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Design thinking for digital fabrication in education

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ABSTRACT

In this paper, we argue that digital fabrication in education may benefit from design thinking, to foster a more profound understanding of digital fabrication processes among students. Two related studies of digital fabrication in education are presented in the paper. In an observational study we found that students (eleven to fifteen) lacked an understanding of the complexity of the digital fabrication process impeding on the potentials of digital fabrication in education. In a second explorative research through design study, we investigated how a focus on design thinking affected the students' performance in digital fabrication processes. Our findings indicate that design thinking can provide students with a general understanding of the creative and complex process through which artifacts and futures emerge in processes of digital fabrication.

1. Digital fabrication in education

Digital fabrication in education is closely tied to the rise of the maker movement and the evolution of digital fabrication technologies, which enable consumers to tinker and create with digital technologies. Using the basic principles "to empower, to educate and to create almost everything" [1], the FabLab movement has introduced digital fabrication in education as a democratizing vehicle for the development of new artifacts towards desirable futures [2]. This democratization of production through digital fabrication has been further developed in educational settings, for example, by Eisenberg [3], Eisenberg and Buechley [4] and Blikstein [5,6]. Today, many initiatives emphasizing the importance of digital fabrication in education co-exist with various objectives for putting fabrication technologies into the hands of children. As summarized by Schelhowe [7], digital fabrication in education provides children with a sustained understanding of digital technology, and supports their ability to create with digital material, while affording access to a general understanding of the postmodern society mediated by digital technology. In this respect, digital fabrication processes do not only lead to STEM competences, as often emphasized, but to a more profound understanding of self and society [8]. In line with this approach, we define digital fabrication in education, not merely as learning-oriented activities of design and construction with technologies such as 3D printers and laser cutters. Rather we emphasize a designerly approach to digital fabrication as *a hybrid learning environment that combines digital fabrication, design thinking and collaborative ideation and innovation to solve (complex) societal challenges*. This definition stresses the entire creative process from early ideation, sketching, and mock-up creation to the initial presentation of a prototype, in which digital fabrication becomes a vehicle and resource for addressing personal or complex societal issues. The focus on design thinking and process that we present in this paper emerged in response to our observational studies of digital fabrication in schools, and the prevailing focus on education for Science, Technology, Engineering, and Mathematics (STEM) in current Child Computer Interaction (CCI) literature. As Blikstein [6] argues, the potential of digital fabrication in education is not merely to bring fabrication technologies into education, but to create engaging learning environments that recognize children's multiple epistemological resources. Such a framework rests on Papert's constructionism [9,1], which outlines the idea of a technology-enabled, project-based learning environment. Following Papert, Kafai [10], and Kafai and Resnick [11], we analyze the relationship between designing and learning, and discuss ways that design activities can provide personally and collaboratively meaningful contexts for learning, incorporating children's imagination in processes of abstract thinking and concrete doing, to produce new digital artifacts. Thus by engaging in digital fabrication processes in education, children may become capable of producing and envisioning their personal approach to current challenges in society [5,12].

Findings from our research into digital fabrication in education in upper primary and lower secondary schools in Denmark reveal that this process of combining abstract thinking and concrete doing is far from something that automatically occurs when introducing

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digital fabrication technology. Students in our observational studies (aged eleven to fifteen) did not fully understand the creative and reflective process underlying digital fabrication, and this affected their ability to navigate and perform given tasks, as well as their abilities to envision personal or collective solutions to set design challenges. In the paper, we outline challenges that prevent the potential of digital fabrication in education from unfolding, owing to a lack of understanding of the digital fabrication processes among students.

The process of creating, ideating, and reflecting on the process in digital fabrication environments has a close resemblance to design thinking (e.g. Nelson and Stolterman [13]; Cross [14], Cross [15]). In processes of digital fabrication and design thinking, the student practitioner engages with ill-defined or "wicked" problems [16], and explorations of trial and error, to make their own choices based on insights or past experience. These are collaborative design processes in which the teacher acts as coach and facilitator. Whereas design thinking offers a well-established vocabulary for addressing the learning processes designers undergo when creating a new digital artifact, design thinking is not widely applied to support students' understanding of the "wicked" and exploratory process of design in digital fabrication in education. Based on findings from our observational studies, we initiated a research through design experiment in which design thinking was introduced as a framework for establishing and supporting digital fabrication for students (thirteen to fourteen). Here, we define "design thinking" as the ability to thoughtfully engage in design processes of digital fabrication, knowing how to act and reflect when confronted with ill-defined and complex societal problems. In the paper, we account for the two studies and discuss how digital fabrication in education may benefit from integrating design thinking into a holistic approach to the creative and reflective process.

Design theory and design thinking are not novel to CCI research. Druin [17] and Read et al. [18], Read et al. [19] draw on design thinking when suggesting methods and techniques for engaging children actively in the design of digital technology. Whereas design theory has been used to address how children can be invited into the process as users, testers, informants or design partners [17], our aim is to add to current research by proposing how design theory can be introduced to children, by focusing on their practices and abilities for designing with digital technology. In a parallel, but unlinked, movement of participatory design, researchers place great emphasis on children as designers (e.g. Read et al. [18]; Druin et al. [20]; Yip et al. [21]; Iversen and Smith [22]; Smith et al. [23]). Here, design researchers team up with children to support the design of future technology. As noted by Read and Horton [24] however, researchers have paid remarkably little attention to the mutual benefit of digital fabrication in education and participatory design with children. These parallel approaches, we argue, can be meaningfully integrated through a perspective on design thinking in the context of children's work with digital fabrication. From our own approach to participatory design, we suggest that design thinking offers digital fabrication in education an understanding of the fabrication process, by providing students with a vocabulary, a sense of quality as well as reflective and retrospective thinking about their own process and product. In the following sections we account for our observational studies and our research experiment, emphasizing process-related findings. First, however, we introduce our research method in relation to existing methods in CCI and HCI research.

2. Research method

The research presented in this paper derives from an ongoing study conducted by the Child Computer Interaction Group at Aarhus University. The research combines social anthropology, interaction design and child development psychology in an interdisciplinary study on digital fabrication in education. We investigate the potential of digital fabrication in upper primary and lower secondary education in Denmark. Particularly, we have studied the students' creative processes when engaged in digital fabrication, through ethnographic studies and research through design experiments with students and teachers in five different digital fabrication courses, in grades five to nine. The studies were conducted in 2014 in conjunction with a newly introduced focus on innovation, entrepreneurship and digital technology across subjects in the Danish school system, specifically visible in subjects as *Crafts and Design*,[1] where students are to work with design and crafting through processes of ideation, fabrication, production and product evaluation, also with the integration of new technologies. The schools however, have almost no experience in developing and facilitating learning processes in relation to digital fabrication and design.

We selected the two schools (7–800 students) for our study from urban areas of Aarhus (pop. 300.000) and Vejle (pop. 55.000), as they had recently established a digital fabrication laboratory (FabLab) to accommodate the IT and design aspects of the new legislation. The schools attract students from relatively similar, middle- to upper-middle-class (in a Danish context) socio-economic backgrounds, comparable within the framework of our research. In both schools, teachers and principals were committed to investigating the possibilities in digital fabrication in an educational context and had invested in 3D printers, LittleBits, Arduino's, MakeyMakey, Sphero, and various analogue design materials such as cardboard, wood, paint, felt, and glue. Teachers and students themselves were unfamiliar with digital fabrication technologies, beyond singular experiments with Scratch or MakeyMakey.

2.1. Observational studies

Our observational studies (participant observation) followed introductory course activities relating to digital fabrication and design in the two schools during a two month period between August and October 2014. In total 45 h of course activity was documented, transcribed and analyzed. The two anthropologists conducting the studies documented the activities using field notes and video recordings to observe the class activities and follow groups of two to four students through their creative processes. When appropriate, the researchers probed into the process by asking questions about the students' choices and actions, following a visual anthropological approach [25,26]. In the paper, we present a general analysis of our insights from the observational studies in the two schools.

2.2. Research through design experiment

Based on insights from the observational studies, the research team developed a research through design experiment integrating digital fabrication and design thinking into a six-week course. In our description of the process we focus on the particular experiences of four students who worked in three different groups. These students function as exemplary cases [27], as they characterize the varied engagement and challenges of students who *actively* sought to be a part of the process. The course introduced a focus on design process, integrating digital fabrication and design thinking to address societal challenges. The aim of

[1] http://eng.uvm.dk/~/media/UVM/Filer/English/PDF/131007%20folkeskolereformaftale_ENG_RED.pdf.