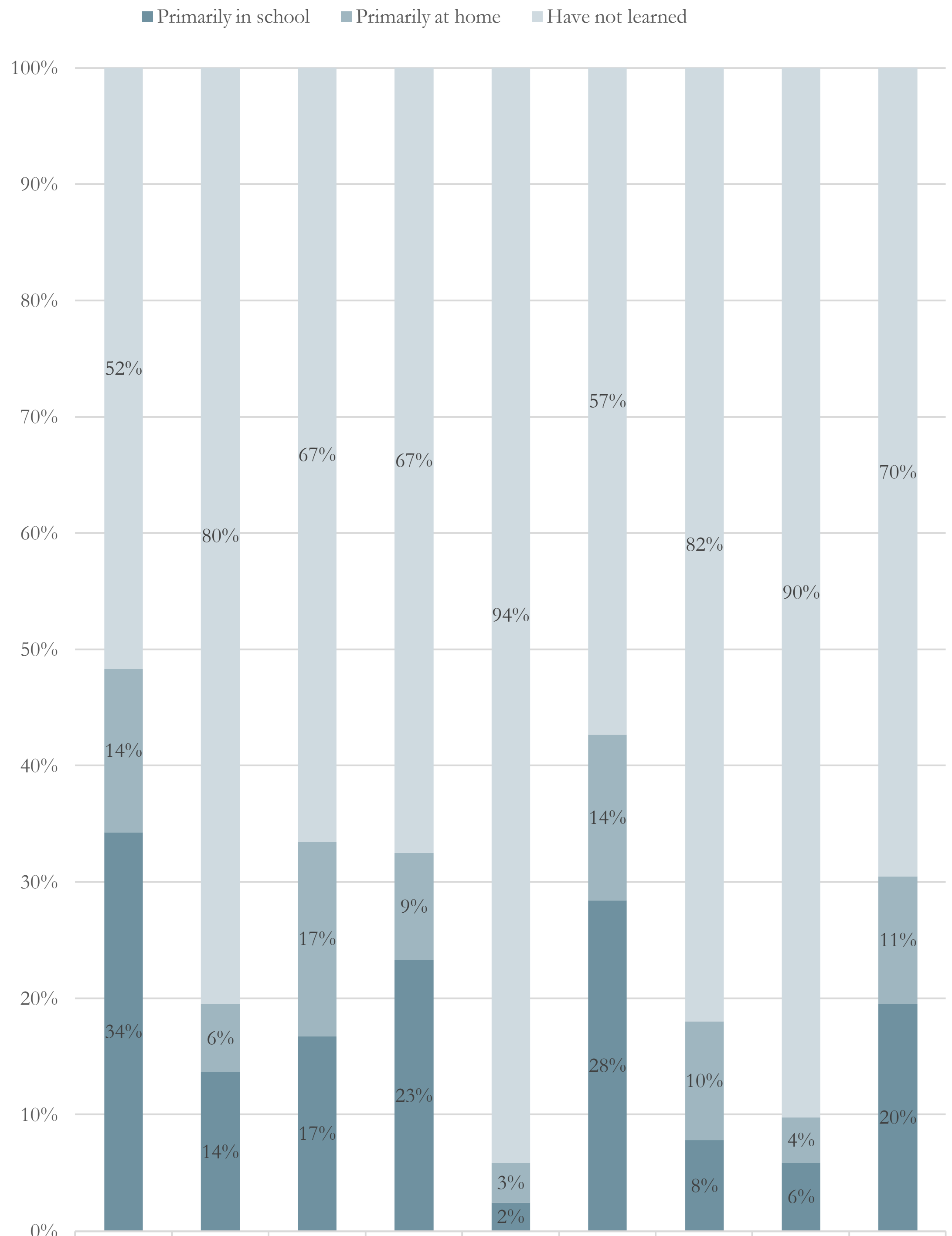
C.II: How familiar are you with these technologies?

Evaluate yourself on a scale from 1 to 6, where 1 is "I know nothing about it" and 6 is "I could teach others about it".



	Smart-phones / tablets	Com-puters/ laptops	3D printers	Block-based/ visual prog.	Micro-control-ler boards	Prog. robots	Text-based prog.	Vinyl cutter	Buil-ding elec-tronic devices	Elec-tronics/ solde-ring	Laser cutters/ CNC
1 (I know nothing about it)	5	1	94	139	165	106	153	181	114	133	174
2	4	5	43	27	16	38	27	14	46	33	18
3	13	18	36	17	5	22	9	3	25	25	5
4	40	79	21	9	11	20	5	2	9	6	5
5	79	53	6	4	2	11	5	2	5	4	0
6 (I can teach others)	62	47	3	7	4	6	4	1	4	2	1

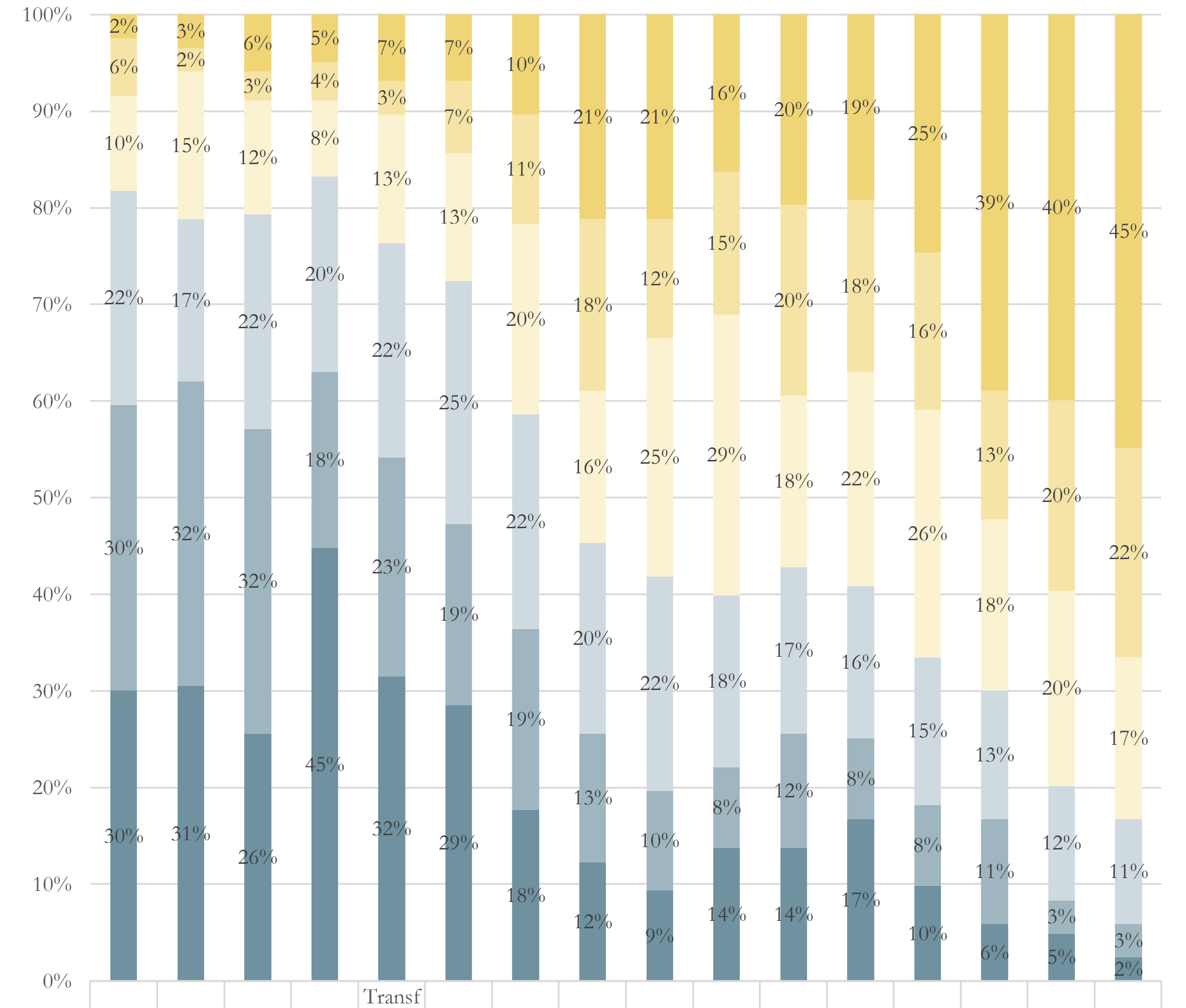
C.III: Where did you learn to use these?



	3D printer	Microcontroller boards	Building electronic devices	Blockbased/visual prog.	Vinyl cutter	Robots (prog.)	Textbased prog.	Laser cutter/CNC	Electronics
Have not learned	107	165	139	139	192	121	168	184	146
Primarily at home	29	12	35	19	7	30	21	8	23
Primarily in school	71	28	35	48	5	60	16	12	41

C.IV: Which parts of the process would be most important to you?

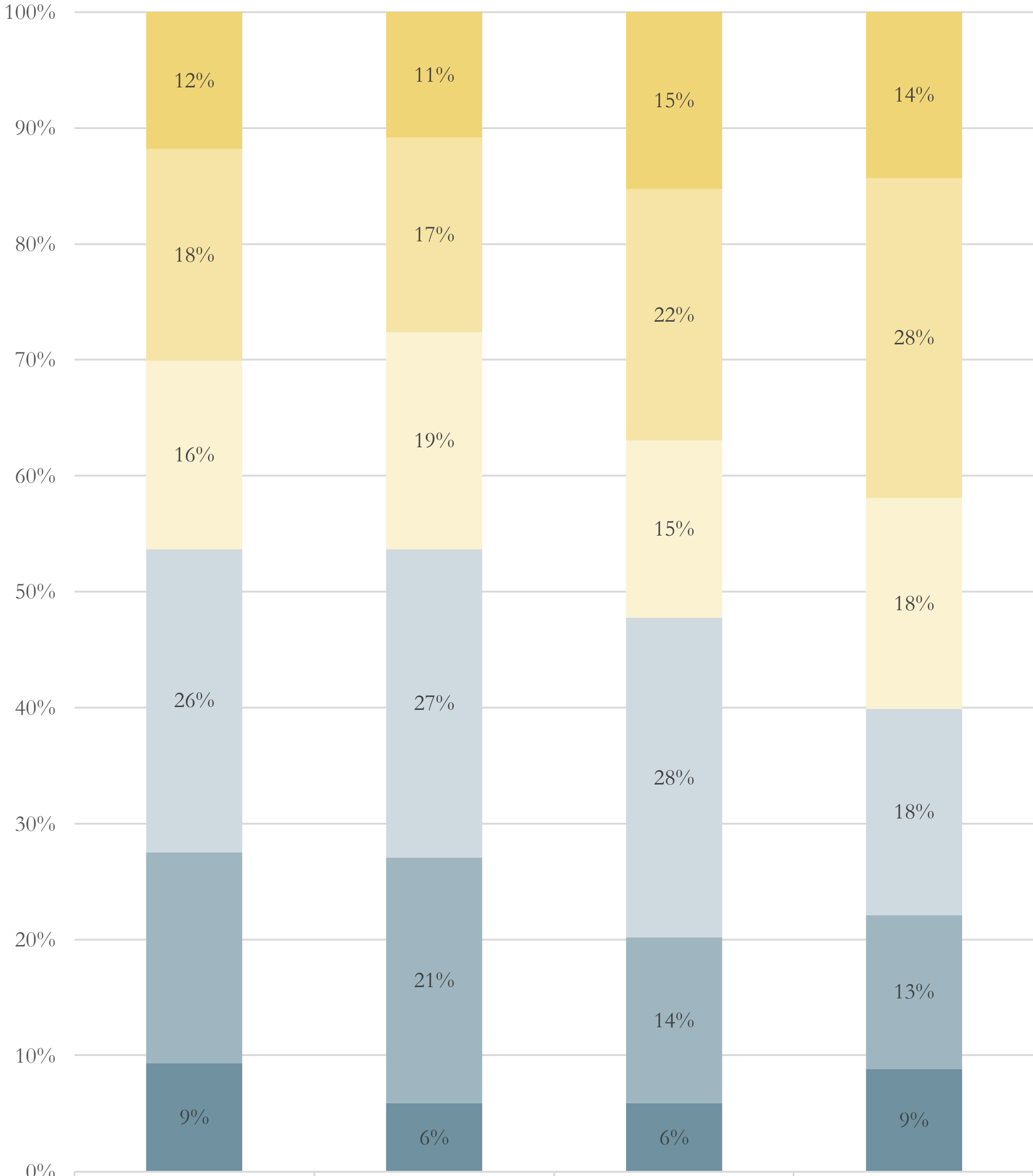
Choose a number between 1 and 6 (1 = not important at all, 6 = really important)



	All should agree	Meet w/ staff/relatives	Study nursing homes	Test solution with elderly	Transfer knowledge to future projects	Create a detailed plan	Use disagreement fruitfully	Study other countries	Sketch on paper	Patent the idea	Market solution/make money	Wait for good idea	Iterate on mock-up or sketch	Test cardboard mock-up	Stop working when finished	Build cardboard mock-up
1	5	7	12	10	14	14	21	43	43	33	40	39	50	79	81	91
2	12	5	6	8	7	15	23	36	25	30	40	36	33	27	40	44
3	20	31	24	16	27	27	40	32	50	59	36	45	52	36	41	34
4	45	34	45	41	45	51	45	40	45	36	35	32	31	27	24	22
5	60	64	64	37	46	38	38	27	21	17	24	17	17	22	7	7
6	61	62	52	91	64	58	36	25	19	28	28	34	20	12	10	5

C.V: Relationship to hacking and reparation in everyday life

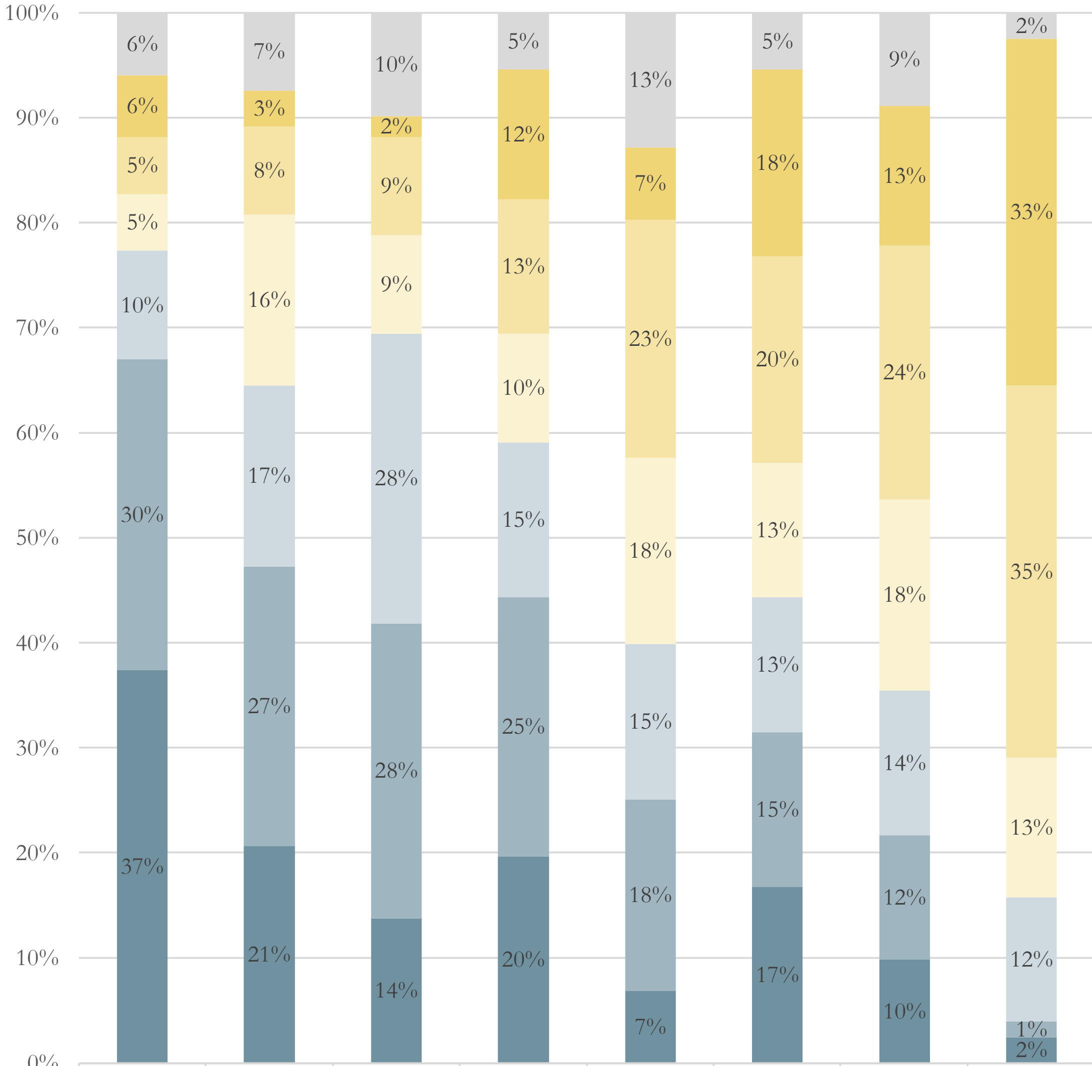
To what extent do you agree?...



	I know what is inside a phone/how it works	I want to know how they work and how to improve them	When things are broken, I think of ways to repair	Don´t care how they work, as long as they work
Strongly disagree	24	22	31	29
Disagree	37	34	44	56
Slightly disagree	33	38	31	37
Slightly agree	53	54	56	36
Agree	37	43	29	27
Strongly agree	19	12	12	18

C.VI: Technology and data

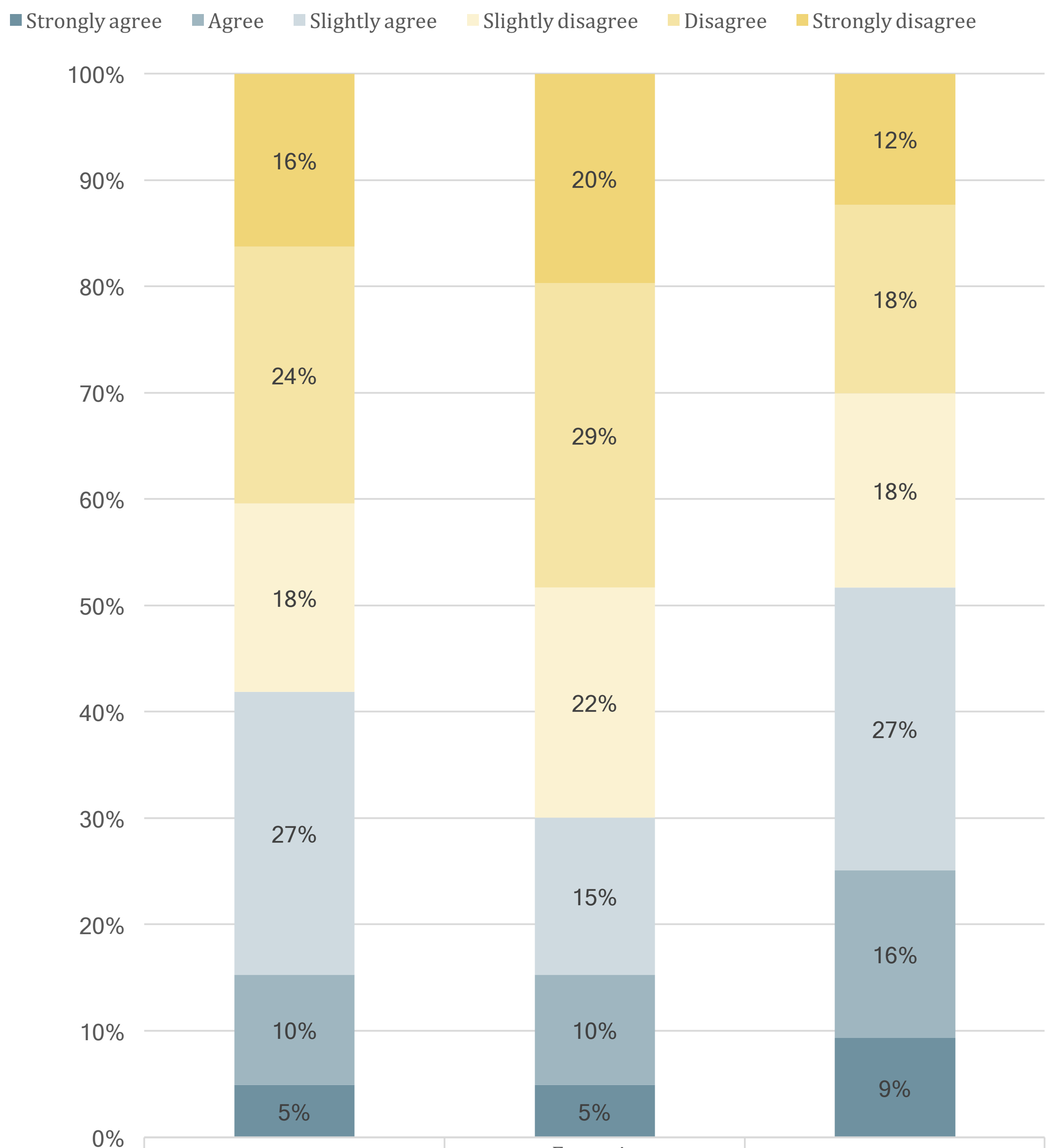
To what extent do you agree with these statements?



	Important who owns data	Technology gives me freedom to express my interests	Technology allows me to understand new contexts and opportunities	Tech./data/ info. should be free/open to everyone	Technology can be combined with other materials	National agencies should store personal data	Hacking is done by criminals	Hacking is done by everyone
Do not know	12	15	20	11	26	11	18	5
Strongly disagree	12	7	4	25	14	36	27	67
Disagree	11	17	19	26	46	40	49	72
Slightly disagree	11	33	19	21	36	26	37	27
Slightly agree	21	35	56	30	30	26	28	24
Agree	60	54	57	50	37	30	24	3
Strongly agree	76	42	28	40	14	34	20	5

C.VII: Thoughts about the future

To what extent do you agree? I would like to/a…



	Future in digital design	Future in engineering/science	Start my own business
Strongly disagree	33	40	25
Disagree	49	58	36
Slightly disagree	36	44	37
Slightly agree	54	30	54
Agree	21	21	32
Strongly agree	10	10	19

Appendix D: The questionnaire

This section contains the original questionnaire in Danish. The questionnaire was administered as an online survey, and therefore the questions were displayed differently.

Digital fabrikation, design og FabLab i skolen

Velkommen til Aarhus Universitets spørgeskema om dig og dit forhold til digital fabrikationsteknologi, design og FabLab i skolen.

Personlig information

Vi vil først gerne vide noget om dig og din skole

Hvad er dit UNI-login (brugernavn)? ____________________

Hvor gammel er du? ____________________

Hvad hedder din skole? ____________________

Hvilket køn er du?

- ☐ Dreng
- ☐ Pige

Hvilket klassetrin går du på?

- ☐ 6.
- ☐ 7.
- ☐ 8.
- ☐ 9.
- ☐ 10.

Teknologier

Vi vil nu spørge dig om konkrete teknologier, du måske har arbejdet med i skolen. Hvordan har du arbejdet med følgende teknologier i skolen?

	Jeg har slet ikke arbejdet med denne teknologi	Jeg har fulgt en instruktion (opskrift) til at lave noget med denne teknologi	Jeg har brugt teknologien til at lave noget, jeg selv har fundet på
3D printer	☐	☐	☐
Laserskærer (Laser cutter)	☐	☐	☐
Vinylskærer (Vinyl cutter)	☐	☐	☐

MakeyMakey	❑	❑	❑
Arduino	❑	❑	❑
LittleBits	❑	❑	❑
LilyPad	❑	❑	❑
Programmérbare robotter (f.eks. LEGO Mindstorms)	❑	❑	❑
Elektronik og lodning (dioder og modstande)	❑	❑	❑
Programmering med tekst (f.eks. HTML, Processing, Arduino, Sonic Pi eller Python)	❑	❑	❑
Visuel eller blokbaseret programmering (f.eks. LEGO Mindstorms, Scratch, ArduBlock eller Weedoo)	❑	❑	❑
Andre former for digital fabrikationsteknologi?	❑	❑	❑

Skriv her, hvilke andre teknologier, I har arbejdet med. Skriv også, hvad I brugte teknologierne til.

____

Hvor godt kender du disse teknologier? Bedøm dig selv på en skala fra 1 til 6, hvor 1 er "*Det ved jeg ikke noget om*" og 6 er "*Jeg kunne undervise andre om det.*"

	1	2	3	4	5	6
Computer / bærbar	❑	❑	❑	❑	❑	❑
Smartphones/tablets/iPads	❑	❑	❑	❑	❑	❑
Lasercutters eller CNC fræsere	❑	❑	❑	❑	❑	❑
Vinylskærer (Vinyl cutter)	❑	❑	❑	❑	❑	❑
3D printere	❑	❑	❑	❑	❑	❑
Bygge elektroniske dimser eller simple maskiner fra bunden	❑	❑	❑	❑	❑	❑
Microcontroller boards (f.eks. MakeyMakey og Arduino)	❑	❑	❑	❑	❑	❑
Bygge programmérbare robotter (f.eks. Lego Mindstorms)	❑	❑	❑	❑	❑	❑
Elektronik og lodning (dioder og modstande)	❑	❑	❑	❑	❑	❑

	1	2	3	4	5	6
Programmering med tekst (f.eks. HTML, Processing, Arduino, Python eller SonicPi)	☐	☐	☐	☐	☐	☐
Visuél eller blokbaseret programmering (f.eks. LEGO Mindstorms, Scratch, ArduBlock eller WeeDoo)	☐	☐	☐	☐	☐	☐

Hvor har du lært det?

	Primært i skolen	Primært hjemme	Har ikke lært det
Lasercutters eller CNC fræsere	☐	☐	☐
Vinyl Skærer (Vinyl cutter)	☐	☐	☐
3D-printere	☐	☐	☐
Bygge elektroniske dimser eller simple maskiner fra bunden	☐	☐	☐
Microcontroller boards (f.eks. MakeyMakey eller Arduino)	☐	☐	☐
Bygge programmérbare robotter (f.eks. Lego Mindstorms)	☐	☐	☐
Electronik og lodning (dioder og modstande)	☐	☐	☐
Programmering med tekst (f.eks. HTML, Processing, Arduino, Python eller SonicPi)	☐	☐	☐
Visual eller blokbaseret programmering (f.eks. LEGO Mindstorms, Scratch, ArduBlock eller WeeDoo)	☐	☐	☐

Har du nogensinde arbejdet med digital fabrikationsteknologi på din skole f.eks. i et FabLab eller værksted?
Digital fabrikationsteknologi er f.eks. MakeyMakey, Arduino, vinylskærer eller 3D printer

☐ Ja

☐ Nej

☐ Ved ikke

Beskriv kort, hvad du har lavet, hvilken teknologi du brugte og hvad du brugte teknologien til?

1. projekt

2. projekt

I det næste, spørger vi til, hvordan det var, at arbejde med digitale fabrikationsteknologier i skolen. På nogle skoler er der et lokale, som hedder FabLab eller Makerspace, hvor man arbejde med disse teknologier.

Hvordan var det at arbejde med digital fabrikation i skolen/FabLab?

	Meget uenig	Uenig	Hverken enig/uenig	Enig	Meget enig
Teknologierne var svære	☐	☐	☐	☐	☐
Det var kedeligt at arbejde med teknologierne	☐	☐	☐	☐	☐
Jeg kan godt lide at være i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Det er interessant at lære i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Det er spild af tid at lære i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Jeg vil gerne bruge teknologierne til mine egne projekter udenfor skolen	☐	☐	☐	☐	☐
Det, vi lærer om digitale fabrikationsteknologier, kan jeg bruge i fremtiden	☐	☐	☐	☐	☐
Jeg elsker at lave projekter med digitale fabrikationsteknologier	☐	☐	☐	☐	☐
Jeg lærer meget i skolens FabLab/Makerspace	☐	☐	☐	☐	☐
Jeg tænker på det, vi har lært om digitale fabrikationsteknologier, når jeg er derhjemme	☐	☐	☐	☐	☐

I hvor høj grad er du enig i følgende udsagn? Brug skalaen fra 1 til 6, hvor 1 er "Meget uening", mens 6 er "Meget enig".

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Undervisning med digital fabrikation i skolen har lært mig at arbejde kreativt med teknologi	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har lært mig at løse svære eller komplekse udfordringer	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har hjulpet mig til at forholde mig til samfundsmæssige problemer	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har hjulpet mig til at forestille mig, hvordan jeg kan forandre ting, f.eks. med teknologi	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har hjulpet mig til at blive bedre til at samarbejde med mennesker med forskellig baggrund og evner	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har lært mig hvordan teknologi påvirker den måde, vi lever på	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har lært mig, hvordan nye ideer, ting og teknologier bliver skabt	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

I hvor høj grad synes du at forløb med digital fabrikation har hjulpet dig til ...

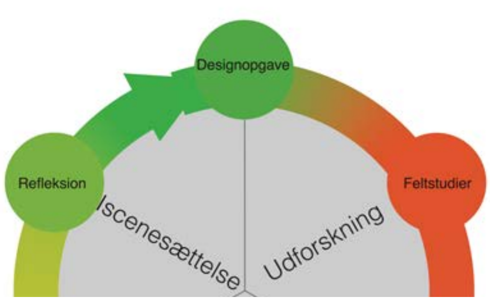
Bedøm på en skala fra 1 til 6, hvor 1 er "*Slet ikke*" og 6 er *"I høj grad*".

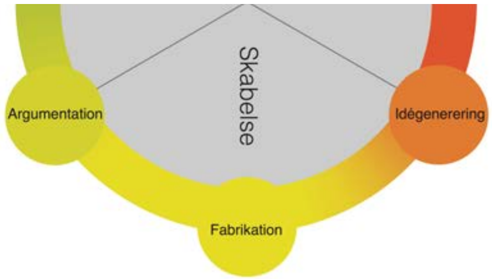
	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Undervisning med digital fabrikation i skolen har hjulpet mig til at forholde mig kritisk til min egen og andres anvendelse af teknologi (f.eks: Er vi for meget på Facebook?, er vores billeder sikre i Snapchat?, skaber vi for meget elektronisk affald?)	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har hjulpet mig til at kommunikere med forskellige mennesker over Internettet	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har lært at bruge teknologi til at arbejde systematisk med opgaver (i f.eks. fysik/kemi, natur/teknik)	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har øget min interesse i at ville have en videregående uddannelse	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har øget min interesse i at ville have en kreativ eller håndværksmæssig uddannelse	☐	☐	☐	☐	☐	☐
Undervisning med digital fabrikation i skolen har øget min interesse i at ville starte din egen virksomhed	☐	☐	☐	☐	☐	☐

Design og kreativitet

De næste spørgsmål handler om at få nye idéer, arbejde kreativt og skabe nye ting med teknologi.

Har du nogensinde arbejdet med denne model (Design Process Modellen) på din skole?





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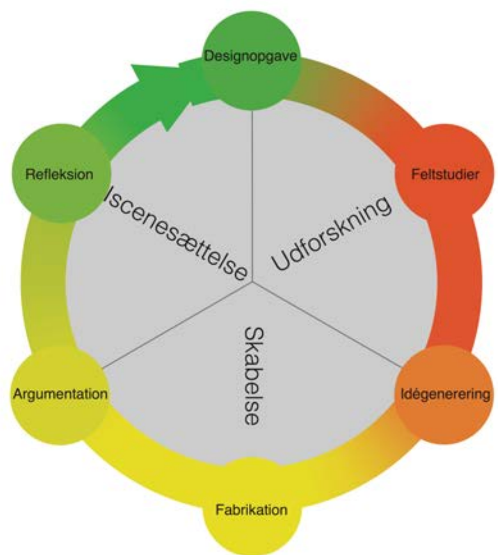
- ☐ Ja
- ☐ Nej
- ☐ Ved ikke

Hvor godt kender du enkeltdelene af Design Proces modellen? Bedøm dig selv på en skala fra 1 til 6, hvor 1 er "Det ved jeg ikke noget om" og 6 er "Jeg kunne undervise andre om det."

	1	2	3	4	5	6
Designopgave	☐	☐	☐	☐	☐	☐



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	1	2	3	4	5	6
Feltstudier	☐	☐	☐	☐	☐	☐
Idégenerering	☐	☐	☐	☐	☐	☐

	1	2	3	4	5	6
Fabrikation	☐	☐	☐	☐	☐	☐
Argumentation	☐	☐	☐	☐	☐	☐
Refleksion	☐	☐	☐	☐	☐	☐

Har du nogensinde haft en idé til et nyt produkt eller opfindelse?

☐ Ja
☐ Nej

Beskriv kort din idé

Har du skabt eller bygget din idé eller opfindelse?

☐ Ja
☐ Nej

Designopgave: Plejehjemmets udfordring

I begyndelsen af 2014 forsvandt 9 bedsteforældre fra deres plejehjem pga. hukommelsestab (demens). Plejehjemmets problem er at skabe tryghed for de ældrene uden at tage deres frihed fra dem.

Hvis du blev bedt om at løse dette problem, hvad ville du så gøre?

Hvordan ville du finde den rigtige løsning på problemet med de demente ældre, som bliver væk? Hvilke dele af processen ville være vigtigst for dig?

Vælg et tal fra 1 til 6 (1 = slet ikke vigtigt, 6 = virkeligt vigtigt)

	1	2	3	4	5	6
Jeg ville lave en grundig plan for hele projektet	☐	☐	☐	☐	☐	☐
Jeg ville vente til at en god idé dukkede op	☐	☐	☐	☐	☐	☐
Jeg vil besøge et plejehjem for at udforske problemet nærmere	☐	☐	☐	☐	☐	☐
Jeg ville finde ud af, hvad de gør i andre lande	☐	☐	☐	☐	☐	☐
Jeg vil skitsere mulige løsninger på et stykke papir	☐	☐	☐	☐	☐	☐
Jeg ville bygge min idé i pap	☐	☐	☐	☐	☐	☐
Jeg vil teste min pap-model på et plejehjem	☐	☐	☐	☐	☐	☐
Jeg vil gentage mine tests med en ny skitse eller pap-model flere gange	☐	☐	☐	☐	☐	☐
Jeg vil afprøve min løsning sammen med ældre plejehjemsbeboerne	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

Vælg et tal fra 1 til 6 (1 = slet ikke vigtigt, 6 = virkeligt vigtigt)

	1	2	3	4	5	6
Jeg vil afholde et møde med plejehjemspersonale, pårørende, for at diskutere min løsning	☐	☐	☐	☐	☐	☐
Jeg vil sørge for, at alle er enige om løsningen	☐	☐	☐	☐	☐	☐
Jeg vil bruge uenigheder mellem personer/grupper til at udvikle nye idéer	☐	☐	☐	☐	☐	☐
Jeg vil tage patent på min idé	☐	☐	☐	☐	☐	☐
Jeg vil starte et firma til at markedsføre min løsning og tjene penge	☐	☐	☐	☐	☐	☐
Så snart min løsning er færdig, stopper jeg helt med at arbejde på problemet	☐	☐	☐	☐	☐	☐
Jeg vil bruge min viden fra dette projekt, i fremtidige projekter	☐	☐	☐	☐	☐	☐

Andet du ville gøre? Beskriv dem her.

Hacking, data og teknologi

Her handler det om dit forhold til hacking og reparation af teknologi i din hverdag. Hvor enig eller uenig er du...

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Jeg er ligeglad med hvordan mine digitale dimser fungerer, bare de virker	☐	☐	☐	☐	☐	☐
Jeg er interesseret i at vide, hvordan mine digitale dimser fungerer, og jeg forbedre dem ofte	☐	☐	☐	☐	☐	☐
Når jeg ser en ødelagt ting, tænker jeg straks på en måde at reparere	☐	☐	☐	☐	☐	☐
Jeg har en god idé om, hvad der er inde i en mobiltelefon, og hvordan den virker	☐	☐	☐	☐	☐	☐

Hvad gør du, hvis noget ikke virker på f.eks. din computer eller mobil? Markér tre muligheder.

☐ Ringer til en ven
☐ Læser i en manual
☐ Spørger en af mine forældre
☐ Ringer til support
☐ Søger på problemet på Internettet
☐ Søger efter hjælp på specifikke hjemmesider
☐ Starter en diskussion på en f.eks. et forum
☐ Roder med forskellige indstillinger, kommandoer osv., som jeg kender
☐ Ved det ikke
☐ Andet. Skriv venligst her:__________

Har du nogensinde skilt din telefon eller andre digitale dimser ad?

☐ Ja
☐ Nej
☐ Ved ikke

Hvorfor åbnede du den? Var det f.eks. for at fikse/forbedre noget?

Hvorfor ikke?

- ☐ Hvorfor skulle jeg?
- ☐ Det kan jeg ikke finde ud af
- ☐ Så ville jeg bryde garantien
- ☐ Ved ikke
- ☐ Andet. Skriv det venligst her:__________

Hvor enig er du i disse udsagn om teknologi og data?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig	Ved ikke
Teknologi, data og information bør være åbne og tilgængelige for alle	☐	☐	☐	☐	☐	☐	☐
Staten skal gemme alles personlige data og information	☐	☐	☐	☐	☐	☐	☐
Jeg går op i hvem der ejer mine data og informationer, f.eks. billeder og musik	☐	☐	☐	☐	☐	☐	☐
Hacking er kun noget kriminelle gør på internettet	☐	☐	☐	☐	☐	☐	☐

...forsat fra sidste side

Hvor enig er du i disse udsagn om teknologi og data?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig	Ved ikke
Hacking er noget alle gør	☐	☐	☐	☐	☐	☐	☐
Teknologi giver mig frihed til at udfolde mine interesser	☐	☐	☐	☐	☐	☐	☐
Jeg kan se hvordan teknologi kan kombineres med andre materialer (f.eks. stof, træ eller papir)	☐	☐	☐	☐	☐	☐	☐
Teknologi giver mig mulighed for at forstå nye sammenhænge og muligheder	☐	☐	☐	☐	☐	☐	☐

Din fremtid

Til sidst vil vi gerne vide, om du eventuelt kunne finde på at overveje en fremtid indenfor teknologi, design naturvidenskab eller som selvstændig. Vi spørger også til, hvor mange bøger, I har, der hvor du bor.

Her spørger vi dig om dine tanker for fremtiden
Hvor enig er du?

	Meget uenig	Uenig	Lidt uenig	Lidt enig	Enig	Meget enig
Jeg vil have en fremtid indenfor teknologi og design	☐	☐	☐	☐	☐	☐
Jeg vil have en fremtid som ingeniør eller indenfor naturvidenskab	☐	☐	☐	☐	☐	☐
Jeg vil starte min egen virksomhed	☐	☐	☐	☐	☐	☐

Hvor mange bøger er der ca. i dit hjem?

(du skal ikke tælle blade, aviser eller dine skolebøger med)

- ☐ 0-10 bøger
- ☐ 11-25 bøger
- ☐ 26-100 bøger
- ☐ 101-200 bøger
- ☐ Over 200 bøger

Tusind tak for din hjælp med at besvare vores spørgeskema.

Hvis du har andet at fortælle om dit forhold til teknologi, eller ideer til hvordan fremtidens skole kan bruge teknologi i undervisningen, så skriv dem gerne her:

Mange hilsner
Ole, Rachel, Kasper og Mikkel
Aarhus Universitet