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The K-12 Maker Studio. Towards Teaching and Development of Design Literacy in Educational Maker Settings

School of Communication and Culture

Mikkel Hjorth

PhD Dissertation

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Abstract

This dissertation presents three years of research into the introduction of maker settings into formal education for students in Denmark aged 11–15. The dissertation is concerned with design literacy as a possible path to prepare students for a world which is and will be radically changed by digital technologies. It is based on six publications: five papers and one report. In the dissertation, I provide an overview of my research, which has explored the possibilities of developing design literacy in the context of maker settings in formal education, guided by the following question:

> *How can activities with maker technologies in formal educational settings contribute to the development of design literacy among adolescents?*

The answer to this question derives from observational and intervention studies in schools, a professional development course for teachers, two large-scale surveys, and post-project interviews with students. In total, three intertwined and overlapping research programs produced contributions to the emerging research field of making in education. This field explores the introduction of maker technologies (such as 3D printers and programmable electronics) and maker practices known from makerspaces to informal and formal education. The research presented here, contributes to the field of making in education in four perspectives:

From a conceptual perspective, I have contributed to a turn towards design in the field of making in education by investigating design process knowledge, design judgment, and stance towards inquiry as aspects of design literacy.

From a pedagogical perspective, I have studied the K-12 maker studio as an approach to teaching as well as teachers who implement such an approach. By unfolding challenges for teachers and development of competences, I have contributed to a focus on teachers in the field.

From an assessment perspective, I have contributed knowledge on how to sustain and scale development of design literacy through K-12 maker settings by investigating tools for assessing larger-scale implementations of such maker settings in education.

From an exemplar perspective, I have contributed exemplars of K-12 maker studio activities with in a design literacy perspective, of professional development of teachers, as well as of ways to research maker settings in education through such exemplars.

Resumé

Denne afhandling præsenterer 3 års forskning i undervisning af 11-15 årige elever i maker settings i skolen. I afhandlingen udforsker jeg design literacy som perspektiv på at forberede eleverne til en verden, som undergår hastige forandringer med udgangspunkt i anvendelsen af digitale teknologier. Afhandlingen er baseret på 6 publikationer: 5 artikler og en forskningsrapport. I den sammenfattende artikel etablerer jeg et overblik over min forskning, som har undersøgt udviklingen af design literacy i maker settings i skolen ud fra følgende spørgsmål:

Hvordan kan aktiviteter med makerteknologier i skolen bidrage til elevernes udvikling af design literacy?

Jeg har udforsket dette spørgsmål gennem observations- og interventionsstudier i skoler og i efteruddannelse af lærere, samt gennem to spørgeskemaundersøgelser blandt elever. Gennem tre indbyrdes afhængige og overlappende forskningsprogrammer har jeg bidaget til det emergerende felt "making in education". Dette forskningsfelt beskæftiger sig med makerteknologier (som f.eks. 3D printere og programmérbar elektronik) og makerpraksis i både uformelle læringsrum og i skoler. Samlet set har min forskning bidraget til feltet i fire perspektiver:

I et konceptuelt perspektiv har jeg bidraget til et designperspektiv ved at undersøge viden om designprocesser, dømmekraft i designprocesser og undersøgelsesstandpunkt som aspekter ved design literacy.

I et didaktisk perspektiv har jeg udforsket K-12 maker studio som en tilgang til undervisningen i skolen, såvel som de udfordringer lærere har med en sådan tilgang. Ved at udfolde læreres udfordringer og efteruddannelse, har jeg bidraget til at skabe et fokus på læreren som afgørende for making in education.

I et målingsperspektiv har jeg udforsket mulighederne for at måle aspekter ved design literacy gennem spørgeskemaundersøgelser. Dermed har jeg bidraget til et fokus på bæredygtigheden af indsatser med maker settings i skolen.

Fra et eksemplarperspektiv har jeg udfoldet konkrete implementeringer af K-12 maker studio som en undervisningstilgang. Jeg har desuden bidraget med eksemplarer på forskning i efteruddannelse af lærere, og ikke mindst har jeg bidraget med eksempler på, hvordan sådanne interventioner kan bidrage til forskning i maker settings i skolen.

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1. Introduction

The research presented in this dissertation investigates the introduction of maker settings into formal education for students in Denmark aged 11–15. Introducing maker settings into the school environment is intended to prepare students for a world which is already radically changed by digital technologies and can only become more so. This radical change is well documented both internationally (Arntz, Gregory, & Zierahn, 2016; Forum, 2016; OECD, 2017) and in Denmark (McKinsey & Company, 2017; Tænketanken CEVEA & HK Danmark, 2015), the context for this dissertation. Further, while there was once talk of children being born as digital natives – "…'native speakers' of the digital language of computers, video games and the Internet" (Prensky, 2001), unlike their digital immigrant parents – there is now ample evidence that adolescents are not as a cohort developing digital competences sophisticated enough to match the developments in digitalisation of our societies (Bundsgaard, Rasmus Puck, & Petterson, 2014; Hjorth, Iversen, Smith, Christensen, & Blikstein, 2015). In other words, exposure to technology in society has not been sufficient to bring about this change. Similarly, while the last decade has seen very large investments in digital technologies in Danish schools, the exposure to technology has not in itself caused school students to become digital natives (Bundsgaard et al., 2014).

Approaches to understanding the new competences which students need to acquire include a focus on *twenty-first century skills* (Ananiadou & Claro, 2009; Voogt & Roblin, 2012) and on *computational thinking* (Barr & Stephenson, 2011; Brennan & Resnick, 2012; Grover & Pea, 2013; Wing, 2006). Both these approaches mention problem-solving with digital tools as a core competence in our present society. In the research presented here, I build upon research in design, which, as discussed in Kees Dorst (2011), has complex problem-solving as its core. Inspired by work on multiliteracies (Kress, 2003) and digital literacies (Lankshear & Knobel, 2008), the dissertation investigates *design literacy* as a new form of literacy for complex problem solving. I have investigated school students' problem-solving with digital technologies in school makerspaces, which have been suggested as learning environments which promote such problem-solving (Sheridan et al., 2014). The investigations were undertaken in the context of what I will refer to throughout this dissertation as *maker settings*. I use this term to denote the use of maker technologies for maker activities (making) in formal educational settings. The dissertation explores possibilities for developing design literacy in the context of maker settings in formal education by addressing the following question:

> *How can activities with maker technologies in formal educational settings contribute to the development of design literacy among adolescents?*

This research question builds on a range of perspectives. I have researched activities with maker technologies within *formal educational settings* in order to better understand the sustainability of such activities. The research question refers to design literacy for all school students, not just those who are signed up for after-school activities, and therefore scalability and sustainability are key aspects. The *adolescents* in the research reported here were aged 11–15, and it is therefore this age group at which my answers to the research question are directed. In the Danish education system it is this age group that offers the best opportunity to investigate design and complex problem-solving in formal school settings as literacy for all school students, because after the age of 15, Danish school students move on to different kinds of high school. Even though my research has been carried out with 11-15-year-old students, I refer to *K–12* (Kindergarten through grade 12) throughout this dissertation, since in research on maker settings, this is an established way of referring to formal educational contexts at pre-college level. I initially chose to focus on *activities* rather than teaching in order to stay open to processes, actions, and interactions in the maker settings; but teachers and teaching are also involved here, and they became a major focus in part of my work. Likewise, the research question addresses the more open notion of *development* rather than *learning*. This corresponds well with the use of the term *literacy*, which, in the interpretation used here, is not confined to content knowledge, skills, and competences to be learned (see also (Biesta, 2005) for a discussion of the problems of the notion of learning). The definition of *maker technologies* applied in this dissertation, as well as in the included publications,[1] is a broad one which includes all technologies frequently found in makerspaces. This includes digital fabrication technologies such as 3D printers and laser cutters, analogue crafting materials, and physical interaction technologies such as programmable microcontrollers and digital construction kits. Finally, the research question addresses *design literacy*. This is a concept which will be unfolded throughout the

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[1] In P1, P3, P4, and R2 a slightly different terminology was used. Here the term *digital fabrication technologies* was used with the same meaning as *maker technologies* is in this dissertation overview. Similarly, in those publications, *digital fabrication* was used instead of the term *making*.

dissertation and which seeks to capture those aspects of design expertise which are relevant to school students' problem-solving in a digital age.

1.1. Contributions

This dissertation is structured around five papers and one published report. These, together with chapter five, present the contributions that I claim as well as the research that I have undertaken. The attempt to answer the above research question derives from intervention studies conducted in Danish public schools, a professional development course for teachers, surveys, and post-project interviews with school students. My work is positioned within and contributes to *making in education*, which is an emerging research field. Accordingly, there are no well-established specialist publications in the area. For this reason, papers 1–5 were published across a range of journals and publications in an effort to ground the work in associated research fields (P1, P2, and P5), while at the same time establishing a dialogue with, and thus contributing to, the emerging field of making in education (P3, P4, and to some degree P1). Through P1–P5, R2, and this dissertation overview my research contributes to the emerging field of making in education from four perspectives.

From a *conceptual perspective*, I have contributed to improving the understanding of design literacy. In this perspective, my research has introduced new approaches to maker settings in education by building on literature on design expertise and design thinking. The research reported here point to students' fixations on initial ideas, and their lack of competences for further developing those ideas as impediments to their development of creative solutions to complex problems (P1, P2, P5). To overcome such impediments, my studies indicate that design-process knowledge, design judgment, and a designerly stance towards inquiry are all essential aspects of design literacy (P1, P2, P5). These findings contribute to a turn towards design in the field of making in education.

From a *pedagogical perspective*, my studies contribute an improved understanding of the implications of a design-literacy perspective for teaching in maker settings. From this perspective, I introduce the *K–12 maker studio* as a teaching-in-a-design-studio approach to maker settings. I discuss the differences between the established design-studio tradition and a K–12 maker studio approach to teaching. I establish that scaffolding student development with a design-process model and a highly structured design process can help to develop students' design literacy (R2, P1). I also unfold teachers' challenges derived from lack of capabilities with regard to materials in maker studio approaches, fixations with regard to students' design solutions, and positioning with regard to student feedback. Further, my research indicates possibilities for teachers' development of competences for overcoming such challenges (P3, P4). These findings contribute to knowledge of teachers' roles in K–12 maker studios as well as to reinstating the teacher as a quintessential element in making in education.

From an *assessment perspective*, I have contributed to knowledge of assessing the implementation of making in formal education. On pre- and post-project surveys student (self-perceived) responses suggested that in schools in which they could work with their own ideas with a diverse range of digital technologies, with their work scaffolded and structured around a design-process model to a high degree, they had on average developed some degree of design literacy (R2). Further, I have contributed to the development of a survey instrument to gauge school students' stances towards inquiry as a way of assessing their design literacy (P2). This tool pointed to a lack of design literacy at the outset of these studies, but it was not able to measure a statistically significant improvement in stance towards inquiry in the project period (P5). Consistent with interventional studies in P1, the survey data suggests that there is a potential for teaching with the aim of design literacy in maker settings in formal education in Denmark, and that the gains are very dependent on the way in which such teaching is implemented (R2). By studying potentials and challenges for implementations of K–12 maker studio approaches across a range of schools, my research from an assessment perspective addresses a trajectory towards sustainability and scalability in formal educational maker settings.

Finally, from an *exemplar perspective*, the discussion and analysis of the concrete experiments with interventions of teaching for design literacy (P1) and training teachers to teach for design literacy (P3, P4) are themselves contributions to the field of making in education. As discussed in (Flyvbjerg, 2006), such exemplars are necessary for any scientific discipline. The exemplars discussed in P1, P3, P4, and in chapter three of this dissertation overview, are manifestations of and challenges to the research program within which they were devised (Binder & Redström, 2006; Dalsgaard, 2009). They are a necessary part of how I have inquired into the world and therefore they are a contribution to a dialogue within the field of making in education, in three important areas: how to teach for design literacy, how to prepare teachers, and how to study making in education. From a teaching perspective, these experiments are instantiations of the pedagogical principles; from a research perspective, they are instantiations of research into concepts such as design literacy.

1.2. Context of my research

My PhD studies were conducted while I held a joint position between Aarhus University and VIA University College, at which I was a lecturer in the department of teacher education. My studies were therefore influenced by and contributed to development of teaching as well as to research into such teaching and student development. At Aarhus University, my studies took place as part of the Child–Computer Interaction Group at the Department of Digital Design and Information Studies. As evidenced by the joint publications, all of the research presented here, has been carried out in collaboration with researchers from this group, and within the project FabLab@School.dk. FabLab@School.dk was a three-year research project (2014-2017) focused on makerspaces as "hybrid learning laboratories, which combine digital fabrication, design thinking, collaborative idea generation and creating in solutions to complex societal challenges" (Hjorth et al., 2015, p. 6). In FabLab@School.dk, the Child–Computer Interaction Group cooperated with the municipalities of Aarhus, Vejle, and Silkeborg to investigate implementation of makerspaces (referred to as FabLabs), and maker technologies (often referred to as digital fabrication technologies). However, this dissertation is not about the makerspaces themselves, or the abundant digital technologies within them. Rather, it is about the new potential processes and interactions between students, teachers, and the world that maker settings in schools – including makerspaces, maker culture and maker technologies – represent.

1.3. Included publications

This is a dissertation by publication. It consists of two parts: (1) five research papers and one research report, and (2) a general overview which connects, unfolds, and provides context for the contributions in the included publications. Chapter five of the overview contains unpublished research, which disrupts this structure. The unpublished research is included since it is necessary in order to unfold teachers' challenges in maker settings. Thus, it represents the perhaps most important trajectory in this dissertation. The synthesis of the included publications and the overview forms the research contribution made by this dissertation. Not included in the dissertation is a published report written in 2015 which assessed the state of digital competence and design literacy of students aged 11–15, as well as their exposure to maker technologies (Hjorth et al., 2015). However, the included report of 2017 provides a follow-up on the parts which are important for the dissertation – design literacy and making in schools.

Figure 1 lists the included publications and indicates to which of the four perspectives each publication contributes. Futher, the last column indicates which trajectories in the literature, the publications address directly. These trajectories, which are unfolded in chapter two, are a turn towards design, towards sustainability and scaling, and towards a focus on teachers.

	Conceptual	Pedagogical	Assessment	Exemplar	Trajectories
P1: Design thinking for digital fabrication...	x	x		x	Towards design
P2: Towards a formal assessment…	x		x		Towards design Sustainability
P3: Video design games…		x		x	Focus on teachers
P4: Educating the reflective educator…		x		x	Sustainability Focus on teachers
P5: Understanding design literacy…	x		x		Towards design Sustainability
R2: Digital technology and design processes…			x		Sustainability

Figure 1: List of included publications. An x marks if the publication has contributed to the given perspective. The final column indicates which trajectories are directly addressed in the publication.

P1: Design thinking for digital fabrication in education

Smith, R. C., Iversen, O. S., & Hjorth, M. (2015). *International Journal of Child–Computer Interaction, 5*, pp. 20–28.

P1 investigates design thinking as a lens through which to view student engagement with maker technologies in K–12 education. The paper is based on two studies. In an observational study, 11–15-year-old students were found to be impeded by a lack of design-process knowledge, while an interventionist study explored the development of design judgment through making in education among grade 7 students (aged 13–14). The paper presents cases in which students showed signs of developing design judgment, and it argues that design judgment is a part of design thinking which can foster a more profound understanding of making processes among students. The paper was published in a special issue on digital fabrication in education in the International Journal of Child–Computer Interaction (IJCCI). The field of making in education does not yet have its own designated journal and special issues like this one have therefore contributed to the establishment of making in education as a field.

P2: Towards a formal assessment of design literacy: analyzing K–12 students' stance towards inquiry

Christensen, K. S., Hjorth, M., Iversen, O. S., & Blikstein, P. (2016). *Design Studies*, 46, pp. 125–151.

In P2, the focus is on measuring stance towards inquiry. The paper presents a tool for quantitative assessment of K–12 students' stance towards inquiry as a part of their development of design literacy. Based on design-thinking literature, a theoretical argument is made for a designerly stance towards inquiry as a prerequisite for engaging with wicked problems. The Design Literacy (DeL) assessment tool contains a design for a qualitative survey question, a coding scheme for assessing aspects of a designerly stance towards inquiry, and a description of how the results were validated. The DeL tool contributes to knowledge about school students' stance towards inquiry and presents the argument that this stance is a prerequisite for developing design literacy in maker settings. The paper's submission to Design Studies was intended to test the validity of the arguments presented within the wider context of design literacy in general: that is, to test the credibility of translating concepts from design research to the emerging field of making in education and back.

P3: Video design games: Training educators in teaching design

Smith, R. C., Iversen, O. S., Christensen, K. S., & Hjorth, M. (2016). *FabLearn Europe*.

P3 marks the turn of my studies towards a focus on teacher competence and teacher training. The video design game presented in the article was developed to train educators in teaching design literacy by helping them to gain new understandings of their own practices. By engaging teachers in a workshop format consisting of three rounds of observing, reflecting and generalising from a video snippet, the video design game helped teachers to go beyond their initial assumptions and prejudices. Based on the video snippets taken from their own practice, twenty-five educators in a digital fabrication and design program were able to critically reflect on their teaching practice and to develop new insights. Thus, the paper contributed to the knowledge of how to prepare teachers for making in education in a design-literacy perspective. The paper was submitted to the FabLearn Europe conference. These conferences are directed at both researchers and practitioners engaged with making in education, and as P3 contributed both to knowledge of teachers' practices and to the development of new practices, we saw this as the publication setting where it would have the most impact.

P4: Educating the reflective educator: Design processes and digital fabrication for the classroom

Hjorth, M., Smith, R. C., Loi, D., Iversen, O. S., & Christensen, K. S. (2016). *FabLearn '16 – Proceedings of the sixth Annual Conference on Creativity and Fabrication in Education*, ACM, New York.

P4 explores the demands for change in teacher mindsets, capabilities, and approaches to design and technology that followed from the introduction K–12 maker studio approaches to the classroom. The paper reports on a research-based professional development course that was developed to address and study the challenges experienced by educators when teaching design in K–12 classes. The paper investigated three aspects that we argued were crucial to teachers' development as they engage with the goal of teaching design literacy: Teachers' capabilities to (1) navigate a complex design process, (2) manage digital and analogue design materials, and (3) balance between different modes of teaching. The paper demonstrates how a combination of design theory, in-school practice, and peer-to-peer learning created a framework for educating design educators – a framework that allowed us to investigate K–12 teachers' development of core competencies for bringing design and digital fabrication to a diverse range of students. The study also showed how the framework in its own right facilitated and supported co-development of new teaching practices. Like P3, therefore, this paper contributes both to research knowledge and to knowledge of development of new teaching practices for making in education. To achieve the maximum impact in the research field and that of teaching practices for making in education, the paper was submitted to the FabLearn Flagship conference at Stanford University and published in the proceedings of that conference.

P5: Understanding design literacy in middle-school education: Assessing students' stances towards inquiry

Christensen, K. S., Hjorth, M., and Iversen, O. S., & Smith, R. C. (2018). *International Journal of Technology and Design Education.*

P5 follows up on P2's assessment of stance towards inquiry as an aspect of design literacy by assessing this trait among middle-school students who had received some degree of training in making in education. The assessments were based on the same survey instrument as P2, but additionally on a range of questions about student experiences with making and knowledge of design processes. Our analysis suggested that participating students had gained routine knowledge about design, but that they had not internalised a designerly stance towards inquiry to a degree assessable by the applied instrument. P5 concludes that, in general, the students were on a path towards becoming more "design literate," but that the results suggested that they generally had developed only routine expertise during the first experiences of making. P5 thus explores school students' development of design literacy through making in education. The paper was submitted to International Journal of Technology and Design Education to test the validity of the arguments within an established research community with focus on education in technology and design as well as to widen the impact of our research to more established educational fields.

R2: Digital technology and design processes II: Follow-up report on FabLab@School survey among Danish youth

Hjorth, M., Christensen, K. S., Iversen, O. S., & Smith, R. C. (2017), Aarhus University.

R2 was part of the quantitative triangulation of qualitative findings in my research. This report is based on an endline survey of the FabLab@School.dk project and is a follow-up to Hjorth et al. (2015). Its objective was to gain deeper understanding of the effects of the FabLab@School.dk educational program from 2014 to late 2016. The endline survey was administered to two groups: 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 (246 students from FabLab schools), and a control group of schools that were not part of the FabLab@School.dk project (203 students from control schools). The report elaborates on a series of survey instruments which aim to capture the development of design literacy through making in education. In so doing, the report contributes to the knowledge of implementations of making in formal education. The report, which is not peer-reviewed, is published by Aarhus University.

1.4. The dissertation

The first part of the dissertation is the general overview, which consists of six chapters.

Chapter two positions the research contributions within the emerging field of making in education. Within this field, I indicate three trajectories, which my research has addressed: towards design, towards sustainability and scaling, and towards a focus on teachers.

Chapter three outlines my research approach. My research has been inspired by Research-through-Design. More specifically, I lay out how my research in a perspective of exemplary design research can be seen as driven by continuous interactions between research question, programs, and experiments.

Chapter four is an unfolding and exploration of the concept of design literacy. In the chapter, I provide exemplars of making in education in which students display beginning appreciations for design processes, design judgment, and a designerly stance towards inquiry as aspects of design literacy. These aspects are explored based on research in design. The chapter also includes my research into quantitative, larger-scale assessment of stance towards inquiry as an aspect of design literacy.

Chapter five takes on the challenge of researching design literacy in-the-wild by focusing on teachers in classrooms. Here, I discuss differences of context between the renowned design studio described in (Schön, 1985) and what I refer to as the K–12 maker studio. I present the challenges faced by teachers as they work to implement a maker studio approach, and specifically, their challenges with materiality, fixations on first ideas, and positioning.

Chapter six concludes and discusses the findings unfolded in chapters 4 and 5 as contributions to the trajectories developed in chapter two. The chapter goes on to discuss the limitations of the research leading to these contributions, as well as the potentials for future research.

2. Related work

This chapter positions my research contributions within the field of making in education and describes how my work builds upon the existing literature in this field. The emerging field of making in education, building on the legacy of Seymour Papert's work with digital construction kits (e.g. LEGO Mindstorms), has been characterised by an overwhelming focus on teaching STEM subject matter. My research, first, has contributed to **a turn towards design** in the field by adding to the conceptual understanding of design literacy and by providing exemplars of teaching aimed at promoting design literacy in maker settings. Second, having described the first steps along the trajectory of studying **sustainability and scaling** rather than isolated interventions, my work contributes to this turn in an assessment perspective with its surveys of large numbers of students and with my work on developing a tool capable of assessing stance towards inquiry as part of design literacy. Third, I argue for a much-needed new trajectory in the field that **focuses on teachers** in preference to technologies, students, and processes. I contribute to this trajectory by describing some of the tensions and challenges that teachers face, as well as outlining possibilities for developing teacher competences that might overcome these challenges. Common to all three trajectories is that my research, like that in the wider field of making in education, has a dual focus on both the research itself and the development of new practices as intertwined.

As the chapter is based partly on a review of the work presented in the publications on which the dissertation is based, excerpts from the publications are included.

2.1. Making in education

At the beginning of 2014, at the time when the research presented here was begun, interest was already growing in incorporating "maker settings" like the technologies, culture, and activities of hackerspaces, makerspaces, and FabLabs into curriculum-based education (Martinez & Stager, 2013; Sheridan et al., 2014; J. Walter-Herrmann & Buching, 2013). According to Paulo Blikstein (2013a), inspiration from the maker movement lent new weight to Seymour Papert's work with LEGO Mindstorms and the LOGO language (Papert, 1980). Researchers working with block-based programming (Kafai, 1995; Resnick et al., 2009) and digital construction kits (Buechley, Eisenberg, Catchen, & Crockett, 2008; Katterfeldt, Dittert, & Schelhowe, 2009; Sipitakiat, Blikstein, & Cavallo, 2004) built on that work. Researchers from a wide range of backgrounds claimed to see opportunities to advance the thinking behind Papert's constructionism (Harel & Papert, 1991) by applying the maker movement to education (Blikstein, 2013a, 2013b, 2014; Stager, 2013; Zeising, Katterfeldt, & Schelhowe, 2013). Emphasising this heritage, Walter-Herman and Buching (2013) suggested that makerspaces could be the ultimate construction kits. What was new here in comparison to the digital construction kits and Papert's work was the accessibility of digital fabrication technologies like 3D printers, laser cutters, and CNC milling machines, which had previously been very expensive, together with their use in communities of practice in makerspaces (Blikstein, 2013a; Eisenberg, 2013; Martin, 2015; Vossoughi & Bevan, 2014). These advancements were hailed as a revolution (Gershenfeld, 2005) which offered opportunities to make almost anything (Gershenfeld, 2012) in a new democratisation of production (Blikstein, 2013a). The maker movement was identified with a wide variety of terms such as "DIY," "hacking," "making," "crafting," and "tinkering" (Halverson & Sheridan, 2014; Hatch, 2014; Martin, 2015; Resnick & Rosenbaum, 2013). All these terms and concepts focused on users' creative processes in using digital technologies. The hype surrounding the maker movement reached its peak when the Obama administration hosted a Maker Faire at the White House in 2014 (Halverson & Sheridan, 2014; Kalil, 2013).

Attempts have been made repeatedly to identify and define aspects of making in education that might open up novel opportunities in education. These have included the maker culture (Katterfeldt, 2013), the maker mindset (Chu, Quek, Bhangaonkar, Ging, & Sridharamurthy, 2015; Dougherty, 2013), tinkering (Resnick & Rosenbaum, 2013), the digital fabrication technologies themselves (Blikstein, 2013a), the hands-on nature of the work (Katterfeldt, Dittert, & Schelhowe, 2015; Schelhowe, 2013), and the ability to emulate production processes from the outside world (Blikstein, 2013a). Inspired by the maker movement, the making-in-education field is an emergent field (Halverson & Sheridan, 2014; Smith, Iversen, & Veerasawmy, 2016) based on this kind of exploration of novel opportunities for education. But far from an emerging consensus, there are still great variations in focus across the field. As will be unfolded in more detail below, my work addresses three central themes: that of the students' design processes, enabled by maker settings in education, that of the scalability and sustainability of such processes, and that of their teachers' support for those processes.

2.1.1. Making in education with a STEM focus

As described, the rise of the maker movement drew the attention of research communities already engaged with education in, with, and through digital technologies. Seymour Papert had shown and described potentials for teaching students mathematics and learning to code in playful ways with block-based programming and digital construction kits in the form of robots (Papert, 1980), and had argued for constructionism (Harel & Papert, 1991) as a further development of the constructivist learning theory of Piaget (Inhelder & Piaget, 1958). Building on this work, Mitchel Resnick et al. (2009) had developed the block-based Scratch programming language. Blikstein and Sipatakiat had developed the GoGoBoard digital construction kit (Sipitakiat et al., 2004), and Buechley et al. (2008) had created the LilyPad Arduino to engage a wider diversity of students (including girls) with physical interaction technologies through e-textiles. All these strands, it was argued, would stimulate school students' interest and learning in STEM subject matter.

At the university level, Neil Gershenfeld argued that maker settings could help students to use technology to make abstract concepts more concrete and thus comprehensible as a way of uncovering the "hidden core" of modern technology (Gershenfeld, 2005). Similarly, Paulo Blikstein argued that physical interaction kits as part of making in school education could be "the gears" of all students´ childhoods – through which scientific concepts would reveal themselves as powerful ideas (Blikstein, 2013b). This focus on educating students for careers in STEM subjects is echoed in Blikstein and Krannich (2013), Honey and Kanter (2013), and Martin (2015), and as evidenced in the literature review by Papavlasopoulou and Giannakos (2017), STEM learning was by far the most common goal of education in maker settings at this time. Other works (e.g. (Dittert & Krannich, 2013; Katterfeldt et al., 2015)) have expanded this perspective by analysing how maker settings enable bottom-up ideation processes and allow children to better grasp (*begreif*) digital technology, in turn offering new educational opportunities that might make digital design and engineering more approachable and better suited to adolescents.

2.1.2. Making as democratic education

An important part of the work of Seymour Papert and the MIT Media Lab was concerned with equal access to STEM. For example, Turkle and Papert (1990) discussed epistemological pluralism as a path towards diversity in technology, Buechley et al. (2008) in part developed the Lilypad Arduino to include girls in STEM, and Papert worked with underprivileged youth in prisons (Stager, 2013). Building on this work, as well as on Paulo Freire's (2018) and Dewey's (2004) work on democratic education, researchers in the emerging making-in-education field argued that maker settings could promote equity and diversity in STEM education and thereby empowerment by bridging the participation gap (Halverson & Sheridan, 2014), breaking down barriers to computing through maker activities with electronic textiles (Kafai, Fields, & Searle, 2014; Peppler, 2017), or working directly with underprivileged youth in Holland (Pucci & Mulder, 2015) and students in Brazilian favelas (Blikstein, 2008). For Martinez and Stager (Martinez & Stager, 2013), maker settings presented new opportunities for all children to better acquire skills, not only in STEM subjects, but also in the area of design and creativity. The argument was that with the use of an abundance of toolkits, machines, and design materials for making and inventing, students were afforded the possibility to gain more control of their lives and learning (Martinez & Stager, 2013). In sum, within strands of the making-in-education field there was a focus on diversity and equity.

2.2. Turn towards design

The initial focus of the research field was on constructionist principles, physical interaction toolkits, and digital fabrication technologies as they might be introduced to STEM teaching in formal and informal K–12 education. Schelhowe (Schelhowe, 2013), however, emphasised that maker settings in education had the further potential to provide children with an opportunity for digital citizenship and complex problem-solving. Thereby, Schelhowe pointed to students' design processes as an object of interest for making in education.

As discussed in P1, scholars from fields of interaction design and children and participatory design have drawn on design research to suggest methods and techniques that would engage children actively in the design of digital technology (Druin, 2002; Read, Fitton, & Hortton, 2014; Read et al., 2002) as well as on children as designers (Druin, Fails, & Guha, 2014; Iversen & Smith, 2012; Smith, Iversen, Hjermitslev, & Lynggaard, 2013; Yip et al., 2013) of future technology. However, as discussed by (Read & Horton, 2013) and as evident in the review by Papavlasopoulou and Giannakos (2017), researchers in the making-in-education field paid little attention to this work. More recently Iversen, Smith and Dindler (2017) argued that, incorporating works from participatory design with children into the field has the potential to empower students both to shape technological development and to critically reflect on the role of technology through design in maker settings. This suggests that participatory design and children as designers can be a path towards the empowerment called for in the field of making in education.

Among design researchers, the idea of developing students' knowledge of design in general education has come up before (Baynes, 1974; A. Cross, 1980, 1984). Nelson and Stolterman (2012), and Keirl (2006) argued that design was relevant for everyone, and Schön argued that "designing in its broader sense constitutes the core of practice in (...) everyday living" (1992b, p. 126). In line with this, Kolodner (2002); Kolodner, Crismond, Gray, Holbrook, & Puntambekar (1998); and Noweski et al. (2012) have argued that design and technology have significant roles to play in citizenship education and democracy. Balsamo (2011), Burdick & Willis (2011), and Razzouk and Shute (2012) have argued further that design offers major educational opportunities to support the new literacies required in the twenty-first century. For these authors, designerly ways of engaging with the world allow individuals to act as agents of change, as creators of preferred futures. Chris Pacione has put forth the similar argument that design should be "put back in the hands of everyone" (Pacione, 2010, p. 8). Here, rather than mastery of design, Pacione is describing "design for the people" as a form of literacy seen as basic skills and techniques that serve us in our daily lives. But while the design-research literature offered accounts of competences of experienced designers and comparisons of novice versus expert designers (N. Cross & Cross, 1998; Ericsson & Smith, 1991; Ho, 2001), there were very few studies of children as designers. Carrol et al. (2010) had introduced design thinking to 24 seventh-grade students in a charter school; Noweski et al. (2012) (2012) had researched design thinking as support for twenty-first century learning in a three-day workshop for 116 tenth-grade students; and Goldman, Zielezinski, Vea, Bachas-Daunert, & Kabayadondo (2016) had found that sixth to eighth-grade students in an engineering summer school program based on design thinking improved significantly with regard to understanding the steps of the process, the language of design, and the purposes and mindsets of design thinking. There were thus a few promising studies on design thinking in schools, but no research had been done on the potential for developing students' design literacy through maker settings in education.

There has been a turn towards design in the field of making in education, a turn which is still unfolding. Even though there was very little research on the introduction of design into formal educational settings, this turn has many similarities with ideas previously put forward by design researchers; what was entirely new was the combination of maker settings and design literacy. While others have argued for design literacy, what was missing from both the field of design research and the turn towards design in making in education was research into the contents and development of design literacy. Which aspects of design expertise could, or perhaps should, students in maker settings in K–12 benefit from, and how could they acquire them? As described in chapters four, and six, my contribution to this research has been in providing theoretical (P1, P2) and empirical (P1, P2, and P5) research into better understanding the educational potential of introducing specific traits of design, combined with maker settings, into K–12 education.

2.3. Towards sustainability and scaling

In 2013, Blikstein and Krannich raised the question of what to do when the 3D-printing honeymoon in schools was over (Blikstein & Krannich, 2013). In 2016, Smith et al. (2016) argued that it was almost over, and that it was now time to focus on sustainability and scaling: it was time to go from researching possibilities for children in more or less lab-like contexts to researching schools as ecosystems for maker settings in education, for teachers in maker settings, and for professional development of these teachers, as well as for assessing effects of larger-scale implementations of making in education. Some discussions had taken place about quantitative assessment of learning goals (Barron & Martin, 2016; Martinez & Stager, 2013; Petrich, Wilkinson, & Bevan, 2013) in both individual initiatives and ranges of individual initiatives (Blikstein, Kabayadondo, Martin, & Fields, 2017) in the making-in-education field, but in 2014, when my studies began, there were no larger-scale, quantitative assessments of the *state* of making in K–12 education, nor any quantitative assessments of the *effects* of larger-scale implementation of maker settings.

Paradoxically, according to Biesta (2010), K–12 schools currently function within assessment regiments, operating as they do in an age of measurement. In such an age, according to Nelson et al. (Bransford et al., 2010, p. 849) finding "appropriate metrics is a key factor for guiding the kinds of decision-making that can lead individuals, organisations, and designers toward successful learning." Here again, as in making in education, larger-scale assessments were also lacking in the design-literacy research field: as described in P2 and P5, despite noteworthy research by Kimbell and Stables (Kimbell & Stables, 2007; Stables & Kimbell, 2007) on small-scale assessment of design literacy, along with Goldman et al. (2016), there is little research on larger-scale assessments of design literacy.

Thus larger-scale implementations and assessments were lacking in both making in education and design literacy. Adding to this gap in the research, there was a gap in the literature on how to assess aspects of design literacy in such larger-scale implementations. This gap in the research is addressed in P2, P5, and chapter four of this dissertation overview, which research the possibility of assessing stance towards inquiry as an aspect of design literacy. Further, as described in R2, P2, and in chapter four, the gap with regard to larger-scale assessment of the effects of implementing making within formal education has been addressed through baseline and endline surveys of students in makerspaces in the FabLab@School.dk project.

2.4. Towards a focus on teachers

When the research presented here was begun, a body of work in the emerging making-in-education field consisted of cases where researchers or facilitators had worked with children in informal or out-of-school settings. Kafai, Peppler, & Chapman (2009) had researched after-school computer clubhouses, Blikstein (2013a) had studied adolescents in university workshops, Wardrip and Brahms (2015) had investigated museum maker settings, Pucci and Mulder (2015) had focused on making with underprivileged adolescents in youth centres, and Katterfeldt et al. (2015) had studied youth in university summer camps. But out-of-school settings, although they provide interesting testing-grounds for youth maker settings, are very different from formal educational settings: not least because they typically include more and different resources than are available in K–12 school settings, and also because they draw on researchers and other specialised staff as implementers of making in education. For example, Martinez and Stager (2013) give advice to teachers to help them avoid interfering too much in students' processes, but their work is based on lessons from Papert's work with prison inmates, in settings very different from the situations in which most teachers find themselves. Most teachers are not Papert; but even if they were, they do not have his resources either in terms of hardware or manpower per student. While these studies document significant opportunities for student learning through creative processes, they do not therefore provide directions on how to successfully integrate making into K–12 classrooms, or how to prepare teachers for such integration.

As described in the review by Iivari, Kinnula, Molin-Juustila, and Kuure (2017), there has been some research into cooperation between researchers and teachers in maker settings in education (T. Bekker, Bakker, Douma, van der Poel, & Scheltenaar, 2015; Blikstein, 2013a; Vasudevan & Kafai, 2016). Litts (2015) discussed the importance of facilitator identities in youth makerspaces (not in formal education), Bar-El and Zuckerman (2016) pointed to mentors as important in youth makerspaces, and Telhan et al. (2014) referenced such mentors' informal exploration with students. Based on such work with makerspaces in non-school or after-school settings, there have been attempts to create frameworks or guidelines for teachers implementing maker settings in education (Cohen, 2017; Honey & Kanter, 2013; Martinez & Stager, 2013; Peppler, Halverson, & Kafai, 2016). Scholars such as Bekker et al. (2015) and Eisenberg (2013) have pointed to the importance of teachers for making in education. Wardrip and Brahms (2016) also point to the need for professional development of teachers in maker settings, and Eriksson, Heath, Ljungstrand, & Parnes (2018) position teacher training as a prerequisite for sustainability of maker settings in education. But in writing about the introduction of maker principles and technologies to teacher education, Cohen (2017) concluded that there was a gap in the literature on teachers' development of technological–pedagogical content knowledge, self-efficacy, and teacher beliefs. With the notable exceptions of Brennan (2015) and Smith et al. (2016), there is still very little research on the role of teachers who implement making as part of, or as a supplement to, existing practices in schools. While there may be insufficient research in place to warrant the claim of a turn towards a focus on teachers in making in education, I contribute to such a possible trajectory in P3, P4, R2, and in chapter five of this dissertation overview, where I elaborate on teachers' competences for teaching in maker settings in a design-literacy perspective.

Brennan (2015) described how teachers implementing open-ended design processes in work with block-based programming in North American classrooms experienced a loss of control and behaved in ways that were not in tune either with students' expectations or the assessment culture they were part of. Similarly, Smith et al. (2016) found that teachers working with maker settings in a design perspective in Danish schools felt challenged with regard to (1) understanding complex design processes, (2) managing diverse materials, and (3) balancing modes of teaching. Smith et al. found that these challenges led the teachers to feel they lacked authority and were losing control over the classroom. The works by Brennan and Smith et al. give valuable insights into teachers' self-perceived challenges with making in education in a design perspective, but they do not investigate interactions in-the-wild between students and teachers. There is therefore insufficient research on the challenges faced by teachers in K–12 maker settings, and more specifically a gap in the research with regard to understanding teacher–student interactions in the teaching of design literacy in such settings. Chapter five of this dissertation overview addresses this gap, comparing teacher positioning in a K–12 maker-settings case with a paradigmatic example from the design-research literature.

2.5. Summary

In this chapter, I have contextualised my research within the field of making in education. As my studies have focused on the potential for the development of design literacy in maker settings, my research therefore builds on the initial research on the introduction of maker settings in education. This in turn builds on the research into digital construction kits which, inspired by the work of Seymour Papert, has contributed to the emerging field of making in education. In summary, my work can be seen as contributing to the following three trajectories.

From STEM to a turn towards design

While much of the literature in the field of making in education has focused on STEM education, there has been a turn towards design literacy. This turn, to which I have contributed, has its roots in research into the potential offered by maker settings for democratic education, while it draws on work from design research. My research has contributed to this trajectory by addressing gaps in the conceptual understanding of design literacy, and by providing exemplars of teaching with the aim of design literacy in maker settings.

From isolated interventions to sustainability and scaling

Very few larger-scale projects have been carried out within the field of making in education. This means that there is very little research into the assessment of such larger-scale implementations. Further, while there have been attempts to assess design literacy in the field of design education, these have mostly been small-scale assessments. I have addressed this gap through baseline and endline surveys of students in the FabLab@School.dk project, as well as through the development of a tool for larger-scale assessment of one aspect of design literacy. My progression along this trajectory has therefore yielded contributions in an assessment perspective.

Towards a focus on teachers

Very little has been written in the literature on making in education about how real-world teachers can implement maker settings. In the same way, the design-literacy research field seen very little work on the role of the teacher. My research has addressed this gap by contributing to an understanding of the teacher as a key factor in the implementation of maker settings in education aiming at design literacy. My progression along this trajectory has therefore also produced to contributions in a pedagogical perspective.

3. Research approach

This chapter outlines the approach I have taken in my research. I review the dilemmas of research and the trade-offs between experimental control and richness and reality that are intrinsic to educational settings, and I argue that a design research approach, in opting to stay with the complexity of in-the-wild settings, offers potential for interventionist research into formal educational maker settings. More specifically, I unfold my research through a lens of research through design. The experimental system (Dalsgaard, 2016; Hansen, 2017), of which my doctoral research was part (see section 1.2), had research through design from an interaction-design perspective as its predominant methodology. While I acknowledge, that this experimental system has influenced my choice of research through design as an approach to my studies, here, I argue for such an approach to educational studies. Traditionally, such an approach has entailed designing physical artefacts. While my research has not done this, the adopted research-through-design approach has offered ways of staying with the complexity of the classrooms by intervening in practice with the aim of engaging with a reality beyond what was already present.

Existing studies involving students in less formal settings such as university makerspaces or after-school computer clubhouses (see chapter two) provide opportunities to study aspects of maker settings that could perhaps to some degree be transferable to a formal educational context. The context for my research, however, is the classroom of formal educational settings. At the time when I began my research, maker settings were only just entering Danish schools. As unfolded in chapter four, the few attempts at using 3D printers in the classroom, for example, were not related to the development of design literacy among students. These contexts therefore did not fit with the investigation of design literacy in Danish schools. The best way to investigate the development of design literacy in maker settings in formal education in my research was therefore to use an interventionist approach, creating the context in which the research could be undertaken.

In this chapter, I will describe and discuss how my attempts to answer the research question have led me through three distinct but intertwined *research programs*. The first of these was to research students' development of design literacy as well as the nature of design literacy; the second researched the sustainability of scaling maker settings in formal educational settings in a design-literacy perspective, and the third researched teachers' challenges and development with regard to competences to teach in such settings. The contributions within these three programs are based on data from six *research experiments*. Overall, this research is an example of interdisciplinary research through design as a triangulation between disciplines (Mackay & Fayard, 1997) of design research, social science, and anthropology. As called for in Flyvbjerg (2006), methods from a range of disciplines have been employed to best help answer the research question at hand, since "more often than not, a combination of qualitative and quantitative methods will do the task best" (p. 242). Figure 2 depicts the relationship between these research experiments and the publications on which this dissertation is based.

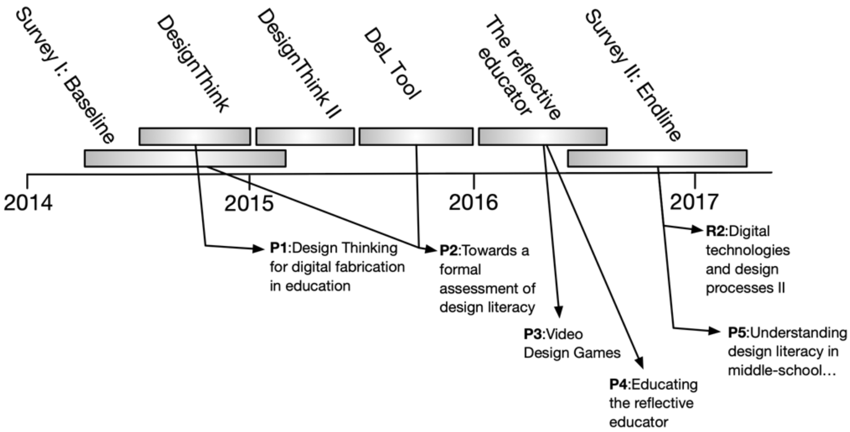

Figure 2: Relationship between experiments and publications.

In all observations, interventions and interviews with children, consent for conducting the studies was provided by school principals, teachers, parents and the students themselves. In the following, I will discuss the methods adopted to generate these data, as well as the relationship between the experiments depicted in Figure 2. First, I will discuss the relevance of the adopted research approach.

3.1. Researching educational settings

> *First of all, there is a dilemma of rigour or relevance (...) One can 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, 1992b, p. 120)

Educational settings are notoriously difficult to research because the number of factors in play is infinite (Brown, 1992). This dilemma is captured by Donald Schön's metaphor of the researcher's choice whether to work on high ground of rigorous but possibly irrelevant abstraction or in the swampy lowlands of real-life issues. The swampy lowlands of educational research are particularly complicated: Sara Delamont (1983) argues that educational settings are especially difficult to research because, as former students, we feel very familiar with them and have strong tacit pre-established conceptions about them. A further issue with qualitative research in real-world educational settings is generalisability (Barab & Squire, 2004). Every situation in every classroom is unique, and it is problematic to transfer knowledge generated in one classroom at one particular time to any other classroom. As described in Brown (1992), a number of strategies have been developed in educational research to overcome these dilemmas, using isolating factors and conducting educational research in laboratory-like settings. But as my research question addresses formal educational settings, as described by Brown (1992), there is an inherent trade-off like that Schön describes between experimental control and richness and reality.

In seeking a better understanding of how maker technologies could be used to promote design literacy in formal educational settings in a sustainable manner, I have found it important to lean towards richness and reality. A large part of the research reported here was therefore carried out in schools, rather than having students or teachers come in to laboratory settings at the university. The aim of these qualitative studies was to gain a better understanding of the nature of design literacy as it showed itself in the classroom, as well as to understand the nature of maker settings in K–12 and the interactions between students and teachers. To achieve these aims, I chose to accept the limitations to generalisability that were entailed by working in situ in the qualitative studies reported here. These studies were informed by research in interaction design.

Degrees of in-the-wildness

A recent trend within interaction-design research has been a move from in-the-lab studies to in-the-wild studies. Rogers (2011) argued that in-the-wild studies provided data that were a better fit with the end-goal of what was being designed. Similarly, Stolterman (2008) argued that when research is aimed at improving interaction-design practice, the nature of design complexity calls for another kind of rigour than traditionally seen in the sciences. His argument was that while science has a tradition of reducing complexity by focusing on one relevant aspect or variable at a time, the nature of design complexity means that the complexity of the whole has to be considered, and that this complexity should be seen as a source of richness and variation (Stolterman, 2008). This recent trend within interaction-design research therefore seeks to provide knowledge that is relevant to practitioners – and, further, knowledge that has the potential to improve practice by staying with the complexity of subsequent use situations.

The object of interest in an interaction-design perspective is typically digital and interactive technologies. My research, however, addresses learning designs, teaching, and student development through formal education. This is a field that is rich in complexity; and as argued by Brown (Brown, 1992) and Schön (1992b) above, staying with this complexity in the swampy lowlands opens up opportunities for richness, reality and relevance. As described below, I have therefore appropriated design research in my studies of formal educational maker settings in order to stay with the complexity of in-the-wild studies as a way of constructing knowledge that is directly relevant to formal educational settings. Rather than working with the design of material artefacts, my studies have dealt with the immaterial design of possible futures for maker settings in formal education.

My research has involved varying degrees of in-the-wildness. DesignThink, described in more detail below (see section 3.5.2), was an intervention into school practice where researchers were teaching students as part of their regular school day. In this experiment the settings were in the wild in the sense that the intervention was carried out in the students' everyday classrooms, but not in the wild in the sense that they were conducted by experienced design educators and researchers who would not normally be teaching in formal school settings. The subsequent qualitative research experiments, DesignThink2 (section 3.6.1) and Reflective Educators (section 3.7.1), represented a higher degree of in-the-wildness: DesignThink2 studied teachers' adoption and implementation of a learning design, while Reflective Educators studied teachers' development of competences for teaching in a maker-studio approach. These studies preserved a greater degree of complexity, richness, and reality. By the same token, there was less experimental control and much larger variation between instantiations of experiments in the classrooms. Overall, as argued by (Bødker, Dindler, & Iversen (2017), the FabLab@School.dk project within which my studies were conducted involved many different levels of authority and a high degree of complexity was maintained throughout. In what follows, I will argue that research through design offered appropriate perspectives on staying with the complexity in my research.

3.2. Research through design as an approach to educational research

> *We may have understated a little the difficulty of observing contemporary classrooms…it takes a tremendous effort of will and imagination to stop seeing only the things that are conventionally 'there' to be seen…to see or write anything beyond what 'everyone' knows. (Howard Becker, 1971; p.10)*

In the last section I argued, as does Howard Becker in the famous quote, that educational settings are notoriously difficult to research. As described by Sara Delamont, as a researcher in the classroom, the task is "to make the familiar strange" (Delamont, 1983, p. 140). Further, in the last section I argued that an interventionist approach that stays with the complexity of such settings is necessary in order to research sustainable development of formal educational maker settings. A number of interventionist approaches have been applied to researching educational practices, including action research (Lewin, 1946) and design-based research (Barab & Squire, 2004), both of which are common in educational research (Anderson & Shattuck, 2012; Stringer, 2013). In what follows, however, I will argue that positioning my approach within research through design has yielded a number of distinct perspectives.

The term "research through design" is usually credited to Frayling's seminal work, which discusses the relationship between research and art/design as research *into*, *through*, and *for* art and design (Frayling, 1994). Among these three perspectives, research through design – like the related approach of constructive design research (Koskinen, Zimmerman, Binder, Redstrom, & Wensveen, 2011) – has a preference for action and construction. Recently, research through design has developed into a methodology for discussing research that draws on design methods (Dalsgaard, 2009; Zimmerman & Forlizzi, 2014) on a pragmatist foundation (Dalsgaard, 2014) – in other words, building on design practice as a way of staying with the complexity of in-the-wild settings. Stolterman (2008), and Fallman and Stolterman (2010) argue that research through design should use its own measures of rigour, rather than simply adopting yardsticks from other scientific fields: research through design is thus developing as a methodology of its own, which reframes Schön's dilemma of the choice between rigour and relevance as a false dichotomy. According to Zimmerman, Forlizzi, & Evenson (2007), in building on design practice, research through design offers opportunities to engage with complex problems by framing and reframing them so as to make the right thing, as well as achieving preferred states. In other words, research through design is interventionist by nature (Binder & Redström, 2006; E. Brandt & Binder, 2007; Dalsgaard, 2014).

As stated by Sara Delamont above, one of the challenges in researching educational settings in the wild is to make the familiar strange. Social scientists have methods for doing this (see for example (Charmaz, 2014) on coding techniques for grounded theory). But making the familiar strange is also the goal of many design methods: there is a long-standing tradition within design for dealing with design fixations (Jansson & Smith, 1991) and for overcoming prejudices and first intentions (Schön, 1987).

Choosing research through design as an approach for my studies provided a way of staying with the complexity of formal educational maker settings, yet at the same time researching their nature and their sustainability. Further, the idea of framing and reframing the problem space, inherited from design practice (N. Cross, 2011), and the iterative nature of such practice acknowledged that staying with the complexity entailed exploring the not-yet-real (Nelson & Stolterman, 2012) – rather than simply implementing an intervention that had been developed outside the context in which it was to be applied. That is, research through design provided a way to both create and research in the wild the targeted formal educational maker settings that aimed at development of design literacy. Finally, my studies dealt with design on three distinct yet intertwined levels. The interventions were design exemplars; they promoted students' design literacy; and they necessitated teacher competences for education in design literacy. Students, teachers, and researchers were all engaged in designing in these interventions. In sum, research through design as an approach functioned within such a design practice, acknowledged the complexity of the formal educational maker settings, and provided a way of staying with the complexity while both creating and researching these formal educational maker settings.

Taking research through design as my point of departure for researching educational settings did not do away with the difficulties of observing classrooms; but it did give me tools to better understand and overcome these difficulties. In my publications, the direct inspiration from design methods is most clearly seen in the affinity diagramming (Beyer &

Holtzblatt, 1999) process in P1, the video design game in P3, and in the overall iterative, contextualised, and genealogical approach to investigating the research question.

3.3. A genealogical approach to research through design

In the previous section, I touched upon the iterative nature of research through design approaches. In their 2007 paper, Brandt and Binder argue that the iterative nature of experimental design research unfolds through research programs that consist of experiments serving to investigate an overall research question (E. Brandt & Binder, 2007). Rather than mapping out the research in advance, this genealogical approach highlights how each experiment influences not only those that follow it, but also the program itself, perhaps even the research question. Brandt and Binder argue that instead projects should subsequently map out the research to create knowledge with a traceable genealogy. I have used Brandt and Binder's distinctions to map out my research programs and experiments in Figure 3. This methodology requires each experiment not only to carefully implement methods tailored to the specific experiment, but also to build on the knowledge gained in previous experiments. The research thus becomes an iterative back-and-forth motion between research driven by real projects and design in which the research insights are actively applied (Korsgaard, Hansen, Basballe, Dalsgaard, & Halskov, 2012). Similarly, the research experiments outlined below have informed both further development and research within the programs.

Research programs

The research-through-design approach sees the research program as analogous to design programs (Binder & Redström, 2006). For Binder and Redström, research programs can be understood as a lens, focusing the attention on particular aspects of what is being investigated. Dindler (Dindler, 2010) argues that the genealogical approach to research through design allows us to understand a research program as a deliberate and reflective adoption of a particular appreciative system. Such appreciative systems (Vickers, 1968) and thereby the research programs shape the focus of inquiries into the overall research question, and therefore shape the inquiries themselves. In this way, the changes in research programs outlined below, changed the focus of research into formal educational maker settings from students' development of design literacy, to challenges for sustainability, and to teachers' development of competences.

3.4. Programs and experiments

In this section, I describe the research activities on which my contributions are based. All of these activities were conducted in collaboration with other members of the Child–Computer Interaction research group at Aarhus University and as part of the FabLab@School.dk project (see section 1.2). Using the terminology from Brandt and Binder's (2007) genealogical approach to RtD, my contributions were developed through six experiments within three research programs. These programs were overlapping and intertwined, but they represented adoptions of different appreciative systems. While other research traditions might see such drifting (Krogh, Markussen, & Bang, 2015) as a weakness in my research, I argue with Redström (2011) that drifting in the context of research-through-design is a natural part of studying possible futures. It is a way of pursuing a journey further and further into the swampy lands of Schön's metaphor – introducing shifts in basic framing to follow *intriguing aspects* pointed to by experiments (Redström, 2011). Figure 3 provides an overview of the experiments and programs from which my contributions are derived. As shown in the figure, experiments have often provided insights within more than one program.

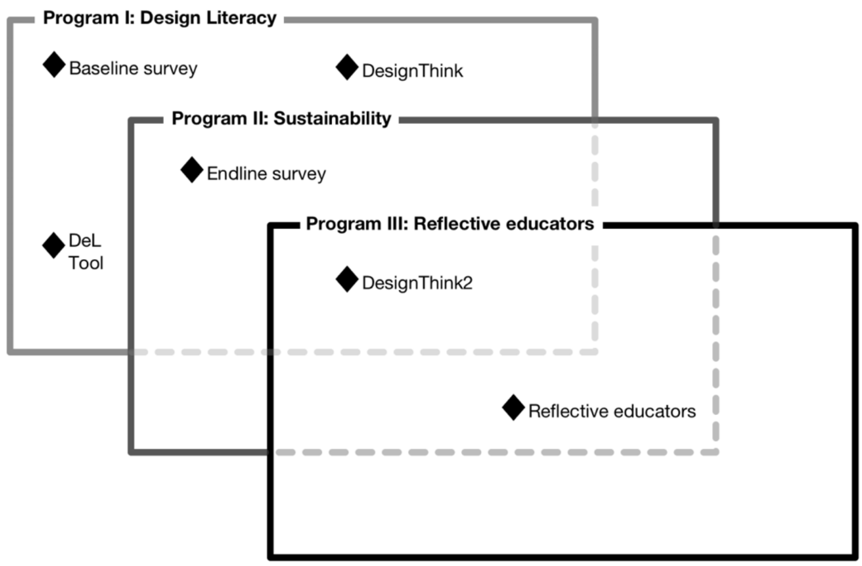

Figure 3: Overview of programs and experiments

Initially, I began the research presented in this dissertation overview with a program focusing on design literacy that aimed to capture the state of design literacy among students through a survey (baseline survey, DeL Tool) and observational studies (P1). My conclusion from this work was that I could not research design literacy in existing practice. For this reason, the design-literacy program contains three iterations of an interventional research design (DesignThink) as well as the implementation of the research design by teachers in their own classrooms, validating the findings in the wild (DesignThink2). By scaling up and by applying the design in-the-wild DesignThink2 marked a shift towards a focus on sustainable implementation of maker settings in a design literacy perspective in formal education. But researching design literacy in the wild turned out not to be easy, if it was even possible, because these studies pointed to the teachers' lack of experience in teaching design literacy rather than the students' development of it. This intriguing aspect led me to change focus, from implementing maker settings for the development of design literacy in Program II, to developing teacher competences for such teaching in Program III. However, the subsequent endline survey was still investigating both sustainability of formal educational maker settings in a design literacy perspective, and the nature and assessment of design literacy.

In total, three intertwined and overlapping research programs produced contributions on four different levels of abstraction: (1) a better conceptual understanding of design literacy; (2) new perspectives on the pedagogical implications of teaching in maker settings with the goal of design literacy, and on the demands that teaching of this kind exerts on teachers, (3) a quantitative assessment of design literacy, and (4) exemplars of teaching and researching into design literacy through maker settings in formal education. In what follows, I map out these three programs and how they contributed to my research. This part of the chapter contains excerpts from the publications on which it is based.

3.5. Program I: Design literacy through maker settings in K–12

Program I was focused on the nature, assessment and development of students' design literacy in maker settings. The activities carried out in this program included two surveys of 11–15-year-old students, observational studies of existing practice, and two intervention studies.

3.5.1. Surveys

Two surveys were carried out as baseline and endline surveys in the three-year FabLab@School.dk project. This research design was quasi-experimental in the sense that participants were not assigned at random (Campbell & Stanley, 1966). Rather, schools which were part of the FabLab@School.dk project were compared to a group of schools outside the project. Many of these students left school before the endline survey was carried out, meaning that we were unable to follow the same students through the project period. The quantitative survey method was chosen in order to gauge the students' initial general level as well as (other) students' developments over the course of the FabLab@School.dk project. That is, the surveys were meant to test both the relevance and sustainability of formal educational maker settings in a design literacy perspective.

Baseline survey

The 2014 baseline survey was conducted on 1,156 respondents among 11–15 year-old students in 48 schools in Vejle, Silkeborg, Aarhus and Favrskov municipalities (Hjorth et al., 2015). The students answered 227 questions in total. These questions probed the students' use of and knowledge of digital technologies both in and outside school, their knowledge of design and creativity, and their perspectives on hacking, open data and privacy issues. However, there were no established survey instruments for assessing elusive concepts such as design literacy. Here, the task was to develop survey items for concrete assessments of single aspects of design literacy. To this end, the survey contained both multiple-choice self-evaluation items (such as Likert scales) and open-ended questions, which probed in greater depth. The questions tested hypotheses held by the research group as a whole, and reflected previous work by members of the Child–Computer Interaction Group with students in this age group. Further, some of the survey questions were based on a re-contextualisation of similar questions in an international survey developed by the TLTL group at Stanford University (Blikstein et al., 2017). Since my research question dealt with the development of design literacy through activities with maker technologies, my focus was on the design perspectives as well as on the students' knowledge of and use of digital technologies for creative or design-like activities. One of the conclusions of this survey was that, as a whole, the students involved were not already design-literate. Because space is limited, the report on this baseline survey is not included in this dissertation overview. However, R2 describes developments between the baseline and endline surveys, P2 builds on data generated in the baseline survey, and P5 builds on data from both baseline and endline surveys.

The DeL tool: surveying stance towards inquiry

As part of the baseline and endline surveys, students were asked an open-ended question aimed at probing their stance towards inquiry (P2, P5). The survey item first described the problem of demented elderly who went missing, and thereafter asked what the students would do, if they were asked to solve this problem:

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?

The DeL Tool experiment investigated this question as assessment of design literacy. The tool's validity was tested with university level students of digital design and information studies. These students, who were in their second year of studies at Aarhus University, were tasked with filling out the same questionnaire as was used for the 11-15-year-old students. The expectation was that digital design students would answer the question differently than the 11-15-year-old students for three reasons: they were older, they were undergraduate students, and they had already passed two semesters of design education. Students of information studies were very similar to digital design students in the two first respects, but these students would not receive design education until their fourth semester. Further, at Aarhus University information studies and digital design were closely related in terms of subjects, students, and staff. By statistically comparing the two groups (using Welch's t-test) we were able to suggest that our tool did indeed assess an aspect of design expertise, and therefore perhaps of design literacy. In DeL tool, respondents were grouped into three categories: Those who took a technical rational stance to problem solving based on their existing knowledge, those who took a more designerly stance by suggesting an inquiry into the problem setting, and those who replied that they did not know. As unfolded in section 4.6, students' stances towards inquiry can be seen as an aspect of their design literacy. Fewer than 3 per cent of the 11–15-year-old respondents on the baseline survey were scored as having a designerly stance towards inquiry. This provided a baseline against which to measure how levels of design literacy among 11–15 year-olds could be improved and to establish a potential need for such improvement. In this perspective, the work on the DeL tool researched assessment of stance towards inquiry, which was found to be a very promising part of design literacy.

Follow-up: DeL tool II

Building on the promises from development of the DeL tool, this tool was used to assess the students' development after the two years of the FabLab@School.dk project. This work, which is described in P5, compared FabLab respondents in the endline survey with control group respondents as well as with respondents in the baseline survey. The results were compared treating school as a random effect (Field, Miles, & Field, 2012), but there was no statistically significant difference between students of the three groups. This conclusion in turn raised many interesting questions about implementing maker settings in project schools. I discuss these questions in more detail in chapter six.

Endline survey

In order to assess longer-term effects and thereby sustainability of the FabLab@School.dk educational program from 2014 to late 2016, an endline survey was administered to 449 students in eighteen schools (see R2). As in the baseline survey, schools were divided into two groups: those in which FabLab and design activities had been carried out in the FabLab@School.dk project throughout a two-year period (FabLab schools), and a control group of schools that did not participate in the FabLab@School.dk project (control schools). The endline survey was conducted in the fall of 2016 among 246 students from FabLab schools and 203 students from control schools, totalling 449 students. The students answered 111 questions probing their use of and knowledge of maker technologies both in and out of school, their knowledge of design, and their perspectives on issues of hacking, open data and privacy. The FabLab schools had been selected by municipalities as schools which had been actively engaged in the FabLab@School.dk project, and classes were suggested on a similar basis. The control schools were selected from the 2014 survey control group, and matched the FabLab schools as closely as possible in socioeconomic status, school size, and placement in rural, suburban, or urban environments. We were however dependent on schools agreeing to participate, meaning that we were not always able to recruit the school with the best fit. Further, the student samples in both groups and surveys were not randomly selected, so and thus I cannot lay claim to representativity (and thereby generalisability). Claims are therefore made only for the included samples. In principle, the endline survey allowed me to directly compare the FabLab and non-FabLab groups for students' development of design literacy and self-perceived development of design literacy. However, it turned out to be very difficult to find differences between the FabLab and non-FabLab group that were statistically significant when schools were treated as a random effect (Field et al., 2012) – that is, when looking for effects that were independent of the differences between schools (see R2). This result was in itself testament to the vast differences between school implementations of maker settings. Differences between school implementations therefore became an intriguing aspect calling for further research.

For the survey, 23 students from eight FabLab schools were interviewed. These students were identified by the teachers in their respective schools as those who had gained the most from the FabLab@School project. In all these eight schools, the research group was familiar with the teachers and their work in maker settings from either the Reflective Educators program (six of the schools), DesignThink (two of the schools), or DesignThink2 (four of the schools). Finally, teachers in the FabLab schools reported data on the amount of FabLab teaching that had taken place, as well as the nature of the FabLab teaching and its relationship to existing subjects. This school-reported data, the analysis of the interviews, and comparisons with survey items on the use of technologies in schools were used to develop a tentative typology of school implementations. This comparison of different implementation types suggested links between school implementation strategies and students' self-perceived development of design literacy. In sum, longer-term effects of activities with maker technologies in formal educational settings on students' design literacy were studied through the endline survey – but mainly as a comparison between different implementation strategies between schools.

3.5.2. DesignThink

The baseline survey had strengthened the hypothesis that the included 11–15-year-old students were not, on average, design-literate. However, the survey did not provide in-depth knowledge about the nature or development of design literacy through maker settings in formal education. As described in P1, the DesignThink experiments, on the other hand, were designed to do exactly that. By observing existing practices and then proposing and creating new practices, DesignThink investigated students' design literacy in practice. The goal of this experiment was to investigate something which was not already present. It was therefore necessary to design an intervention in the practice of real-life schools. In DesignThink, a learning design was developed in collaboration with teachers from a local public school. Maker settings and design thinking were integrated in this experiment into a six-week course modelled on a design-studio approach (Schön, 1985). This interventional study was carried out in three seventh-grade classes at a local school between October and December 2014. One design researcher acted as the main facilitator in collaboration with the teacher, while three researchers documented the process using video recordings and field notes. The context for the teaching was the schools' makerspace. This, which they named FabLab, included 3D printers, programmable robots, programmable electronic kits, and crafts materials, and was set up as an informal, adaptable space with boxes, mattresses, a green screen, a stage, and pavilion tents. As this was an iterative research-through-design experiment, the activities were continuously developed, evaluated, and refined by the team between the three iterations. In total, 69 students were engaged in the research experiment for approximately fifteen hours. The data included video and field notes as well as semi-structured interviews (duration 20–30 minutes) with fourteen pairs of students. The data were logged and analysed with a particular focus on these selected groups of students, and the interviews transcribed and coded. Students' development of design literacy was analysed in an affinity diagramming approach (Beyer & Holtzblatt, 1999) with triangulation between field notes, video recordings, and interviews. In P1 as well as in chapter four, four of these students from three different groups are used as exemplary cases (Binder & Redström, 2006) of students actively seeking to be a part of this process. The qualitative nature of the data collected through DesignThink made it possible to dig deeper into students' acquisition of such elusive concepts as design judgment, sense of quality, and the development of a design language. This work included identifying further aspects of design literacy, and it led to the identification of design-process knowledge, and design judgment as aspects of design literacy.

3.6. Program II: Sustainability and scaling of the maker-studio

In DesignThink2, which ended up being the main activity in Research Program II, the goal was to study teachers' implementation of the DesignThink learning design: that is, to study the development of design literacy in classrooms where teachers were implementing their own, contextualised versions of the *maker-studio* learning design developed in DesignThink. My research question concerns the development of design literacy in formal educational settings: therefore, the development created by researchers in DesignThink would be of little relevance, if it could scale and be sustainable in the wild in real-world school contexts. However, the challenges that the materials seemed to pose for the teachers made it very difficult to see any development of design literacy among the students. These challenges emerged as an intriguing aspect (Redström, 2011). As a result, the main focus in Program II into sustainability and scaling became the challenges faced by teachers, in particular the different positions and roles that teachers took in relation to their students. The comparison between implementations of maker settings in different schools in the endline survey was conducted as part of this program, although only the DesignThink2 research experiment was specifically developed to investigate scaling and sustainability for a K–12 maker-studio approach.

3.6.1. DesignThink2

DesignThink2 was an intervention in teachers' existing practice in which teachers implemented a learning design that had been developed in DesignThink. Eight teachers from six different schools within the

FabLab@School.dk project participated in three half-day workshops at Aarhus University. Here, they were introduced to the materials developed as part of DesignThink. . In DesignThink2, teachers were to implement their own, adapted versions of this learning design and the included materials. In the workshops, teachers discussed how to adapt materials to better fit the concrete settings, in which they were to teach. The teachers, who represented a wide range of subjects and student-ages, were selected by their municipalities based on their interest in being part of DesignThink2. The findings described in chapter five, are derived from video, field notes, and interviews from following four of these teachers' implementations as well as from teacher workshops.

In DesignThink2, teaching was carried out by the class's usual teachers within the students' usual school ecology. The research experiment thus studied the sustainability of a maker-studio approach such as DesignThink for teaching in formal educational settings. The study revealed many challenges, stemming from various different levels of authority (Bødker et al., 2017). My main focus in the research included here became the interactions between students and teachers. Accordingly, in chapter five, I explore positions that a teacher might take with regard to giving student feedback in a maker-studio approach. The specific case discussed in chapter five took place in a maker-studio project spanning 8 1,5-hour lessons over a period of ten weeks at an inner-city school with students of low socioeconomic status.[2] Twenty-two students from grades 7, 8 and 9 took part in the elective course, which was named FabLab. Students were divided into mixed teams, three to four in each group. The course took place in a designated room with maker technologies (called the FabLab). In the room, students were positioned around groups of tables. Along one side of the room were four 3D printers, and on another wall were shelves with discarded technologies, now used for disassembling, studying, and tinkering. In a small separate room were an abundance of craft materials. The findings from this case has been presented to and discussed with the involved teacher. Designthink2, and the specific case unfolded in chapter five, can be seen as "*most likely", critical cases* (Flyvbjerg, 2006) for the sustainable implementation of the learning design in DesignThink, and perhaps for a design studio approach to maker settings in formal

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[2] Please note that Denmark has one of the most equal distributions of income (as measured by the GINI coefficient) and one of the highest BNPs in the world, so that low socioeconomic status in a Danish context may not be comparable to low socioeconomic status in most other countries.

education in general: teachers in DesignThink2 had been selected by municipalities based on teachers' own interests, they were given a learning design, which had been shown to work, and they attended workshops to help with the implementation. If these teachers experienced difficulties, it was likely that other teachers would also experience such difficulties. In the case described in more detail in chapter five, students had even elected a course by the name FabLab, and where thus more highly motivated, than what can be expected among the school population in general.

3.7. Program III: Educating Reflective Educators

Research Program III focused on teachers' development of competences for teaching in a maker-studio approach in the formal educational settings of Danish public schools. In order to study sustainable and scalable implementation of maker-studio approaches, and thus in order to study students' development of design literacy in formal educational settings, Program II had indicated a need to better prepare teachers for such teaching. That is, in order to investigate answers to the question of how to develop students' design literacy in formal educational settings, I studied development of the teacher component of formal educational settings in more depth. This was done in the Reflective Educators program.

3.7.1. Reflective Educators

DesignThink2 had revealed a range of challenges for teachers implementing a design studio approach to making in education. These challenges, which are unfolded in P4 and chapter five, indicated a need for professional development of teachers. Therefore, as described in P4, as part of the FabLab@School.dk project, twenty teachers and six lab leaders took a course (5 ECTS corresponding to 1/12 of a year's work) in design processes and digital fabrication. This was a professional development course for in-service teachers; at the same time, it also represented a research experiment to study teacher's development of competences for teaching in a maker-studio approach. That is, the course had the dual aim of providing in-service professional development for teachers and investigating opportunities for a preferred state (Nelson & Stolterman, 2012) in which teachers were better able to teach with the aim of design literacy.

The course was built around a case of designing better futures for Ghanaian handlers of discarded electronic waste (e-waste). Teachers on the course had to implement a version of the case in their own practice: their students had to design for ways to directly reduce amounts of e-waste created in Dnemark, for increased awareness among Danes of the problems of e-waste, or they had to design better ways of handling the e-waste for Ghanaian workers. Teachers participated in workshops and lectures, implemented the design case in their practice, and worked together to discuss and reflect in peer groups of four to five. The experiment generated data from baseline and endline surveys (Likert scale items and open questions, 37 respondents) and from observations of classroom discussions, including shadowing the work of two groups (video and field notes, six days of workshops and lectures), observations of implementation of the case in two schools (video and field notes, approx. 25h), semi-structured interviews with the three teachers in these two schools (30–45min), and the teachers' final exam papers on the course (group examinations). The analysis that led to the results presented in P4 was based on finding coherent patterns across the mixed data in an affinity diagramming approach (Beyer & Holtzblatt, 1999).

As a research experiment, the Reflective Educators project studied the teachers' development of competence to teach in a maker-studio approach. More specifically, teacher development was studied with regard to three challenges that teachers in DesignThink2 had identified (Smith et al., 2016), as well as with regard to teacher positioning. The study of these developments is described in "Video design games" (P3) and "Educating the Reflective Educator" (P4). Those papers investigate instances in which teachers showed a change in their appreciation of central tenets of teaching design literacy. As described in P4, the diverse data gave rise to a better understanding of how to prepare teachers for understanding (1) students' design processes, (2) the mix of digital and analogue materials, and (3) different roles involved in teaching for design literacy.

3.8. Summary

In this chapter, I have described and discussed the ways in which I have investigated my research question through three distinct but intertwined research programs: (1) researching the nature of design literacy as well as student development of design literacy; (2) researching sustainability of implementing of a maker-studio approach in formal educational settings; and (3) researching teachers' development of competences for teaching in a maker-studio approach. The research was contextualised in situ – that is, directly within the scope of the research question, which deals with the classrooms of formal educational settings as stipulated by my research question.

The research question concerned contexts which did not yet exist. The studies were therefore carried out in an interventionist approach. These studies used research through design as an approach with which to research educational settings. With a special focus on overcoming fixations, this interventionist approach, rooted in design research, has offered perspectives on making the familiar contexts of formal educational settings unfamiliar to me as a researcher. That is, the particular stance towards inquiry of research through design has provided a path to staying with the complexity (Stolterman, 2008) of the swampy lowlands of research into formal educational settings (Schön, 1992b). In the publications included, the direct inspiration from design methods and research through design is most clearly visible in the affinity diagramming (Beyer & Holtzblatt, 1999) processes in P1 and P4, the video design game in P3, and in my overall iterative, contextualised and genealogical approach to investigating the research question.

In sum, through six experiments conducted in three research programs in a research through design approach to educational research, I have investigated the development of design literacy in formal educational maker settings in the following four perspectives: (1) the conceptual perspective of understanding design literacy (P1, P2, P5); (2) a pedagogical perspective (P3, P4); (3) a perspective of assessing design literacy (P2, P5, R2); and (4) an exemplar perspective of creating educational setups in which design literacy can be developed through activities with maker technologies in formal educational settings with 11–15-year-olds (P1, P3, P4). Figure 4 depicts the data generated in each of the six experiments.

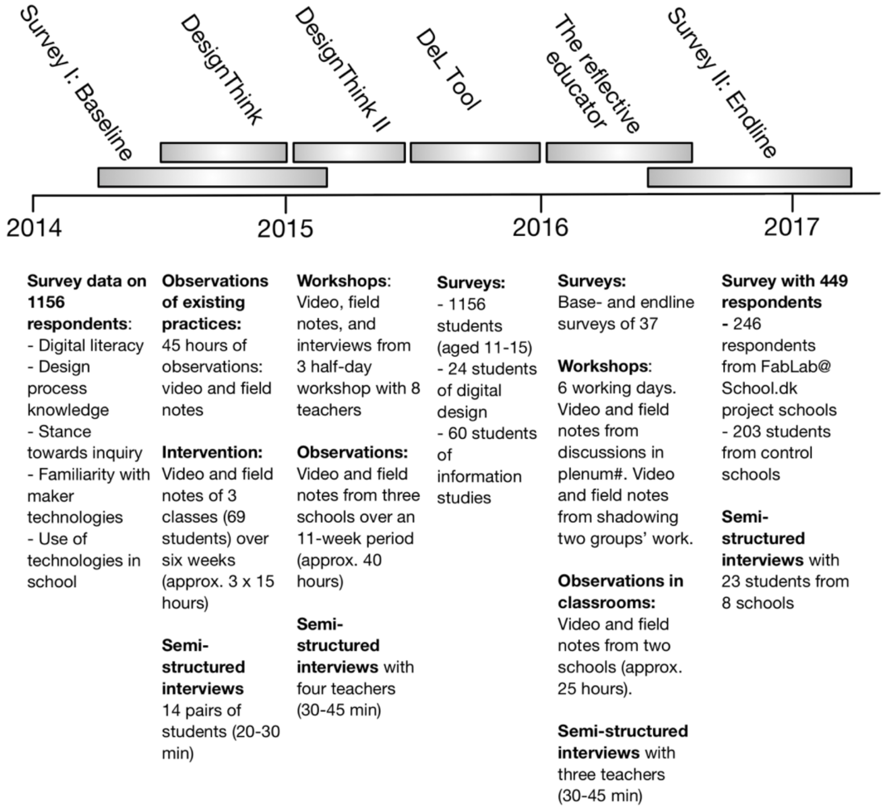

Figure 4: *Relationship between research activities and data.*

4. Design literacy

This chapter explores both the nature and development of design literacy among students in K–12 maker settings. Like that of a number of other researchers in the field of making in education (Buechley et al., 2008; Katterfeldt et al., 2015; Sipitakiat et al., 2004; Vasudevan, Kafai, & Yang, 2015), the research discussed in this chapter has centred around physical interaction technologies such as The MakeyMakey and The Arduino. Accordingly, most of the examples used in this chapter are of students working with such technologies. There is a body of literature on the nature of the expertise needed by designers dealing specifically with interaction design (Löwgren & Stolterman, 2004) and by professional designers in general (N. Cross, 2011; Lawson, 2006; Nelson & Stolterman, 2012; Schön, 1987). As described in chapter two, there are also examples of arguments for design for all and for design literacy within the design research literature. However, very little has been written about *the nature of design literacy* as opposed to design expertise and about assessing such literacy, and there is no body of literature on design literacy in the context of making in education. Likewise, although the design studio has been described as a method for developing design expertise (Schön, 1985), very little has been written about *teaching design literacy* and, even more specifically, doing so through making in education.

In this chapter, I discuss students' development of design literacy from four perspectives: From a conceptual perspective three aspects of design literacy are investigated: design-process knowledge, design judgment, and stance towards inquiry. Second, from a pedagogical perspective, the chapter explores how such design literacy can be developed by exploring a design-studio approach to K–12 maker settings. Third, the chapter provides an exemplar of such teaching. Finally, it explores assessment of design literacy. The chapter is based on P1, P2, P5, and R2, and it contains excerpts from these sources.

4.1. Design expertise

Design is described in Herbert Simon's (1969) influential work as a discipline in which designers devise courses of action to change existing situations into preferred ones. This broad definition is echoed by, Nelson and Stolterman (Nelson & Stolterman, 2012), who position design as an inquiry into the existing, to develop a desired future, the not-yet-real.

According to Nelson and Stolterman this is a natural human ability, but it is one that can function at very different levels of expertise. In their work, Nelson and Stolterman build on Donald Schön's (1983) critique of a stance of technical rationality towards design problems. Rather, according to Schön, designers should develop a form of professional artistry. Building on these notions, Cross (2011), Nelson and Stolterman (2012), Lawson (2006), Löwgren and Stolterman (2004), and Krippendorf (2005) have investigated the nature of design expertise. Echoing Schön's assumptions that designers, as well as practitioners in general, engage with messy situations, there is a consensus among these works that designers deal with problems, which are often referred to as wicked.

4.1.1. Wicked problems

The notion of the wicked problem was introduced in Rittel and Webber's (Rittel & Webber, 1973) seminal work on city planning. It was a way of moving the field beyond an understanding of city planning as definable, understandable and consensual, and it was intended to counter technical views of the problem-solving process within this field. Rittel and Webber suggested that only problems from which the wickedness had been removed were in fact determinate. It follows from the indeterminateness of a wicked problem that there are no right or wrong solutions, there is no telling when the work on a solution has come to an end, and there is no definitive formulation of the problem itself. This idea of wicked problems as indeterminate and in need of problem setting or framing has been seminal to the field of design studies. As argued by Buchanan (1992), design as a liberal art is in part defined by designers' approaches to design problems as wicked. Whereas technical, well-determined or tame problems can be defined and thereafter solved, with wicked problems, this is impossible according to Buchanan. In line with this, Schön indicated that with such problems, solution and definition of the problem are developed in parallel (Schön, 1983). Similarly, Cross (2011) identified the self-confidence to define, redefine, and change the given problem, in light of the solutions that emerge through the process of design, as essential to design expertise, and Dorst identified framing of wicked problems as a core competence of designers (Dorst, 2011).

Thus development of design expertise entails development of competences for engaging with wicked problems. Within the field of design education, the design studio (Schön, 1985) has become the modus operandi for design schools preparing students to practice such work with wicked problems (Shaffer, 2003). In the following section, I will describe the design studio as an established way of developing design students' abilities to provide solutions to wicked problems.

4.2. The design studio

The design studio approach is an established method for educating professional designers and architects through engagement with wicked problems (C. B. Brandt et al., 2013; Shaffer, 2003; Stevens, 1995). Schön describes the studio setting as "a type of professional education, traditional in schools of architecture, in which students undertake a design project under the supervision of a master designer" (Schön, 1983, p. 79). The approach is project-based and is driven by the students' work and their reflections on that work. According to Schön, the process of working with a given design problem is scaffolded by the studio master through a series of so-called desk critiques (feedback sessions at students' desks), reviews (presentation and feedback in group settings), and a final critique (presentation and feedback at the end of the project – often including external juries). According to the more recent work by Shaffer (2003), the outcome of crits and reviews in the architectural program at Oxford Studio at MIT was *pointed criticism*, which students used to refine their projects. By contrast, in the influential example of Petra and Quist (Schön, 1987) discussed in chapter 5, the desk crit involved the teacher, Quist, co-developing the idea and even taking over parts of the project development by both telling and showing his student how he approached the given problem. Through crits and reviews, the student learns both about designing and about learning to design. Thus, the student is asked to design before she knows what designing is. In this paradoxical situation, Schön (1987) claimed that the student should be in a state of *willing suspension of disbelief* – expecting to gain clarity later in the process from the ambiguity, vagueness and obscurity that precede it. Thus, according to Schön, students have to trust the educator to be a master of designing.

Brandt et. al. (2013) describe current practice across a range of university-level studio-based learning courses in architectural, HCI and industrial design. In all courses studied, the studio approach was project-based and based on wicked problems, with design critiques and reviews as the main pedagogical activities. Brandt et. al. note that the meaning of the term design studio varies between disciplines as well as between individual educators. According to Brandt et. al. (2013), in design education, design studios act as bridges between academic and professional communities as *practice communities* in which students practise design without participating in the design community. However, the preconditions for a design-studio method for practitioners and for K–12 students in search of design literacy are of course very different. Therefore, it does not seem plausible to assume that a design-studio teaching method will function in K–12 in the same way as described by Schön (1983, 1985, 1987), Shaffer (2003), and

Brandt et al. (2013). I elaborate on these differences in chapter five, but first, throughout this chapter, I will explore the content of design literacy as developed in design-studio approach tailored to suit grade 7 students. This intervention explored how a design-studio approach might function to develop abilities for design judgment and understanding of design processes among the students.

4.3. DesignThink: A design studio approach

In the following, I analyse results from the DesignThink intervention (see section 3.5.2) which aimed to use a design-studio approach to investigate potentials for design literacy offered by maker settings in education. In the intervention, students were challenged to redesign two public parks in a scenario where these were to be fused to form a single park. At the time, the parks were less heavily used as a social everyday space than their location in the city centre might have predicted. Therefore, the semi-authentic design brief invited students to create proposals for creating an engaging urban space especially for young people by integrating social, digital, and novel aspects into new concepts for the combined park (P1). The following sections discuss the DesignThink intervention, as well as prior observational studies of existing practices in maker settings in formal education. When these observations of existing practices were compared with research on design expertise, design-process knowledge, design judgment, and stance towards inquiry emerged as aspects of particular interest.

4.4. Design-process knowledge

One of the many ways expert designers approach a wicked problem is to develop knowledge of the context and environment in which the problematic situation is present. To do this, the designer creates an initial framing of the problematic situation (N. Cross, 2011; Dorst, 2011; Schön, 1984), instead of following her first intentions. This initial framing allows the designer to seek a deep, holistic understanding of the problematic situation, as called for in design research literature (Kelley & Littman, 2005; Kembel, 2009; Löwgren & Stolterman, 2004; Nelson & Stolterman, 2012). In this early stage, designers often utilise a diversity of ethnographic and/or anthropological techniques, many of which have been tailored to design(Gunn, Otto, & Smith, 2013; Hanington & Martin, 2012; Randall, Harper, & Rouncefield, 2007). In sum, one characteristic of expert designers' engagement with wicked problems is that rather than jumping to a finalised solution, design literature prescribes that they should jump into the problematic situation as a way to initiate a process which can in time lead them towards a solution that they cannot yet foresee.

In the observational studies leading up to the DesignThink intervention (P1), many students faced with design problems had failed to recognise the wickedness of the problems they were tasked with. On the contrary, they had developed a design fixation (Jansson & Smith, 1991), which had led them towards finalisation based on assumptions and first intentions. An example is two girls in grade five at a school participating in the FabLab@School.dk project who had been tasked with designing a sofa that would also function as a workspace (the sofa was to be 3D printed). They brainstormed and chose the design they liked best. However, when the teacher challenged their design, their reaction was that they were already done: the teacher was only creating unnecessary problems. While the teacher remarked that the students had only just begun, the students did not appreciate an iterative process – they liked their first model. In general, students in the observational studies did not display any appreciations of iterative processes as ways to engage with wicked problems. For example, they did not show signs of engaging with any kind of investigations into the problematic situations, nor did they engage in ethnographic or anthropological fieldwork. They neither observed nor described the problematic situation, and they did not try to gain a deep, holistic understanding of it. Further, rather than framing the problem, students seemed to try to guess how to solve the task to an acceptable level with the least effort. In sum, the observational studies showed that students did not of their own accord engage with a problem as wicked. Rather, they tended to fixate on first ideas and therefore to finalise simplistic solutions.

In the DesignThink intervention, in order to counter students' fixation on first ideas, the investigative part of the students' design process occupied a large portion of their work. Structuring this, the AU design-process model, which was developed together with DesignThink, incorporated three steps (out of the original five) in the process leading up to fabrication. That is, students spent time investigating (1) the design brief and (2) the problematic situation, before they (3) ideated. Only after extensive ideation did they start the fabrication process. Thus in the six-week DesignThink intervention, students spent three weeks in the processes leading up to the fabrication phase. Since the observation studies had shown a lack of creativity among students in ill-structured processes, in DesignThink the processes were in general highly structured. For example, in their field studies each student was given a role as interviewer, photographer, or 'mapper'. Students then had to create and discuss interview questions, and generate a common plan with very specific foci. The students found this way of working motivating but also very challenging, and it was clearly a novel way for them to work: they were not used to generating empirical data based on investigations into problematic situations. The students therefore needed to be directed through several rounds of observations, interviews, and annotations (P1). The current version of the AU design-process model, which is depicted in Figure 5, includes six phases in design processes: *Design brief*, *Field studies*, *Ideation*, *Fabrication*, *Argumentation* and *Reflection*.

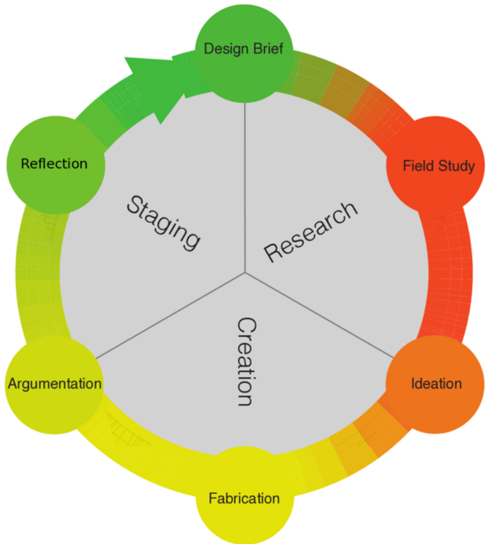

Figure 5: The AU design-process model

The AU model differed from similar models by placing extra emphasis on the parts of the process that precede ideation and fabrication. Scaffolded by the AU model, students used scenarios, ideation, and prototypes in a highly structured approach. For many groups, this structure created a foundation for iterative cycles of reflection and action which enabled them to gradually navigate and direct their own creative process (P1). Contrary to this, other students remained fixated on their initial ideas and they did not therefore invest the work needed to generate knowledge on their paths through the design process. These students had more and more trouble with presenting arguments for their design as the process unfolded and the critique from researchers and peers became more demanding. Thus students experienced the difference between basing a design on assumptions and first intentions and basing it on knowledge gained through a design process, as seen in this student dialogue taken from P1:

> Theis: You really have to think things through before you act.
> Naja: The idea with the toilet is a pretty good example. They hadn't thought about that idea.
> Theis: They just said something random.
> Naja: They hadn't thought about the qualities and the challenges of it.
> Researcher: Did you do that? Spend time considering your idea?
> Theis: Yes (...) You really need a long, long time to design things, I know that now, for sure.

In the example, Naja and Theis are criticising an idea which other group members have come up with. Here, they are communicating a demarcation between random ideas and designs which are a product of working with the design problem for a "long, long time". Naja and Theis were seemingly beginning to develop a repertoire of design processes against which to measure other processes. Thus in this context, a highly scaffolded and structured process helped some of the students to develop more creative solutions and gain a better understanding of design processes. In sum, observations from the DesignThink intervention suggest that highly scaffolded and structured experiences with design processes have the potential to add to students' repertoire of problem-solving processes, and thus to add to what I have here labelled their design-process knowledge.

4.5. Design judgment

Expert designers engage with design problems as wicked. In so doing, they renounce the existence of right and wrong answers deriving from pre-established objectives and linear processes, and choose rather to work through iterative and explorative design processes. Working in iterative processes entails choosing between a range of possible next steps, and this in turn necessitates judging between possible choices. In Schön's words, the reflective practitioner imposes his own order on the problematic situation, and is open to the backtalk provided as answers to his experiments in a reflective conversation with the materials of the situation (Schön, 1992a). The practitioner thus eschews a positivist epistemology of right and wrong answers in favour of a pragmatist epistemology including (but not limited to) value-based abductive reasoning (Dorst, 2011). In a pragmatist design discourse, it is up to the practitioner to judge which choices provide the most desirable outcomes. Such judgments are made throughout the design process, and judgment is therefore central to iterative design processes and a core competence for professional designers (Löwgren & Stolterman, 2004).

Students who were prone to design fixation and finalisation in the observational studies conducted before conducted before DesignThink had been choosing more or less randomly between ideas. If they were to engage with wicked problems through iterative processes of making in education, their judgment would need to be scaffolded. In their book on becoming a *thoughtful* interaction designer, Löwgren and Stolterman (2004) point to four aspects of developing design judgment: a sense of quality, a developed language, reflective thinking, and retrospective reflection. In the following, based on results reported in P1, I will discuss the development of each of these four aspects in the context of maker settings in education exemplified by the DesignThink intervention.

4.5.1. A sense of quality

A practitioner working with wicked problems, according to Löwgreen and Stolterman (2004), has to trust the right feeling. For the practising practitioner, this sense of quality is acquired through experience and through developing a repertoire. The notions of trusting the right feeling and having a sense of quality are akin to Schön's analogy of hitting the ball right when playing tennis: good tennis players "have to be able to feel when they're hitting the ball right, and they have to like that feeling, as compared to the feeling of hitting it wrong, but they need not, and usually cannot, describe either the feeling of hitting it right or what they do to get that feeling" (Schön, 2001, p. 195). This feeling comes through the experience of hitting the ball over and over again and through more or less tacit reflecting on the results of those hits. In the same way, for Löwgren and Stolterman, a design practitioner must experience enough design processes to gain a sense of quality about the potential next steps in a design process.

The design fixation of some students in the observational studies that led up to DesignThink meant that they did not practise their sense of quality through multiple iterations and judgments. One of the goals of DesignThink, on the other hand, had been to have students use and develop their sense of quality (P1) to qualify their choices beyond the somewhat random choosing between ideas that had occurred in the observation studies preceding the intervention. DesignThink had been set up to encourage the students to train their sense of quality with multiple instances of experiments, failures, and successes, in order to create the possibility for multiple reflections on "hitting the ball" both more and less right. The iterative nature of the process was emphasised through exploratory questions and multiple desk critiques and reviews. These invited the students to reflect on whether or not they had "hit the ball right" by returning to the design brief again and again. As mentioned above, these iterative processes were scaffolded by the AU design-process model.

An interesting case from DesignThink was Agnes's development. Agnes' group developed a possible solution in the form of a bicycle bridge with space underneath for pedestrians to rest and socialize. Agnes was a driving factor in the groups' work, which led them through multiple iterations to choose the design principle of separating cars, bicycles, and pedestrians onto different levels of elevation. The students did not yet have the design language to name this as a principle, but it felt "right" to Agnes. In line with other such cases from DesignThink, the case of Agnes and her group suggests that some students working in maker settings can develop their sense of quality by working through highly structured, iterative processes that are scaffolded by a design-process model, exploratory questions, and multiple desk crits and reviews.

4.5.2. A developed language

An expert tennis player does not need to be able to communicate how it feels to hit the ball right, or what he or she does to accomplish this. But unlike a tennis player, according to Löwgren and Stolterman (2004) a designer does need to be able to communicate the quality of a proposed design step or solution to others. When collaborating in heterogeneous groups, a designer uses his design language to argue for judgments based on a sense of quality. As highlighted by Löwgren and Stolterman, such language is not limited to words: a sense of the quality of emerging ideas can be communicated through externalisations (Dix & Gongora, 2011) such as sketches, scenarios, mock-ups, prototypes, or storyboards. These externalisations, as well as the process itself, then become materials of the situation and thus become the objects of reflective "backtalk" (Schön, 1992a) and a basis for judging between possible next steps or solutions. In this way, externalisations reveal and communicate the qualities of such next steps and solutions. By contrast, students in the observational studies discussed in P1, where not able to use their sketches and mock-ups as a way to further develop their designs: they did not display a design language, whether verbal or non-verbal, that helped them to exercise or develop their design judgment.

To develop their non-verbal design language, the students in DesignThink worked with an array of means for externalisation, including storyboarding (to communicate and synthesise research findings), inspiration cards (to articulate new design ideas), mock-ups (to ideate and iterate on the design idea), and video prototyping (to finalise the design argument). These design tools, which in themselves provided a language for communicating about the design process and the potential solutions, also provided objects for backtalk about the materials of the situation in Schönian terms. That is, they initiated both verbal and non-verbal dialogues between students, researchers, and the objects themselves. The verbal dialogues between the students and between the students and the researchers gave students the opportunity to practise their verbal design language and expand their verbal design vocabulary by imitating the researchers' vocabulary, as well as by using the vocabulary offered in the design brief and written design-process materials. Thus, the students were to some degree offered the possibility of acquiring a design language by legitimate peripheral participation in the researchers' community of practice (Lave & Wenger, 1991) as well as participation in a practice community within the class (C. B. Brandt et al., 2013).

Throughout the DesignThink intervention processes, it was a requirement that each activity should result in a tangible outcome. For example, the field studies were categorised by placing post-it notes, photographs, and maps on (analogue) brown garbage bags, which later served as a knowledge repository on the field studies for students in DesignThink. Later in the process, students included digital materials in their design language, which gave them the opportunity to better communicate the functionality of their design ideas. An example here was Sarah, who worked through multiple versions of prototypes to communicate her group's idea for hedges that could function as bicycle parking space. In these prototypes she experimented with various analogue materials including cardboard and felt and tried using both Arduino and MakeyMakey technologies to displays whether a space in the hedge was occupied. Through these iterations she was able to experiment with how closely the functionality needed to match the end solution. Working through iterative processes in maker settings allowed Sarah to extend her design language with regard to both analogue and digital materials. The same can be said for Agnes's work, described above, in which a model made with popsicle sticks, cardboard, felt, and an Arduino was used to communicate and test the groups' ideas. The results of the DesignThink intervention thus suggest that highly structured iterative processes in maker settings have the potential to help students develop their design language with regard to both analogue and digital materials.

4.5.3. Reflective thinking

Löwgren and Stolterman's (2004) notion of reflective thinking builds upon Donald Schön's influential notion of reflection-in-action, which he developed to describe the practices with which designers engage in a conversation with the situation (Schön, 1992a). Schön compared reflection-in-action to improvisation by jazz musicians. They feel the direction of the music that is developing out of their interwoven contributions, make new sense of it, and adjust their performance to the new sense they have made. Thus reflection-in-action is likened to how musicians improvise based on a feel for the music. Through such reflection-in-action, a practitioner "judges a problem-setting by the quality and direction of the reflective conversation to which it leads" (Schön, 1983, p. 135). By judging an experiment on "quality" and "direction" rather than "confirmation" or "negation," reflection-in-action rests on a pragmatist epistemology and abductive reasoning, as described in Dorst (2011).

Because reflection-in-action is often a tacit, even unconscious process based upon the "feel" of a situation and judgment about the quality and direction that experiments provide, it follows that a capacity for reflection-in-action is developed through experience. *Virtual worlds* (Schön, 1983) such as sketches on paper and externalisations in general allow students to experiment in rapid iterations without having to make irreversible judgments. DesignThink therefore incorporated a diverse range of visual tools the students could use to structure their experiments, insights, and reflections, and to support their judgments and developing arguments.

Since reflective thinking is often tacit, it was not easy to document the existence or non-existence of such processes among students. As discussed, in the observational studies preceding DesignThink, students did not go beyond their initial ideas. Therefore, it is unlikely that these students engaged in reflection-in-action with regard to these ideas. Contrary to this, Sarah's group had engaged with the situation of the park and had discovered that abandoned bicycles were being left in the hedges. They had framed the problem as a need for bicycle parking by the hedges, but through their design process they had developed a design principle – that the hedges should provide a parking space for bicycles (rather than making bicycle stands outside the hedges, as would usually be done). The group developed this principle through a number of externalizations, and this work suggests a sensitivity to the backtalk provided by the externalizations. Similarly, Agnes's reflection-in-action had led her to reframe part of her group's problem as separating pedestrians, cyclists, and cars at different levels of elevation, which became the major design principle of this group's proposed solution. Subsequently, Agnes engaged with both MakeyMakey and Arduino technology as she experimented with various different solutions involving first one and then the other of these technologies. Her experiments provided backtalk in the form of different materialities and possibilities of the two technologies. In Agnes's and Sarah's groups, reflective thinking thus helped to (re-) frame the problems and create design principles, and it furthered the students' ability to present an argument for their solutions. For Schön (1983), reflection-in-action depends on the designer's ability to continuously ask "What if...?" In the post-intervention interview, Agnes and Sarah, appeared to be developing an understanding of such a need to continuously question the choices made in their design processes. For example, Agnes displayed a willingness to enter into a reflective conversation with the situation when she was asked what she had gained from DesignThink: "You begin to think differently: 'How could I do this?' and 'What if I did it this way?' (...)"

4.5.4. Retrospective reflection

For expert designers, judgments and reflection-in-action are based on their ability "to see the unfamiliar, unique situation as both similar to and different from the familiar one, without at first being able to say similar or different with respect to what" (Schön, 1983, p. 138). Thereby, the designer's repertoire of situations, processes, or solutions, determines her abilities for reflection-in-action and judgment in general. Situations in which a designer has applied reflection-in-action by using her repertoire to understand the situation may in turn add to the practitioner's repertoire by contributing exemplary themes. Further, according to Löwgren and Stolterman (2004), students of interaction design can benefit from reflecting on other design students' actions and thoughts, or those of expert designers. Through reflecting on the design choices made by a designer, on the problem the designer was trying to solve, on how the process might have looked, and on what qualities the final solution embodied, a student can enlarge her repertoire of design solutions by retrospective reflection. Similarly, retrospective reflection on own design processes (as described in Schön's notion on reflection-on-action: Schön, 1987) can develop the student's repertoire further.

In the DesignThink intervention, retrospective reflection was scaffolded by listening to, questioning and critiquing other students' design processes, solutions, and judgments based on their presentations of design arguments and solutions. Listening to the researchers' critiques of their design arguments and suggested solutions encouraged them to reflect on their own design processes and judgments, as well as those of the other students. Further, the students' peer critique was scaffolded by rules on feedback and point-giving in order to encourage reflection from all students and thereby train students' retrospective reflection in a practice community. It was through this kind of reflection-on-action that Naja and Theis developed their abilities, repertoire and understanding of design processes to a level where they were able to reflect on their group members' toilet idea as something which "they hadn't thought about the qualities and the challenges of". In sum, some students reflected on other students' processes and solutions, and thereby developed their own repertoire of design processes and solutions.

4.5.5. Developing judgment through making in education

The process of critique in DesignThink engaged the students in retrospective reflection by revealing the design judgments behind other students' solutions. Further, because these design judgments had been based on the students' reflective thinking, development of design language, and sense of quality, these retrospective reflections provided the possibility for students to develop their own ability for design judgment. Thus the students' development of design judgment was scaffolded not only by their own practice and the critiques offered on their own solutions, but also by critiquing the solutions of other groups. Although the students did not become professional designers during the six-week DesignThink intervention, they gradually became accountable for their choices, building up an argument for the qualities of their design solution. The DesignThink intervention – highly structured with a design-process model and scaffolded by the involvement of four researchers and two teachers – was therefore able to initiate the development of an understanding of design processes and design judgment among some of the students engaged in making in education.

4.6. Stance towards inquiry

When a practitioner such as an expert designer engages with a wicked problem, he does so, according to Schön, with a particular stance towards inquiry. Schön (1983) defines a practitioner's stance towards inquiry as his "attitude toward the reality with which he deals" (p. 163), and he contrasts a reflective practitioner's stance with a stance of technical rationality. According to Schön, there are epistemological differences between the two contrasting types of stance towards inquiry: the stance of technical rationality rests on a positivist epistemology, which entails distancing oneself from the situation and providing solutions to pre-established objectives, whereas a reflective stance entails "jumping" into the situation by imposing an order on it – that is, by framing the problem. Thus for Schön a more designerly stance towards inquiry is a prerequisite for initiating a reflective conversation with the situation. By attempting to provide solutions to pre-established objectives, practitioners with a stance of technical rationality fail to acknowledge the wickedness of the problematic and indeterminate situation. Similarly, beginning design students have been shown to erroneously see problems as well-defined and tame, seek a single, "correct" solution, and therefore suggest less adequate solutions (Portillo & Dohr, 1989; Simmonds, 1980) as they approach wicked problems of this kind. In contrast, an expert designer approaches problematic situations by engaging with these situations through reflective conversations with stakeholders, the design situation, and its artefacts (N. Cross, 2011; Nelson & Stolterman, 2012; Schön, 1984). In the following, I will discuss investigations on students' stances towards inquiry based on P1, P2, and P5.

4.6.1. Observing stance in the classroom

P1 includes a description of an observational study in which two students had been tasked by their teacher with using a 3D printer to prototype novel designs for a work sofa. After the first try, they thought their design was finished, because they were certain that they had met the pre-established objectives by 3D-printing a round sofa. When their teacher tasked them with further development, they complained that he had given them a problem they did not want: "But we've already solved that problem. *You* are giving us a problem (...) but honestly, we are done." At every stage of my observational studies, I saw similar examples of design fixation (Jansson & Smith, 1991) leading students towards simplistic solutions and finalisation. Such finalisation occurs when the students try to come up with solutions based on their previous knowledge, assumptions, and prejudices – in other words, when they approach a wicked problem with a stance of technical rationality. As shown in the example described here, when the students fixated on their first ideas for a solution, they did not see the point in engaging in a reflective conversation with the situation. They saw no point in framing and re-framing the situation, and they did not value investigation into the problematic situation by use of externalisations or field studies.

4.6.2. Working with stance in the classroom

Students in DesignThink displayed a more designerly stance towards inquiry than students in the preceding observational studies: in DesignThink many groups did manage to use the fragmented but insightful data from their research to create concepts for their designs, with some groups even managing to use these concepts as design principles (P1). During their field work Naja and Theis had been asking people if they thought the park needed more art, but because the interviewees were more interested in the number of playgrounds or dustbins, Naja and Theis gained concrete experience of the problems with basing solutions on first ideas and assumptions. On the other hand, Sarah's group, who encountered a lot of bicycles randomly thrown on the ground, used this discovery to develop a cycle–park–hedge concept and so gained concrete experience of the value of investigating the problem setting. The DesignThink intervention showed that with the aid of scaffolding from design researchers, many students were able to perform such a stance to a degree which led them to base their solutions on explorations of the problem settings rather than on assumptions, prejudices and first ideas and intentions. The intervention did not show if these concrete experiences with taking a more designerly stance towards inquiry led the students to internalise such a stance for future problem-solving. In the following, I will describe my work with developing a tool for assessing students' stances towards inquiry.

4.6.3. Measuring students' stance with a survey question

In the 2014 baseline survey, students were asked how they would solve the wicked problem of elderly people suffering from dementia disappearing from their care homes (see section 3.5.1). This survey item, which we named the DeL tool, was meant to assess how students would approach a wicked problem, which was outside their everyday context: would they recognize the wickedness of the problem and suggest an investigation into the problematic situation, or would they jump to finalised solutions?

As described in P2, 66 per cent of the 11–15-year-old students, suggested finalised solutions, such as locking the doors, hiring more personnel, and tracking the inmates with GPS sensors. In providing finalised solutions, these students were categorised as taking a stance of technical rationality. 31 per cent of the students responded that they did not know, or gave a response which was uninterpretable to us as coders of the responses. It is impossible to guess why so many students ended up in this category. If these students had had a designerly stance towards inquiry, however, they would not have thought they were supposed to know the answer; they could therefore have answered with a process, rather than failing to answer with a finalised solution. For this reason, these students too were categorized as taking a stance of technical rationality.

Only the remaining 3 per cent of the students were coded as taking a more designerly stance towards inquiry. This very small proportion corresponded well with the observational studies (in which students had jumped to finalisation), the DesignThink intervention study (in which it had been difficult to keep the students from finalising on their first intentions), and the argument in the design literature that such a stance towards wicked problems is a constituent of design competence (and thus not something which most people already have). In conclusion, only a very few of the Danish 11–15-year-old students in the 2014 pre-intervention (baseline) survey were scored as taking a designerly stance towards inquiry on the survey item used.

In 2016, the same survey item was used in the endline survey of 11–15-year-old students in the FabLab@School.dk project (see section 3.5.1 for further details). Students from the schools participating in the FabLab@School.dk project (FabLab group) were tested against the 2014 cohort and against control schools from the 2016 survey with regard to two hypotheses: (1) that FabLab group students take a designerly stance towards inquiry to a greater extent than the control group students, and (2) that FabLab group students take a designerly stance towards inquiry to a greater extent than the students from the 2014 baseline study. For both hypotheses, we were unable to find a statistically significant difference between students who had participated in the FabLab@School.dk project, and students who had not. Instead, the students seemed to primarily approach wicked problems with a stance of technical rationality, regardless of whether or not they had participated in the project. The students from DesignThink were not assessed with the DeL tool, and I have not yet had the chance to correlate between stance in classroom practice and assessment of stance on the DeL tool. Therefore, the lack of statistically significant results can in fact point to shortcomings in the classroom practice within the FabLab@School.dk project. While the teachers in the project were informed of the importance of stance towards inquiry, and while most of these teachers based their teaching on the AU design-process model, which emphasized field studies and gaining a holistic understanding of the problematic situation, I cannot assume that students' stances towards inquiry were directly targeted in their work in maker settings. That students on the endline survey were not assessed as having a more designerly stance towards inquiry suggests either that the students were unable to develop a more designerly stance towards inquiry, that the DeL tool is not fine-grained enough to assess this development, or that such development was impeded by one or more factors in the school ecology – such as teacher competences, student motivation, or the schools' existing practices. In chapter five, I will elaborate further on teacher difficulties with teaching for design literacy in maker studio approaches.

4.7. Assessing other aspects of design literacy

In the 2016 survey, students from the FabLab group were asked to rate their development from being taught in maker settings ("FabLab"). This was done by asking the participants to report to what degree work in maker settings had helped them to develop their knowledge about overarching topics and to rate their own knowledge of the different phases of the AU design-process model (see R2 for a more detailed description). 69% percent of the students reported that their work in maker settings had been structured around the AU model, whereas 11% did not know, and 20% reported that they had not used the model. On the more overarching questions of design literacy, students in some schools reported experiencing enhanced abilities for imagining change with technology, working creatively with technology, understanding how new technologies are created, and understanding how technology affects their lives, as well as in solving complex problems. That is, the survey results suggested that students in some schools were on a path towards becoming more design-literate.

The data showed large variations between those schools in which the students on average reported heavy use of the design-process model, and those in which fewer than half the students reported using the model. As the teachers were free to choose their method of teaching in maker settings, it is not in itself surprising that there was a large variation in the use of the proposed design-process model. Comparing use of the AU design-process model with students' self-perceived outcomes of work in maker settings, the data suggests that the more students worked 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). Thus, the data suggests that the students gained more with regard to complex problem-solving, critical reflection on the use of technology, and the ability to work creatively with technology when their work in maker settings was structured around a design-process model. The data did not provide opportunities for testing statistical significance of one such correlation, but this finding points to the scaffolding of design processes in maker settings through the use of design-process models as an interesting area for further research, and it is in line with results from the qualitative case studies.

4.8. Summary: Developing design literacy in maker settings

In this chapter, I have unfolded design process knowledge, design judgment, and stance towards inquiry as aspects of design literacy. I have provided an exemplar of teaching in a design-studio approach in K–12 maker settings, and I have discussed assessment of stance towards inquiry. The results suggest merely adding maker technologies to classrooms does not facilitate development of design literacy, and they suggest that tailoring the design-studio approach to students in this age group might open up possibilities for developing design literacy among these students in the context of making in education.

The tailored design-studio method was highly structured by a design-process model, and the students' moves were scaffolded by design researchers. Here, the DesignThink intervention serves as an *exemplar* of a design-studio approach to teaching in the formal educational settings of K–12 education. While this exemplar was carried out by design researchers, the DesignThink intervention suggests that students aged 12–13 were able to overcome design fixation to gain a more designerly stance towards inquiry into the problematic situation, that it was possible to initiate their development of design judgment, and that this all helped students to develop solutions to the wicked problems with which they were tasked. Therefore, at the *conceptual level*, I argue that design-process knowledge, stance towards inquiry, and design judgment are relevant aspects of design literacy. In Figure 6, I present these aspects together with examples from the DesignThink intervention and with the scaffolds applied to support students' exercise and development of these aspects of design literacy.

At the *assessment level*, I have discussed the development of the DeL tool to assess stance towards inquiry. The quantitative research discussed in this chapter suggests that students were not on average able to develope a designerly stance towards inquiry within the project period. Students' responses to other, more overarching, survey items did suggest that students in some schools had become more design-literate. These results, however, varied greatly between schools. The variations between schools in the survey confirmed the importance of teachers and the ecologies in which they function. In chapter five, I explore and discuss the pitfalls of transferring the tailored design-studio method discussed in this chapter to real-world teachers in real-world schools, and I discuss how further qualitative studies pointed to the importance of teachers.

Concept	Entails	Examples	Scaffolded by
Design-process knowledge	Understanding design processes as iterative, consisting of different phases and a way of going beyond initial ideas	Naja and Theis distinguishing between random ideas and "working for a long, long time"	Using a design-process model to facilitate a highly structured design process
Design judgment	A sense of quality	Agnes' sense, that it was a good solution to separate pedestrians, bicycles, and cars into different levels of elevation	Multiple iterations in all early phases of design processes
	A developed language	Sarah's work with a variety of digital and analogue materials to communicate the idea of bicycle park hedges	Externalisations, critiques and peer-feedback offering examples of verbal and non-verbal design communication
	Reflective thinking	In Agnes' and Sarah's groups, reflective thinking helped (re-) frame the problems, create design principles, and furthered their ability to present an argument for their solutions	Using externalisations as experiments in the world, continuously asking students "what-if?", and explicitly using reflective thinking in dialogues with students
	Retrospective reflection	Naja and Theis exerted retrospective reflection on their group members' idea, which "they hadn't thought about the qualities and the challenges of"	Establishing multiple sessions of critique in design processes. Offering criteria for peer-feedback on processes as well as solutions
Designerly stance towards inquiry	A propensity for inquiring into a situation rather than trying to suggest a solution based on prejudices, assumptions, and initial ideas	Both Sarah's group, and Naja and Theis changed their original assumptions about the settings they were inquiring into	Assigning roles to each student (e.g. interviewer, photographer, or 'mapper'), discussing a common plan with very specific foci

Figure 6: Aspects of design literacy studied, including examples of student development and scaffolding from DesignThink.

5. Teaching in the K–12 maker studio

Clearly, just as some people learn to reflect-in-action, so do others learn to help them do so. These rare individuals are not so much "teachers" as "coaches" of reflection-in-action. Their artistry consists in an ability to have on the tip of their tongue, or to invent on-the-spot, the method peculiarly suited to the difficulties experienced by the student before them. (Schön, 2001, p. 204)

The previous chapter explored design literacy as a possible end goal for teaching with maker settings in formal education. Its focus, in other words, was on the students. This chapter explores the other half of the student–teacher relationship in formal educational maker settings. In the chapter, I will unfold challenges for teachers, who tried to implement a design-studio approach similar to the one described in chapter four. These challenges meant that this approach would not be sustainable in the grade 7-9 maker settings, to which it was targeted. In other words, there was a need to better understand the teaching approach as well as the teacher competences which were required. In this chapter, I unfold my research into understanding the role of the teacher if the implementation of a K–12 maker-studio approach to such formal educational contexts is to be sustainable.

While the role of teachers in successful educational change is widely acknowledged in the educational literature (Ben-Peretz, 1990; Fullan, 2007), there is very little work in the field of making in education which deals specifically with the teacher in such settings (see chapter two). Within the field of interaction design and children, Druin (2002) has discussed how children can participate in the design of interactive products for children. In common with Iversen et al. (2017), however, this chapter investigates the reverse of this question: how can teachers (as designers or design educators) initiate, scaffold, and participate in the design processes of children?

In the chapter, I list tensions arising from differences in the ecologies of design-studios and K–12 maker studios. Its focus, however, is on teachers' challenges in facing and overcoming three intertwined and interdependent aspects: materiality, design fixation, and positioning. For this purpose, I contrast an critical case in a K–12 maker-studio setting with Schön's paradigmatic case of teaching in the design studio (Schön, 1985). While this contrast is developed through the introduction and analysis of unpublished research, the chapter also builds on P3, P4, and R2, and it contains excerpts from these sources. This chapter builds on teachers' implementations of their own tailored versions of a design-studio approach in the DesignThink2 experiment, as well as in connection with a professional development course for teachers in the Reflective Educators experiment (P3, and P4).

5.1. The design studio as a teaching approach in K–12

The DesignThink intervention discussed in chapter four used a design-studio approach to developing students' design literacy. The design-studio approach in DesignThink was tailored to fit the context of working with grade seven students. In this intervention, up to four researchers and two teachers were present together with each class of 21–25 students in a school makerspace. That approach initiated the development of the K–12 maker studio as a teaching approach by scaffolding students' design through highly structured design processes. To gain insight into the nature of the challenges that teachers face when introducing such an approach, I now turn to Schön's descriptions of a design-studio approach in his works *The Reflective Practitioner* (1983), *The Design Studio* (1985), and *Educating the Reflective Practitioner* (1987). In these seminal works, Donald Schön describes education in the architectural design studio as a way of preparing students for engagement with wicked problems through engagement with real-world projects (see section 4.2). Here I take inspiration from the paradigmatic case of the design educator Quist.

5.1.1. The paradigmatic case: Petra and Quist

In his famous design-education example, Donald Schön describes Petra, an architecture student who has got stuck while developing her ideas for a solution to the problem of building a school on a hilly site. Petra had initially developed the idea of creating L-shaped buildings that would accommodate two classes with a shared space between them. Her problem was that these buildings did not fit the slopes of the hilly site on which the school was to be placed according to the design brief. In the example, Quist the educator is standing at Petra's desk. To begin with, he is listening to her troubles. But soon he engages with working on Petra's ideas for a solution, by sketching on top of her drawings. He draws and he talks – using what Schön terms the *language of designing*. There is an important materiality in what he does: Quist's words do not make much sense by themselves, as his talk refers to the drawings with "here," "this" and "that." In this way Quist is showing how he would work on Petra's project and "displaying for her the competences he would like her to acquire" (Schön, 1987, p. 81). At the same time, however, he is meta-communicating about the things he is doing to the drawings. In Schön's words, he is communicating in a *language about designing*, for example stating that "You should begin with a discipline, even if it is arbitrary" (Ibid). Quist identifies Petra's L-shaped buildings idea as one such discipline or design principle, and he goes on to apply it to the sketches. This application leads to the realisation that there will be a 15-foot difference in height from the bottom building to the top one, which in turn will allow for five feet between the ceiling of a lower building and the floor of the building above it. This then creates the possibility of connecting the buildings by creating nooks five feet high (the tallest pupils were expected to be five feet tall). Connecting the buildings influences the way in which the outside area can be divided, and this division of what Quist terms the gallery ends up being "the major thing" (ibid, p. 90). It becomes "the sort of thing Aalto would invent just to give it some order" (ibid). As Quist works with the externalisations (sketches), he is having a reflective conversation with the situation. What is special here is that he is also at the same time meta-communicating about this *reflection-in-action*, identifying a discipline as important, talking about going back and forth between *the unit* and *the total*, and pointing to further steps, such as "You'll have to investigate which way it should or can go" (ibid, p. 89). In sum, Quist moves fluently between roles of telling and demonstrating as he engages in working with Petra's ideas; and using the analogue materials of pen and paper for sketching, he also engages in a reflective conversation with the materials of the situation.

5.2. The K–12 maker studio

Teaching in formal educational settings in Danish public schools takes place within a very different context than the design studio described by Schön. There are numerous important differences between the setting Schön describes and implementations of a K–12 maker studio. First, the K–12 students are not on a path to becoming professional designers; rather, they are at the most supposed to attain literacy in design processes through maker settings. Second, as Waks (2001) points out, the fact that students in K–12 are not on a path towards their own chosen careers means they cannot be expected to be as self-motivated as the students who Schön describes. In fact they are more likely to be expending mental energy on trying to guess how to satisfy their teachers than engaging with the wicked problem in front of them (Nicholl & McLellan, 2008), something that in turn could make the K–12 students more inclined to adopt their teacher's idea uncritically. Third, in K–12 schools there is much less teacher time per student (Quist uses 20 minutes on Petra's project while the rest of the class refrain from climbing up the walls). Fourth, the students I observed in K–12 did not have their own workspace where they could keep and display the materials they had developed throughout the design process. This kind of space is important for a number of reasons – being able to pick up the project where it was left last time, sustaining attention to the project, and inspiring the continuing creative process. Fifth, according to Biesta (2010), schools function within an age of measurement, and this was certainly true of the Danish context, in which the teachers repeatedly asked for help to interpret the measurable learning goals of teaching for design literacy in maker settings. Nicholl and McLelland (2008) find that such a focus on learning goals and assessment promotes risk-averse school ecologies. In the English schools they studied, this was not conducive to creativity. Similarly, Smith et al. (2016) found that teachers implementing a design-studio approach in Danish schools were focused more on student completion of the assignments than the creative processes themselves. Finally, teachers in K–12 schools are not, and (for the most part) have never been, practitioners of design. Thus, in both the DesignThink2 and the Reflective Educators experiments, they were tasked with creating a practice community for design when they had not fully appreciated the design process themselves: they had not yet mastered either a language of designing or a language about designing. All of these differences need to be considered when discussing the sustainability of K–12 maker-studio approaches. In the following, I focus on the teachers.

5.3. Teachers' challenges

Paper four, "Educating the reflective educator", describes a professional development course that was developed to meet three central challenges These challenges were (1) how to understand a complex design process, (2) how to manage digital technologies and design materials, and (3) how to balance different modes of teaching. These three aspects are in fact intricately interwoven. One cannot balance modes of teaching design without understanding the design process to some degree, and the same is true of managing diverse materials in a design process. There is even an interdependency between teaching modes and understanding the roles of different materials in design processes. In the following section, I will discuss teachers' challenges with materiality, students' design processes, and positioning in regard to student feedback. Feedback situations with students are in situ contexts in which these challenges are manifested.

Therefore, feedback situations are particularly interesting with regard to researching such challenges. As indicated in the case of Kurt below, feedback is also of great importance with regard to students' design processes, and therefore to their development of design literacy.

5.3.1. Materiality in teacher feedback

Schön describes how Quist, the design educator, gives his student Petra feedback by demonstrating and telling. As he gives this feedback in the design-studio approach, Quist sketches his thoughts on top of Petra's sketches. In a language of designing, Quist demonstrates his use of the material at hand. In the Petra and Quist example, Quist can demonstrate a reflective conversation with the situation in a language of designing by interacting with the materials of the situation – in this case, pen and paper for sketching. In this way, Quist's externalised reflective conversation becomes visible to Petra, and Quist can refer to the drawings using "here," "this," and "that." Likewise, Quist draws on a repertoire of uses for the materials of the proposed solution, including building materials, ground materials, and modelling materials. His understanding of design materials and his language of designing influence the modes of teaching available to him and to his language about designing.

Teachers taking part in the Danish K–12 maker-studio approach implemented by DesignThink II, on the other hand, displayed and talked about difficulties in managing both analogue and digital materials (P4). These difficulties were echoed when twenty teachers were tasked with participating in the video design game described in P3. Here, teachers analysed video clips of examples from their own implementations of a K–12 maker-studio approach. The video design game framed a comparison with Quist, and in so doing it demonstrated to teachers their lack of physical engagement with materials in sketches, mock-ups, etc: they "spoke about" but did not "engage with" student materials. Unlike Quist, they did not display a language of designing with the materials at hand. In one group a teacher had, however, worked specifically with visualising feedback by 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. Thus these teachers' findings corresponded well with the example of Petra and Quist, in which Quist's feedback was to a high degree based on his interactions with Petra's sketches. In general though, the teachers' findings pointed to a lack of such externalisations in the feedback they gave on their students' design processes.

The video design game was used in the context of the professional development course on design processes and digital fabrication described in more detail in P4. All the groups of teachers who took the exam for this course included reflections on externalisations like those of group 5 in their papers. Here they themselves pointed to externalisations and physical materials as important for their students' design processes. While the video design game helped teachers to enrich their understanding of the role of externalisations in communicating and assessing ideas, the teachers in the course – as well as in the rest of the studies I participated in –still struggled with managing a diverse set of digital and physical materials. This struggle with materials in both situations – sketching and solution (ideally inseparable) – influenced the teachers' ability to demonstrate, rather than just tell the students what to do. Not having mastered a language of design limited their ability to engage in the students' design processes, and thus their ability to communicate in a language about designing.

5.3.2. Fixations in teacher feedback

In design research, design processes are generally described as developing in messy and unpredictable ways (N. Cross, 2011; Löwgren & Stolterman, 2004; Nelson & Stolterman, 2012; Schön, 1983, 1987). This underscores the importance of working through iterations in a reflective conversation with the situation (Schön, 1992a), so as to avoid premature judgments and design fixations (Jansson & Smith, 1991) based on prejudices, preestablished assumptions, or a stance of technical rationality (Schön, 1983). Similarly, in Schön's example, Quist can balance demonstrating and telling because he is neither expecting nor expected to give the correct final answer to the problem he has been presented with. Quist can explore the problem and the solution at the same time by engaging with the materials of the situation, rather than trying to judge the current solution based on whether or not it can be completed in time and lead to the correct solution. Unlike most of the teachers in English K–12 classrooms studied by Nicholl and McLellan (2008), he can deal with projects that are ambiguous and that risk failure.

In classroom observations connected to DesignThink2, as in previous classroom observations, teachers tended even in the early stages of the design process to evaluate student ideas against the possibility of creating an end product that would fulfil the task set in the design brief. Echoing Nicholl and McLellan's findings in the UK (Nicholl & McLellan, 2008), the teachers seemed to try to avoid ambiguity and the risk of failure. They were more focused on whether or not ideas were "right" or "wrong" and whether the students would complete their assignment on time than on helping them develop their ideas through iterative processes. The same tendency was also evident during the professional development workshops (P4), when groups of teachers were asked to give presentations in which they reflected on their experiences with maker settings. In one such presentation, group 1 chose to focus on their challenges with students who developed design fixations. Their students had been tasked with coming up with ideas for a product that could create awareness about e-waste. One group of students "could only think about making a hat". For the teachers, this was a "wrong" idea. During the subsequent discussion between researchers and teachers on the presentation, however, it became a shared understanding that a hat could in fact work to create awareness about e-waste, and that the teachers in fact had fixations of their own: they were prone to first intentions, prejudices, and fixations of their own. Accordingly, rather than acting on first intentions, teachers needed to take a more designerly stance towards inquiry into the students' work (see section 4.6).

In this understanding, rather than discarding the students' ideas as irrelevant, the teachers could have explored the foundations and possible next steps of the idea of making a hat to create awareness of e-waste. By participating in and demonstrating the exploration of foundations and possible next steps (with inspiration from Quist) the teachers could have scaffolded and structured the students' design processes – using discussions about doing research, user groups, developing multiple ideas rather than just one, early prototyping, and testing of prototypes. Later in this chapter, I describe in more detail a case in which a teacher develops fixations at an early stage and as a result judges an idea prematurely. First, however, I turn to the epistemological challenges teachers might face in a K–12 maker-studio approach.

5.3.3. Epistemological challenges in a K–12 maker studio

> *And another thing about this process of reflection-in-action is that it not only applies knowledge, but generates knowledge (...) that there are different forms of knowledge and that a teacher is dealing continually with a question of epistemology, that is to say, with knowledge, the nature of knowledge: what counts as knowledge and how one justifies knowledge; and specifically, with a form of knowing (...) distinct from the formal understandings that are practiced in school and valued in school (...) School prizes and gives privilege to formal understandings, categorical understandings. (Schön, 1995, p. 6)*

Throughout the research reported here, in line with discussions in Nicholl and McLellan (2008) and Smith et al. (2016), I have seen teachers focus mainly on whether or not students would meet the set of requirements described in the design brief within the given time frame (see e.g. P1). For such a focus to be productive, teachers would need to be able to judge the endpoint of the design process at any point in that process. Such an assumption in turn rests on what Schön has termed an epistemology of technical rationality. But Schön's work is based on a quite different pragmatist epistemology (Dalsgaard, 2009), as are his descriptions of the design studio as an educational approach (and the descriptions in this dissertation overview of the K–12 maker studio). Through reflection-in-action and reflection-on-action, students in a design-studio approach generate situated knowledge – which either works or does not work towards a desired next step. But, as Schön describes, school privileges formal and categorical forms of knowledge.[3] In the Reflective Educators experiment, I shadowed two teachers, whose grade 8 students were to come up with ideas to minimize e-waste. These two teachers had been part of the DesignThink intervention, and they were among the most experienced teachers with regard to the K–12 maker studio approach. Their students struggled to come up with ideas, but eventually more and more groups suggested developing modular iPhones to allow partial upgrades or biodegradable plastic from algae as a building material for the exterior of smartphones. Both of these ideas came from the teachers, but in a subsequent interview, the teachers were unable to reflect on, where the ideas had come from – they did not display any recognition of their own reflection-in-action. Rather, paraphrasing Schön (Schön, 1992a) it seemed as if they had unconsciously wiped it out, like the error that one makes and quickly forgets on the way to discovering the solution to a puzzle in what Schön terms cognitive historical revisionism.

These two teachers did not display a pragmatist epistemology of design processes as generation of situated knowledge through reflection-in-action and reflection-on-action. On the other hand, if teachers have not developed the ability to understand their own creative design processes in a language of designing, it is difficult to see how these teachers can be expected to help students develop their own ideas further when they are stuck, have developed a design fixation, or if they are on what the teacher

[3] Which is particularly evident in national attainment goals, national testing regiments as well as in international assessments such as the PISA tests administered by the OECD.

assumes is a wrong path.[4] That is, teachers may need a shift in epistemology in order to be able to scaffold students' design processes in K–12 maker studios in a language about designing. Further, teachers may need to appreciate a pragmatist epistemology in order to be able to take a position of both demonstrating in a language of designing and telling in a language about designing, as Schön describes Quist doing. Finally, teachers in a maker-studio approach face a double challenge: being able to reflect-in-action with the materials of the *design situation,* and then also, based on reflection on this action, being able to reflect-in-action with the materials (including the students) of the *teaching situation*. In the following, I will investigate teacher attempts to navigate the positions and epistemologies of a K–12 maker studio.

5.4. Positions in teacher feedback

A problem which has been brought up frequently by teachers in both DesignThink2 and Reflective Educators is how to give feedback to students who have become fixated on a bad idea. In the previous section, I discussed how such cases can be brought about by teachers having fixations of their own. In this section, I examine the positions a teacher can take in giving student feedback in such a case.

5.4.1. Understanding teacher positions

In the following, I analyse and compare two cases of teaching: one of them situated in a design-studio approach (Quist), the other in a K–12 maker-studio approach (Kurt). I will analyse the metaphorical positions taken by the educators as being metaphorically in front of, beside, or behind their students. First, I unfold the meanings I give to these positions in the context of teaching in a K–12 maker studio approach.

In my analysis of the K–12 maker studio, being *in front of* is analogous to what is often referred to as the traditional teacher role: knowing the right answers and telling the student what is right and what is wrong. In this position, the teacher knows the answers and the relevant knowledge before the student. The teacher is, in a metaphorical sense, in front of the student. This position is to be understood as at one extreme of a spectrum on which the teacher tells the student what is wrong and what is right: the student is then expected to accept this knowledge as right and relevant in

[4] I do not suggest that this is an either/or situation. My own experience points to a gradual internalisation of knowledge generation, reflection-in-action, and pragmatist epistemology.

order to be able to reproduce it. Thus, from the perspective of educational philosophy, the position of being in front of the student could be described as resembling that of a *master explicator* (Bingham & Biesta, 2010), resting on a banking model of education (Freire, 2018). This position rests on the assumption that "the problem and its answer are already out there" (Roehl, 2012, p. 111). Accordingly, it hinges on a technical rational epistemology rather, than a pragmatist one.

At the other end of the scale, the teacher is behind the student in regard to knowledge generation when she sets up structures for the students' design processes, provides materials, and perhaps asks authentic, generative questions without already knowing or expecting a specific answer (Dysthe, 1996). In the extreme case, the teacher sees herself as someone who does not possess knowledge of what is right or wrong and does not even know what sort of knowledge is relevant – perhaps even as someone who must be careful not to pollute the pure ideas of the child. The antithesis of the master explicator, the *ignorant schoolmaster* in a position behind the student sets the student down a path to instigate a capacity already possessed (Bingham & Biesta, 2010). This position resembles that of a facilitator in the descriptions of after-school maker settings by Vossoughi & Bevan (2014). A position behind the students can be seen as a radical antithesis to the position of master explicator and the banking model of education.

The spatial metaphor of being in front of, beside, or behind suggests that being *beside* the student is a middle-of-the-road position. Here, however, I use it as a third, extreme position. When a teacher explores solutions together with the student, she has taken a role in which she does not already know the right answers, perhaps does not even know what knowledge is most relevant in the situation. She metaphorically is beside the student as they discover relevant knowledge more or less at the same time. By making judgments and developing ideas in the presence of the student, the teacher at the same time demonstrates her approach to such experimentation and knowledge generation by participating in, perhaps sometimes even taking over the design process in a language of designing. If the teacher starts to tell the student what is right or wrong, she is no longer beside them: she has moved to a position in front of the student. If, however, she co-develops a solution as the student's equal, she is in a position beside the student. Unlike the position in front of the students, this one rests on the assumption that the problem and answer may *not* already be out there. For Quist, this pragmatist epistemology was unproblematic, because knowledge that is relevant to a design process is often very situational, generated through reflection-in-action and reflection-on-action over the whole duration of the design process. Knowledge is sorted into categories of more and less applicable based on situational backtalk as well as on the designer's repertoire. Teaching design students in a design-studio approach inherently entails working with a pragmatist epistemology, and Quist is accustomed to such an epistemology.

5.4.2. Kurt's feedback

In this section, I explore the case of Kurt, a teacher in a K–12 maker studio. Kurt was a science teacher in a Danish K–9 public school, where he was also tasked with special assignments regarding the use of digital technologies. In this capacity, he helped his colleagues with their use of digital technologies, and he met weekly with a network of teachers in similar roles from other schools in the municipality. The case was documented in the context of the DesignThink2 intervention. Here, Kurt was implementing his own tailored version of the maker-studio learning design developed in DesignThink in an elective course named FabLab, and which included students from grades 6-9. Prior to the situation transcribed below, students' development of solutions to the design brief had been scaffolded through processes of understanding this brief and doing field studies; the teacher then introduced them to tasks of conceptualisation and idea-generation with inspiration cards. Groups of students were then tasked with choosing an idea to work with. In the transcript, taken from the fourth two-lesson activity in the project, the students have been asked to evaluate whether or not their idea matches the design brief. The brief asked students to create a product which would get other students moving and exercising more in the one-hour break the school had just introduced into the daily timetable. The teacher has made three explicit constraints in the brief: the product should be social, digital, and different (novel).

On the lower floor of a Danish public school, a room has been dedicated to machines, digital technologies, and crafts materials. This school, like more than ten others in the area, has invested heavily in the FabLab initiative. On the wall are the words "3D printing will be bigger than the internet." Beneath the quote are five 3D printers, but they are quiet now. Positioned around tables are groups of students. They are not quiet. These students are discussing solutions that can motivate fellow students to exercise more during the one-hour midday break. The teacher, Kurt, has asked the groups to review whether their current idea fulfils the demands stated. The students in group 2 all agree that their idea for a mobile game is digital, social, and different, as demanded in the brief:

Time (m:s)	Speaker	Utterances	Gestures etc.
12:52	Sean	Hey, this is fucking social, isn't it?	Sean and David are talking. Mark is fidgeting with something. Looks down at his hands
	David	Is it social? Yes! Is it digital?	
	Sean and David	YES!	
	David	Is it different? Yes!	
	Sean	Well. It is something that exists, but it is a completely different way	
	Mark	It's a new way of doing it	Looks up
	Sean	New images, new [undecipherable] in which a commander is standing, like	Snaps his fingers
	David	And maybe new rules. Maybe new rules	
	Sean	Including that you have to wait one minute before getting a new card	Points (approvingly) at David
	Mark	Yes. Respawn or?	
	Sean	No. It takes too long. 30 seconds. Respawn: 30 seconds	Mark turns towards Matt from another group and tries to throw something at him
	Sean	Mark. Mark. When you die, you should respawn. Then it will be 30 seconds until you get a new card	Sean snaps his fingers. Mark turns towards his group. Everybody is participating now
	Mark	Yes. Then you get the card in the app.	
	David	But if you are dead, you don't have any cards	
	Sean	But then you get a new card. And the person, who decides, is the one you have chosen, and who decides everything	
	Matt	GAME MASTER	Matt from another group enters the discussion (loudly)
	Sean	YES, a game master	
	Mark	Then there will be … perhaps 30 cards for each team, and ten persons on each team	
14:16	Sean	And he distributes the cards to like [undecipherable]	Kurt approaches

The transcription above shows the strong motivation students get from working on their own projects – a student snaps his fingers in excitement, their idea really is that good. The whole group engages in taking the idea further. Mark, who was fidgeting, looking down, and talking to Matt from another group, and who (according to Sean) finds these lessons boring (see below) is drawn to participate by the excitement; Matt from the other group joins the discussion of how the respawning should work, how long you should be dead before respawning, and how the game master should be in charge. Kurt has by now worked his way towards this group.

Time (m:s)	Speaker	Utterances	Gestures etc.
14:26	Kurt	Have you chosen?	Standing at the table leaning in above students' heads
	Sean	What? Yes, we have	
	Kurt	Good. Then you have to compare it to the design brief. Does it solve the problem? Is it social, digital and different? Does it fulfil the demands? If it	

		doesn't, you have to push it in a direction, which will make it do	
	Sean	So far, we know, that it fulfils a lot of this	
	Kurt	You have chosen to do something with an app?	
	Sean	It's digital technology	
14:48	Kurt	Yes	Sighs – the whole upper body participating in the exhale
	Sean	It's social, and…	
	Kurt	For now, it's fine. I might shoot it down later, because it isn't realistic for us to create an app, and I would like to end up with something we put into practice. I would like to end up with something which will be something in reality. But we will look into it [later]	

Kurt leaves the group with this message. Sean and David seem rather disillusioned. They protest to one another that their idea was fine, while Mark talks to Matt from the other group. Little over a minute has passed. when the group starts talking about being bored.

Time	Speaker	Utterances	Gestures etc.
16:08	Sean	You actually say, that time passes quicker, if you are bored.	
	Matt	No, everyone says, it passes faster, when you are having fun. Fuck, if it was like that.	Laughs
	Mark	Yes: That time passes quicker, when you are bored and slower, when you are having fun, then it would be fucking great.	
16:24	Sean	Mark thinks it is boring: These lessons! (Mark protests). I want to tell it to Matt. Matt: He is bored in these lessons.	Mark and Matt start wrestling. The group's work stops completely

The demotivation comes to a head when one member of the group starts to brawl with a member from are a different group. The case described here very explicitly shows features of many such feedbacks given by teachers I observed: Kurt, like other teachers in the project, evaluates the students' ideas as if he is expected to know from the early stages whether they are right or wrong. He does not present a way forward, and the members of the group are clearly demotivated.

5.4.3. Kurt's fixations and use of materials

In the following, I will explore Kurt's example. First, Kurt tells the group he will probably shoot down their idea later in the process because it is unrealistic (in his view). Kurt focuses on how the students can realistically reach an end product that correctly corresponds to the specifications of the task. Unlike Quist, Kurt does not demonstrate a process of reflective conversation with the situation by engaging with the students' work in a language of designing, and he does not help the students take their idea further by pointing to next steps in a language about designing. Further, his feedback has no interaction with any analogue or digital materials and no sketching – no externalizations for communicating ideas. The feedback is a simple right/wrong situation, and these students are apparently wrong. In sum, Kurt displays a stance of technical rationality, has a fixation with regard to the students' idea, and does not use a repertoire of design processes or design materials to try to overcome this fixation.

5.4.4. Analysis of Kurt's positioning

As he judges the students' idea, Kurt positions himself in front of them (telling). But in choosing to let the students carry on working on their own, at the same time he seemingly jumps to a position behind the students. He does not work with them to develop their idea towards a potential end product, so he does not take up a position beside the students. Had Kurt positioned himself beside the students, one could counterfactually imagine that he had identified a design principle (a discipline, in Quist's words) in the students' idea and that he had shown them how he would develop the idea further while maintaining this principle. If we imagine Kurt as Quist, we can picture him demonstrating, in a language of design, the competences he would like his students to acquire, while at the same time telling them, in a language about design, how and why his demonstration was taking the course it took – he would have positioned himself both beside the students and in front of them. In fact what happened was that Kurt had left it to the students to evaluate and choose between ideas, and when he asked them about their idea, he was still positioned behind them. Then, from a position in front of them, he told them their idea was wrong. When he found himself in front of the students, shooting down the idea, he seemed to jump back to a position behind them – a position of letting their idea be. In the following, I describe these movements between positions in more detail.

5.5. Moving between roles

I have described the positions a teacher can take, but I have not discussed movement between these positions. In the following, I compare Kurt and Quist as they move between such positions. When Kurt approaches the students, they have already been working with problem framing, field studies and idea-generation in a structured design process. Kurt has facilitated this process, and has for the most part refrained from interfering in the groups' development of ideas. On his way to this group, Kurt engages with other groups, and his explicit intention is to make sure that students in the group understand the task of self-evaluating their ideas. In my interpretation, therefore, the teacher's aim has been to sustain the groups' attention to the constraints of the design brief. I conclude that by the time Kurt engages with the group, he has positioned himself behind them in regard to their idea for a solution. He then breaks up the conversation about constraints by interjecting, "You have chosen to do something with an app?" He then assumes a position in front of the students, judging between right and wrong. He says: "For now, it's fine. I might shoot it down later. But we will look into that." And then he leaves the group, thus leaving it up to them to figure out how to move on. Kurt has judged the idea as "fine", but only "for now", and he has threatened to "shoot it down" later. In the video clip, Kurt's body speaks its own language: his whole-body exhale indicates disappointment or tiredness. My conclusion is that Kurt has switched from a position behind the students to one in front of them – to evaluating the product on a right/wrong basis. Then, leaving it up to the group to figure out the way forward, he switches back to a position behind the students. Importantly, these switches seem to occur unconsciously and without any intermediate positions. It is as if Kurt has jumped between positions as an electron jumps between energy levels in an atom (in the Bohr model of the atom): there seem to be no possible positions in between.

In Schön's example of Petra and Quist, one can find examples where Quist is only telling, and others where he is demonstrating without telling. As Schön (1987) himself did, therefore, one can separate the two roles of instructor (telling) and master (demonstrating). These roles in turn translate into extremes of positioning in front of and beside the student. At other points in Schön's paradigmatic case, Quist is telling and demonstrating at the same time, so it is not clear which position he is taking – he seems to be in more positions at once. Staying with metaphors from quantum mechanics, I have chosen to talk about such teaching as being in a superposition of roles. Further, while Quist seemed able to move fluently and flexibly between superpositions, Kurt switched between extreme positions – jumping like an electron between orbits.

5.6. Summary

In this chapter, I have pointed to a range of tensions that have arisen as K–12 maker-studio approaches have been introduced in Danish public schools. These tensions hinge upon differences in context between a design-studio approach and a K–12 maker-studio approach, and they range from students' motivations to physical space, from timetables to risk-aversion on the part of schools and the privileging of formal and categorical knowledge. The chapter has focused on the difference between K–12 teachers and educators in design-studio approaches. That is, I have investigated teachers as a factor in the sustainable development of students' design literacy through maker settings in K–12 education.

Here, I have explored the challenges faced by teachers whose students get stuck in the design process, develop design fixations, or go down what the teachers perceive as wrong paths. The chapter thus suggests a need for professional development for teachers if they are to teach with the aim of design literacy. Two of the papers included in this dissertation, "Educating the reflective educator" (P4), and "Video design games" (P3), on which this chapter is based, point to the first signs of teachers beginning to develop competences for teaching in a K–12 maker-studio approach. In this chapter, I have attempted to understand aspects of such competences in greater depth.

Echoing Schön, I conclude that the teachers in these studies were challenged because they lacked a language of designing as well as a language about designing. Just as the students in the studies displayed design fixations with regard to design solutions, the teachers displayed fixations with regard to the students' design solutions. I argue here that the teachers' lack of language of designing impeded their engagement with developing the students' ideas further, while their lack of language about design hindered their ability to scaffold students' design processes so that students could move beyond their design fixations. Likewise, I argue that the lack of a language of designing impeded the teachers' ability to use a greater range of design materials in their interactions with students' ideas, and that the lack of language about designing impeded their ability to communicate about the use of design materials to the students.

I further argue that these teachers' lack of language of and about design impeded their ability to move fluently and flexibly between metaphorical positions in front of, beside, and behind the students. In the chapter, I have unfolded these positions in a K–12 maker-studio approach through theoretical considerations as well as through comparing a case of teacher feedback with Schön's paradigmatic example of Petra and Quist . I argue that teachers' competences to move fluently and flexibly between positions and superpositions while communicating in languages of and about design may be hindered by a lack of appreciation of a pragmatist epistemology.

If making in education is to be sustained beyond the honeymoon phase, it will have to be implemented by real teachers in real-world school settings. Knowledge of teacher practices in K–12 maker studios is therefore of the utmost importance. But teachers in are not educating would-be professional designers in the design studio; so, there is still a need to investigate to what extent they need to internalise a pragmatist epistemology of reflection-in-action, how they are to acquire repertoires of design processes and design materials in order to overcome their own and their students' fixations, and how they are to metaphorically position themselves with regard to the students.

6. Conclusion

This dissertation is a summary of three years of research into maker settings in formal education. It is based on six included publications (P1-P5, R2) as well as on previously unpublished research (in chapter five). In the dissertation, I provide an overview of my research, which has explored the possibilities of developing design literacy in the context of maker settings in formal education, guided by the following question:

> *How can activities with maker technologies in formal educational settings contribute to the development of design literacy among adolescents?*

In chapters four and five, I described the contributions, which form my answer to this question, in four perspectives: (1) a conceptual perspective, exploring aspects of design literacy; (2) a pedagogical perspective, understanding teaching in the formal educational settings of K–12 maker studios; (3) an assessment perspective, assessing the development of design literacy; and (4) an exemplar perspective, investigating activities and teaching design literacy in the K–12 maker studio. I have developed these contributions through six experiments in three research programs. In these programs, I explore design literacy, sustainability and implementation of K–12 maker studios, and teachers' roles and competences respectively. The research experiments, which have all been carried out in the context of the Danish FabLab@School.dk project and in collaboration with other members of the Child–Computer Interaction Group at Aarhus University, include surveys and assessments (R2, P2, P5), as well as observations and interventions (P1, P3, P4). Throughout the dissertation, I refer to K-12 as the context of my research. However, students in the research described in this dissertation were all aged 11-15 years, and therefore, even though I suspect that most of the findings will be relevant to K-12 students in general, the results are only directly applicable to 11-15-year-olds. As described in chapter 2, my contributions can be seen as a response to three trajectories in the field of making in education. The overarching claim is that my research has contributed to these trajectories: a turn towards design, towards sustainability and scaling, and to reinstating the teacher as a quintessential subject of research in maker settings. In what follows, I will discuss how the outcomes contribute more specifically to research into making in education, what the limitations of these outcomes are, and the future research, which these outcomes point to.

6.1. Conceptual perspective: turn towards design

Based on the work of Seymour Papert, research into digital construction kits (Papert, 1980) had explored different ways for students to engage with coding and physical computing (Buechley et al., 2008; Katterfeldt et al., 2015; Resnick et al., 2009; Sipitakiat et al., 2004). Early work on maker settings in education built upon this work by proposing maker technologies as construction kits (Blikstein, 2013a; Blikstein & Krannich, 2013; J. Walter-Herrmann & Buching, 2013), as well as drawing on Papert's constructionism (Harel & Papert, 1991). Based on this research, maker technologies were introduced into informal educational settings to mimic the creativity, engagement, and culture of the maker movement (Halverson & Sheridan, 2014; J. Walter-Herrmann & Buching, 2013). Studies in the field of making in education which built on the work of Seymour Papert focused overwhelmingly on teaching students about scientific (Blikstein, 2013b; Blikstein & Krannich, 2013; Honey & Kanter, 2013) and technological (Buechley et al., 2008; Resnick & Rosenbaum, 2013; Vasudevan et al., 2015) concepts – sometimes within engineering-like contexts (Blikstein, 2013a; Dittert & Krannich, 2013; Katterfeldt et al., 2015). The literature, in other words, has mostly focused on students' learning of concepts relating to STEM education (Papavlasopoulou et al., 2017).

Within the field of making in education, STEM learning has also been seen in a perspective of empowerment (Blikstein, 2013a; Martinez & Stager, 2013), digital citizenship (Schelhowe, 2013), and emancipation (Blikstein, 2008). Building on such notions of democratic education, the field of making in education has seen a turn towards design and design thinking as a way of engaging with real-world or wicked problems in formal education (Iversen, Smith, Blikstein, Katterfeldt, & Read, 2015).

The research presented in this dissertation overview, building explicitly on work in design research (N. Cross, 2011; Nelson & Stolterman, 2012; Schön, 1983, 1985, 1987) and interaction-design research (Löwgren & Stolterman, 2004), has contributed to this turn towards design by suggesting that design-process knowledge (P1, R2), design judgment (P1), and stance towards inquiry (P2, P5) are both means and educational goals in design processes in maker settings in K–12 education. These results suggest that specifically working with making in education through design processes can further students' development towards complex problem-solving and understanding technological issues in society. The research presented in this dissertation also points to design judgment as an important aspect of working with design in K–12 maker settings. With the aid of heavy scaffolding, students in intervention studies were able to display early development of aspects of design judgment. Finally, the research presented here suggests that while students did display signs of a more designerly stance towards inquiry when they were scaffolded by researchers in intervention studies, students in the project as a whole did not develop such a stance (to a degree which could be assessed with the quantitative DeL tool) – which in turn suggests that developing a designerly stance towards inquiry in such settings is a challenging goal. Together, the three aspects of design-process knowledge, design judgment, and stance towards inquiry contribute to knowledge of the development of design literacy through maker settings in K–12 education. In this way my studies have contributed to a turn towards design in the field of making in education by pointing to design literacy as viable end goal of making in education, and to maker settings as a viable context for teaching design literacy.

6.1.1. Limitations and future work

The research presented in this dissertation overview has singled out three aspects of design literacy. Given the complex nature of designing and of design expertise (Nelson & Stolterman, 2012), design literacy is very likely to benefit from research into more aspects than just these three. It has, however, been outside the scope of the work presented here to investigate all aspects of design literacy as well as the interdependency of such aspects. The three aspects chosen here emerged from observation of the challenges facing students' complex problem-solving in maker settings in education. Focusing on these three aspects has allowed for triangulation between qualitative and quantitative investigations in the case of design processes, and stance towards inquiry, and for in-depth, qualitative research in the case of design judgment.

Owing to the qualitative nature of the observational and interventional studies in design-process knowledge, design judgment, and stance towards inquiry, these studies do not in themselves provide evidence of the potential for generalisation of the findings. However, since these aspects are all developed from the literature on professional design competence, I find it likely that the findings will apply to a larger number of students and classrooms. Further (and consistent with interventionist studies in schools in general), the investigations into the potential for design literacy in maker settings in K–12 education were carried out in settings which were to some degree artificial to the students who participated: while the investigations in DesignThink (P1) were carried out in a real-world school in the presence of real-world teachers, teaching was planned and carried out by the researchers, and therefore this intervention cannot provide answers with regard to the sustainability of such approaches in-the-wild (this was the aim of DesignThink2).

The interventions described in this dissertation were conducted over the course of seven to fifteen weeks. The researched aspects of design literacy were therefore all in the very early stages of development. For future work, it will be important to undertake longitudinal studies of the qualitative development of aspects of students' design literacy to investigate the sustainability and possible depth of understanding among students.

6.2. Pedagogical perspective: towards a focus on teachers

In the research literature on making in education, very little has been written based on studies of real-world teachers in maker settings. The field has seen attempts to create frameworks or guidelines for teachers implementing maker settings in education (T. Bekker et al., 2015; Honey & Kanter, 2013; Martinez & Stager, 2013; Peppler et al., 2016). These works are, however, not based on empirical studies of teachers introducing making in formal educational contexts. Eriksson et al. (2018) discuss teachers' calls for professional development, as do Wardrip and Brahms (2016), but these studies do not specify the role of the teacher or the teacher competences involved beyond technological proficiency. Even so, consistent with the literature on educational change discussed in chapter five, I found the teacher to be an essential factor in the sustainable introduction of maker settings to formal education. Overall, therefore, there was a research deficit with regard to the role of the teacher in making in education. In response to this gap in the research, I have contributed to reinstating the teacher in maker settings – that is, this dissertation has emphasised the importance of research from a pedagogical perspective on making in education.

The research presented in this dissertation overview has introduced a design-studio (Schön, 1985) approach to the field of making in education. This featured the scaffolding of students' design processes by means of a design-process model and a highly structured approach to design processes as a possible route to developing their design literacy (P1, R2). As discussed in P3, P4, and chapter five of this dissertation overview, I conclude that the teachers studied were challenged by their lack of language both *of* and *about* designing. I argued that this lack impeded their ability to use a range of design materials in their interactions with the students' ideas, as well as making it hard for them to communicate to the students about the use of design materials. I further argued that the teachers' lack of a language of and about designing impeded their ability to overcome their own fixations with regard to students' design solutions, whether this might take the form of engaging in further development of the students' ideas or scaffolding the students' design processes in order to move beyond their initial ideas. I also argued that the teachers' lack of language of and about design impeded their ability to move fluently and flexibly between metaphorical positions in front of, beside, and behind the students. I unfolded these metaphorical positions in a K–12 maker-studio approach in the chapter, both on a theoretical level and through a comparison of a critical case (Flyvbjerg, 2006) of teacher feedback with Schön's paradigmatic case of Petra and Quist (Schön, 1983, 1985, 1987). Finally, I argued that teacher competences to move fluently and flexibly between superpositions communicating in languages of and about design might be hindered by teachers' epistemology.

If making in education is to be sustained beyond the honeymoon phase, it has to be implemented by real teachers in real-world school settings. For this reason, knowledge of teacher practices in K–12 maker studios is important. From a pedagogical perspective, therefore, I have contributed to the field of making in education by offering a preliminary description of the opportunities, challenges, and professional development available to teachers in a K–12 maker studio. More specifically, I have explored the challenges faced by teachers whose students got stuck in the design process, developed design fixations, or went down what the teachers perceived to be the wrong paths. I argue that these teachers are challenged by their epistemology, as well as by their insufficient repertoire of design processes, design materials, and modes of design teaching from a variety of positions.

6.2.1. Limitations and future work

In the observations of teachers in schools presented in this dissertation overview, I have shadowed five teachers in three projects as well as carried out one-time observations of other teachers. The professional development course offered one qualitative half-year study of the development of twenty teachers within the context of the Danish FabLab@School.dk project in Eastern Jutland, Denmark, as well as surveys of this group and a subsequent group of 24 teachers. The challenges explored in these studies were observed across many instances. I do not have statistically valid data which can point to the degree of generalisability of these findings, but I will argue that I studied most-likely critical cases (Flyvbjerg, 2006). The teachers were motivated to take on design-studio approaches to maker settings in education, they were part of a project, which focused on such approaches, and they received support from researchers. Therefore, these teachers were the most-likely teachers to succeed in implementing a design-studio approach to maker settings in education. Accordingly, I find it very likely that the challenges experienced by these teachers is to some degree generalizable to other teachers without training in design.

Since a repertoire of design processes, design materials, and modes of teaching takes time to develop, a more longitudinal study could provide very valuable insights. Teachers are not professional designers, and so there is still a need to find out to what extent they need to internalise a pragmatist epistemology, and how they are to acquire repertoires of design materials, design processes, and design teaching from a variety of positions in order to develop abilities to communicate to the students in both a language of design and a language about design.

6.3. Assessment perspective: towards sustainability and scaling

My research has focused on the potential offered by maker settings for developing design literacy in formal educational settings and for all students. For this reason, the potential for sustainability and scaling of implementing maker settings in education has been an important part of the research. There have been attempts to quantitatively assess learning goals in making in education (Barron & Martin, 2016; Martinez & Stager, 2013; Petrich et al., 2013), both in individual initiatives and in ranges of individual initiatives (Blikstein et al., 2017), but very few of these have been on a large scale. Because the turn towards design in the field of making in education is a recent development, the assessment of design literacy has not been attempted. While there have been a few noteworthy studies of assessment from a design literacy perspective (Goldman et al., 2016; Stables & Kimbell, 2007), these have focused on small-scale assessments.

In my research from an assessment perspective, I have contributed to developing a survey instrument to gauge students' stances towards inquiry as an aspect of design literacy (P2). This work has contributed to the conceptual understanding of stance towards inquiry, but in assessment perspective, it has raised concerns with regard to students' attainment of design literacy (P5). Perhaps students need long-term exposure to design in order to develop such a stance as described in P5. Further, through pre- and post-project surveys, I have contributed to the knowledge of implementation of making in formal education. As reported in R2, students' self-perceived gains from implementations of making varied greatly between schools. Student responses suggested that in schools where they worked with their own ideas, with a diverse range of digital technologies and with their work scaffolded and structured to a high degree around a design-process model, 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, consistent with the intervention studies in DesignThink, the survey data suggested that there is potential for teaching with the aim of design literacy in maker settings in formal education. Also consistent with the qualitative parts of my research, the survey data suggested that scaffolding students' work around a design process model can assist their development of design literacy.

6.3.1. Limitations and future work

Through the DeL tool, I have contributed to the assessment of one particular aspect of design literacy: stance towards inquiry. There are other aspects of design literacy, which I have not yet engaged with, and if design literacy is to become an integral part of school education, it is important that tools are developed to assess its additional aspects, including design-process knowledge and design judgment. In the intervention studies students displayed signs of a more designerly stance towards inquiry, but such a development was not measurable in the endline survey of students in the FabLab@School.dk project in general. As described in chapter 4 and P5, this result might have been due to challenges in the development of stance towards inquiry from either a student or teacher perspective. Further, as argued in P5, it may be that this aspect is only developed enough to assess as proposed when a student moves from routine to adaptive expertise. However, the lack of students, who were assessed to have a more designerly stance towards inquiry, might also be a result of the assessment tool itself: the DeL tool used in the survey may not be sufficiently fine-grained to assess early development towards a more designerly stance towards inquiry. Further work on this tool could include exploratory-factor (Osborne, Costello, & Kellow, 2008) or Rasch (Boone, Staver, & Yale, 2013) analysis of student answers to the initial question to develop a more fine-grained assessment of students' responses, or further development of other types of questions.

The remaining quantitative assessments of student design literacy reported in my work are self-perceived measures, and these are naturally limited by the students' ability and desire for correct self-assessment. If students try to provide the optimal self-assessment, these might more accurately be seen as students' self-efficacy (Bandura, 1982) with regard to design literacy and the use of maker technologies. That is, the survey items assess students' self-perceptions rather than their actual performance. On the other hand, students' might not have been motivated to answer accurately. As described in Krosnick, Narayan, & Smith (1996), if respondents are not motivated to *optimize* their response (provide the highest possible degree of accuracy), they might instead *satisfice* – provide answers that are deemed acceptable by the respondents, but which appear to demand least amount of effort.

The between-school comparisons are to be seen as descriptive and suggestive. The schools were grouped on the basis of triangulating student interviews, the teachers' work in relation to the professional development course (see P4) for some schools, observational studies in some schools, and students' responses in the endline survey. However, the data for between-school comparisons is not in a form that can be statistically validated, and therefore I have treated the generalisation of the results as suggestive. I would of course find it very valuable in the future to be able to create statistically significant data on such a between-school comparison of implementation strategies, but the scale required to provide answers that could withstand a statistical test treating school as a random effect (Field et al., 2012) would be overwhelming. I would therefore prefer a few longitudinal qualitative studies as a way of gaining deeper insights into important aspects of the implementation of maker settings in formal education with a goal of design literacy.

6.4. Exemplar perspective

Very few larger-scale research projects have been carried out in the field of making in education. Accordingly, there was very little research on larger-scale assessment of implementing maker settings in education when my studies began. As indicated in section 6.3, the field has seen efforts to quantitatively assess learning goals both in individual initiatives and in ranges of individual initiatives. However, the survey reported in R2 (as well as the survey to which it is a follow-up but which is not included in this dissertation) provides exemplars to the field with regard to how to assess the implementation of maker settings in education in general, and how to assess the development of design literacy more specifically. The turn towards design within the field is a very recent development: there had been no previous attempt to assess design literacy in the field. I would therefore argue that the survey items reported on in R2, P2, and P5 concerning the assessment of student design literacy and self-perceived design literacy provide much-needed exemplars of assessment that can support the turn towards design in the field of making education. While some attempts have been made to assess design literacy in adjacent fields, the number of exemplars is low and the research has mostly focused on small-scale assessments. The survey item on stance towards inquiry reported in R2, P2, and P5 offers an exemplar of larger-scale assessment instruments to a broader field of research into the introduction of design processes in formal schooling and thus into design literacy.

In chapter two, I listed the works that are most directly related to my research. I concluded that there has been a turn towards design in the field of making in education, but that because this turn is a very recent development, there are very few exemplars of how to use maker settings in education to (1) developing students' design literacy, and (2) researching this development. The DesignThink exemplar described in P1 offered the possibility of investigating students' development of design literacy in the context of formal schooling – albeit with the presence and participation of researchers. In this intervention, which was part of my research program one (see chapter three), the mechanisms of working with real-world problems in a highly structured approach were investigated. In this sense, the exemplar embodies both the investigation into the concept of design literacy and the K–12 maker studio as a research setting.

In research program two, the intervention from program one was taught by teachers without the participation of researchers. This DesignThink2 intervention was thus an exemplar of how to research the development of design literacy in maker settings in a more scalable and sustainable setting (in the wild). Research program three involved the development and implementation of a professional development course in how to implement activities with maker technologies in formal educational settings with the aim of design literacy. This intervention is both an exemplar of such a professional development course, and of research into development of teacher competences. In sum, the interventions carried out across three research programs have therefore contributed exemplars to the field of making in education in three research perspectives: (1) how to research design literacy and students' development of design literacy through maker settings; (2) how to research teachers' implementation of maker settings in education; and (3) how to research teachers' development of competences to implement a maker-studio approach in K–12. Likewise, the exemplars contribute to knowledge of (1) how to develop students' design literacy, (2) how to support teachers' implementation, and (3) how to design professional development for teachers who are to implement a maker-studio approach in K–12.

6.4.1. Limitations and future work

All exemplars were tailored to the contexts in which they were implemented, and therefore the activities are not directly transferable to other contexts. However, it is likely that the mechanisms behind the exemplars will transfer well to other schools and school systems. For example, while the wicked question posed to assess stance towards inquiry might have to be changed in a different context, the mechanisms of the question would not. Likewise, the interventions were carried out across a range of Danish public schools. Exemplars of the interventions included here such as DesignThink or DesignThink2 might not be directly implementable elsewhere. In the future, comparative studies between such exemplars in different formal educational settings would be of great value to educators and policy makers. Further, from a research perspective, implementing a maker studio approach in different school systems could serve to investigate sustainability while at the same time exposing mechanisms within such an approach as well as differences in the educational settings, in which is applied.

7. References

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Included Publications

P1: Design thinking for digital fabrication in education

Smith, R. C., Iversen, O. S., & Hjorth, M. (2015). *International Journal of Child–Computer Interaction, 5*, pp. 20–28.

NOT INCLUDED IN THIS VERSION

P2: Towards a formal assessment of design literacy: analyzing K–12 students' stance towards inquiry

Christensen, K. S., Hjorth, M., Iversen, O. S., & Blikstein, P. (2016). *Design Studies*, 46, pp. 125–151.

NOT INCLUDED IN THIS VERSION

P3: Video design games: Training educators in teaching design

Smith, R. C., Iversen, O. S., Christensen, K. S., & Hjorth, M. (2016). *FabLearn Europe*.

NOT INCLUDED IN THIS VERSION

P4: Educating the reflective educator: Design processes and digital fabrication for the classroom

Hjorth, M., Smith, R. C., Loi, D., Iversen, O. S., & Christensen, K. S. (2016). *FabLearn '16 – Proceedings of the sixth Annual Conference on Creativity and Fabrication in Education*, ACM, New York.

NOT INCLUDED IN THIS VERSION

P5: Understanding design literacy in middle-school education: Assessing students' stances towards inquiry

Christensen, K. S., Hjorth, M., and Iversen, O. S., Smith, & R. C. (2018). *International Journal of Technology and Design Education.*

NOT INCLUDED IN THIS VERSION

R2: Digital technology and design processes II: Follow-up report on FabLab@School survey among Danish youth

Hjorth, M., Christensen, K. S., Iversen, O. S., & Smith, R. C. (2017), Aarhus University.

NOT INCLUDED IN THIS VERSION