From Computational Thinking to Computational Empowerment: A 21st Century PD Agenda

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ABSTRACT

We propose computational empowerment as an approach and a Participatory Design response to challenges related to digitalization of society and the emerging need for digital literacy in K12 education. Our approach extends the current focus on computational thinking to include contextual, human-centred and societal challenges and impacts involved in students' creative and critical engagement with digital technology. Our research is based on the FabLab@School project, in which a PD approach to computational empowerment provided opportunities as well as further challenges for the complex agenda of digital technology in education. We argue that PD has the potential to drive a computational empowerment agenda in education by connecting political PD with contemporary visions for addressing a future digitalized labour market and society.

CCS CONCEPTS

• **Human-centered computing → Participatory design**;

KEYWORDS

Computational empowerment, computational thinking, education

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1 INTRODUCTION

Digitization is rapidly changing the labour market, everyday lives and societies at large. During the past decade, increasing attention has been given to children's digital competence in order for them to fit a highly digitalized and automatized future work market. Moreover, a deep understanding of digital technology has been voiced as a necessity to understanding society in the 21st century. Consequently, *computational thinking* (CT) is being introduced into education to provide children with a basic understanding of algorithms, decomposition and pattern recognition. As much as CT is relevant for understanding programming and computer models, it fundamentally lacks a critical and reflective stance towards digitized society; further, it lacks an agenda of empowering children to understand and make informed choices about technology and participate in technological development. Many countries implement CT in educational programmes with a strong focus on Science, Technology, Engineering and Mathematics (STEM).

In this paper, we suggest that participatory design (PD) should engage with the CT agenda that is currently being implemented in educational contexts. We propose *computational empowerment* (CE) as a PD alternative, focusing on how children can build their understanding of technology and their agency in a digitized world. CT, at large, promotes the idea that children and young people need to be taught the basic principles of decomposing, analysing and creating solutions to problems in such a way that computers can process them. Based on this idea, children across the world are currently learning programming skills and the basics of algorithms and data structures. The rationale for introducing CT is that children, and adults, live in a digitised world where computation pervades almost everything and, hence, everyone needs to understand the mechanisms of computation. While this aim seems sound and admirable, we believe there is a wider concern that follows digitalization and that PD is in a position to respond.

We frame CE as a concern for how children are empowered to make critical and informed decisions about the role of technology in their lives. CE shifts focus from programming skills as an end in themselves towards providing children and young people with the means necessary to take part in technological development. Where CT is primarily occupied with understanding the concept of computing, CE seeks to engage children in broader questions such as the following: How does digital technology challenge our democratic rights and civic engagement? How are digital technologies altering our personal relations and our practices? How do we interpret intentions embedded in everyday technology and how can every child partake in society by remixing, redesigning or creating digital technology that is more attuned to visions for a better future? In addressing these questions, understanding the logics of computing is obviously important, but it is not sufficient. We define *computational empowerment* as the process in which children, as individuals and groups, develop the skills, insights and reflexivity needed to understand digital technology and its effect on their lives and society at large, and their capacity to engage critically, curiously and constructively with the construction and deconstruction of technology.

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We believe that PD has a lot to offer in terms of driving an agenda related to children's education concerning technology and digitalization. We highlight three reasons in particular. First, PD has a long history of engaging in processes aimed at developing new insights, skills, visions and democratic awareness among people through their engagement with design and technology. The early PD projects in particular reflected these political commitments and sought to empower future users to take part in technological development and have a place at the bargaining table [7]. Second, PD has a substantial catalogue of approaches, methods and practices for how people can develop these skills and insights through participatory engagement in design activities. Third, PD offers approaches for understanding how challenges, such as empowering children to live in a digitalized society, require engagement on several levels, reaching from political arenas to everyday activities in schools.

This paper is structured so as to unfold the CE agenda. In the next section, we review the literature and practices relating to CT. We then discuss in more detail the potentials that PD holds for addressing this educational agenda. Based on this discussion, we then present the main principles of CE. In order to demonstrate how a commitment to CE can be realized, we present a case study in which we have worked with a PD approach to digital technology in education. This approach and research represents the foundations of arguments around CE. It also crystalizes the challenges and complexities involved in this agenda. These potentials and challenges of CE will be discussed in the final section.

2 COMPUTATIONAL THINKING FOR 21ST CENTURY LEARNERS

CT is a concept attracting much attention but with little agreement about its definition [4, 18, 39]. A popular definition is to define CT as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" [21]. CT is closely linked to an American approach to STEM education that is currently being infused, with some cultural adaptations, into teaching programmes world-wide. The federal CSforALL programme (www.csforall.org) in the US is an attempt to bring CT to all children nation-wide. Similarly, the Computer Science Framework (www.k12cs.org) offers an essential set of computer science concepts and practices evolving around CT. The Cool Think project in Hong Kong (www.coolthink.hk) also develop its core thinking from CT and from the ideas of *computational practices* and *computational perspectives* [18]. In Australia, Digital Technologies has been introduced as a compulsory discipline in K-10, and in South Korea the Software Education programme focuses on CT, coding skills and creative expression through software. A 2016 report from the European Commission finds that the integration of CT, and more broadly of computer science in compulsory education, is evident across the European educational systems [10]. Eleven countries have incorporated CT into compulsory subjects, while seven countries are currently planning to introduce CT into education. Finally, seven other countries are integrating CT by building on their long-standing tradition in Computer Science education. Some of these countries are expanding Computer Science education to include lower secondary and primary levels [10, p. 8-9].

As CT is rapidly brought into global educational programmes, we must critically reflect on the skills and competences acquired from this kind of teaching and consider whether CT sufficiently covers the requirements for computational skills, competences and digital citizenship. Cuny et al. [21] argue that CT for everyone means being able to:

- Understand what aspects of a problem are amenable to computation.
- Evaluate the match between computational tools and techniques and a problem.
- Understand the limitations and power of computational tools and techniques.
- Apply or adapt a computational tool or technique to a new use.
- Recognize an opportunity to use computation in a new way.
- Apply computational strategies such as 'divide and conquer' in any domain.

According to Cuny et al. [21], CT primarily addresses capacities to understand, apply and evaluate computational phenomena. Brennan and Resnick [18] have proposed a broader understanding of CT to also encompass other perspectives. They suggest a framework for CT consisting of *computational concepts* (the concepts designers employ as they program), *computational practices* (the practices designers develop as they program), and *computational perspectives* (the perspectives designers form about the world around them and about themselves). In Brennan and Resnick's framework, they acknowledge CT as a social phenomenon with broader consequences for society at large. This is also found in the work of Kafai and Burke [36], who envision CT in terms of computational participation to emphasize that 'objects-to-think-with'- to use one of Papert's key ideas - are indeed 'objects-to-share-with' others [36].

Within digital making literature, CT is treated somewhat differently. Schelhowe [46] argues for digital making in K12 classrooms to strengthen children's 'Bildung' (self-cultivation) and to provide them with the resources to become digital citizens through processes of digital fabrication. This approach is supported by Blikstein [8], who argues for democratization of innovation by bringing digital technologies into the hands of school children. According to Blikstein [9], students' projects related to digital technology should be "deeply connected with meaningful problems, either at a personal or community level, and designing solutions to those problems would become both educational and empowering" [9]. The aspects of 'Bildung', democratization and empowerment, through equal access to digital fabrication resources, are not found in CT frameworks or in the description of educational programmes in relation to programming or digital technology.

The notion of CE that we discuss in this paper extends the trajectories of democratization, empowerment and providing children with the opportunity to develop their capacity for engaging with technology found in the work of Blikstein [9] and Schelhowe [46]. In the following, we discuss why we believe that PD is a suitable candidate for driving this agenda.

3 EMPOWERMENT, LEARNING AND CHILDREN IN PD

As described in the introduction, we believe that there are at least three interrelated reasons that PD has the potential to drive a CE agenda in education. We have structured this section around these three reasons.

First, PD has a track record of responding to the introduction of technology by emphasizing the need for learning, skill-development and empowerment. While the current focus on programming and the increased introduction of fabrication technologies in schools might seem a distant relative of the challenges facing unions and workers in the early days of PD, there are fundamental parallels in terms of the inherent challenges and possible responses. Unions were faced by top-down processes of introducing technology and a situation where workers, in general, lacked the knowledge and organization necessary to understand and pose demands for technology [2]. Similarly, today, children in general have a very limited understanding of technology in terms of its current and potential role in their lives. Moreover, there are few means for them to develop this understanding as educational institutions are poorly equipped for the task. In the early Scandinavian projects, the approach chosen was not simply to design new technologies that were more attuned to the needs of workers. Rather, the collaborative efforts were aimed at mutual learning where unions and workers developed knowledge about technology in order to pose more qualified demands. While tangible products and concepts also emerged from the collaborations, the most important outcomes were, arguably, the skills and insights developed that empowered unions and workers to take part in technological development more broadly. Hence, much of the material emerging from the projects (e.g. DEMOS, DUE, UTOPIA) was educational content and reports that documented local experiences with technology introduction [7]. As Ehn [27, p.9] notes, the early PD approaches coined a learning strategy of 'local knowledge production' based on the Scandinavian ideals of democracy, with Freire's learning strategy of liberation as the 'pedagogy of the oppressed'. While it has been argued that PD's political engagement has declined (e.g. [6, 12, 38]), it remains evident in PD's history and is, arguably, alive and well in new guises that have gained traction in recent years; the creation of 'commons' [44] and 'design things' [25] carry with them the concern for democratic approaches to development and empowering local communities to act in a political landscape. We believe that PD's insistence on responding to top-down technological processes with initiatives that provide people with skills, knowledge and agency makes it highly relevant within contemporary debates of digitalization.

Our second reason for suggesting PD's candidacy is that PD has a substantial catalogue of methods, techniques and practices not only for co-designing technology but for supporting (mutual) learning. The catalogue reflects PD's engagement with a wealth of aspects relating to participatory practices and their outcomes and dynamics. In terms of scope, PD research spans from the micro-dynamics of participatory sessions [41] to wider issues of shaping social relations [42] and giving voice to values [40]. Moreover, the PD literature documents an array of different ways of arranging participatory work, from cooperative prototyping [13] to design games [16], storytelling [28] and walking methods [37]. The tools and materials used have also been studied at length, exploring, among other things, the use of video [19], scenarios [5] and props [17]. The catalogue is anything but systematic, but reflects a long-term engagement with the principles and practices of participatory work. Most importantly, it can be argued that PD's methods and practices, to some extent, are aligned with the political and ethical agendas that often pervade PD initiatives [33]. While PD methods and practices are not a homogeneous collection, several overviews have been provided over the years (e.g. [30, 45, 47, 49]), most recently related to PD in the learning sciences [22].

Also, considerable work has been done relating specifically to PD and children, most notably at the Interaction Design and Children (IDC) Conference series and the journal of Child Computer Interaction. Here, the PD engagement stretches back at least twenty years to the work of Druin[24] and has continued as a prominent topic, with a considerable expansion in recent years relating to PD methods for children (see [57] for overview), addressing issues such as PD in schools [3], game environments [56] and children with special needs [43]. Further, values and PD's political commitments have been developed in the context of engaging with children (e.g. [35, 55]). In sum, PD and neighbouring disciplines, such as IDC, have a well-developed catalogue of methods and practices, many of which reflect PD's ethos and political heritage.

The third reason that supports PD's candidacy is that PD has a relatively well-developed discourse for articulating how complex challenges, such as that of CE, require work across political arenas and involvement of diverse stakeholders. Considering the challenge of preparing children for a digitalized society, it is evident that this requires efforts that stretch from local initiatives to top-tier political levels, and that efforts can be scaled up and down. In many countries, this will also involve dialogue and collaboration with technology providers and NGOs. The issue of supporting work between diverse stakeholders has been a hallmark of PDC, and the importance of scaling and maintaining results across power structures and political arenas also has a long history (e.g. [11, 29]) with recent contributions focusing on issues such as effects [32] and sustainability [34].

The three reasons provided here are closely connected and reflect essential aspects of PD. Indeed, it is arguably a reason in itself for PD's candidacy that it provides a more or less coherent approach that stretches from the arrangement and micro-dynamics of participatory work to overarching issues related to influencing political arenas and the sustainability of project achievements. In the following section, we unfold individual aspects of the CE agenda in more detail.

4 COMPUTATIONAL EMPOWERMENT

While governments world-wide are currently considering how to prepare future generations for a digitalized future by introduction of CT, we address the need to critically consider the intellectual remedy for this transformation to occur. CT includes many important skills and competences needed for a 21st Century labour market regarding the ability to think and create digitally, including children's ability to see problems in the world as solvable through code. In that respect, CT is a resourceful perspective for current societal challenges. CT cannot, however, stand alone. It lacks a wider contextual approach to technological, cultural and societal challenges and change. To this end, we suggest CE inspired and driven by PD as described above. As noted by Spinuzzi [54], what is meant by empowerment is sometimes different in the various strands of PD. Here, we define Computational Empowerment as an approach to developing abilities for 1) engaging creatively in technology development, 2) understanding the role of digital technology in society, and 3) reflectively and critically understanding the role of technology in one's own life. By pointing to CE, we emphasize the following intentions related to computing, education and development of future society:

Computing as cultural production
CE is an approach to CT that acknowledges technology as bearer and creator of culture. CE provides children and youth with the ability to co-create the future, which is formed through design of digital technologies and includes critical decision making and reflection on the technology, and the ability to understand the impacts of digital technology on their personal and societal contexts.

Computational empowerment to support skills, competences and 'Bildung'
CE emphasizes the need to build children's capacities in at least three respects, which we separate as skills, competence and 'Bildung'. Supporting the development of skills points in the direction of building a capacity to perform an activity well and with confidence. Competence draws attention towards how skills may be used to respond to particular phenomenon in the world and act productively. Finally, 'Bildung' points towards personal self-cultivation as children become increasingly culturally mature.

Computational empowerment through hands-on/mind-in activities
CE aims for students to competently and critically engage in the development of novel digital technologies and thereby partake in the development of democratic and digitized societies: encoding the world. Moreover, this wider focus also attempts to strengthen children and youths' ability to understand the impact of technology on human relations and their relations to technology: decoding the world. Just as a development process of encoding technology with meaning and intention involves a series of ethical, structural, functional and aesthetic choices and considerations, so does understanding and decoding the consequences of these choices for the people who will use the technology.

Computational empowerment through coding and decoding
CE is about developing a nuanced language for articulating and reflecting on the phenomena that emerge from technological development. It should empower children and youth to express their decoding of the world as encoding of digital artefacts. They need skills and competences to understand and make choices concerning digital materials, understanding their potentials and qualities in relation to creating technology themselves. This also encompasses the fundamental skills involved in CT: to formalize and transform a problem into something (code) that be executed by a computer. But CE also includes the ability to judge the relevance of the specific digital technology for potential users and contexts, and assess the impact of its implementation for these people, other technologies and society at large.

Computational Empowerment is co-creation of the future
CE aims at providing children and youth with the ability to understand how others have developed digital technologies for them, and how these technologies produce meaning in their everyday lives, relations and society at large. It aims at making the intended use that designers have inscribed into the digital technology, and their motives for doing so, visible and comprehensible. In this way, CE aims for children and youth to gain access to co-creating the future that emerges through the design of digital technologies.

CE thus broadens the scope of CT to include empathic, aesthetic, ethical and structural aspects of technology design and development. It is closely linked to PD ideas and values by creating opportunities for future generations to engage as agents and co-creators of potential and critical alternatives. Consequently, CE denotes the processes in which students creatively, critically and reflectively investigate digital technologies in order to create new artefacts adapted for meaningful practices. To demonstrate how these principles and intentions of computational empowerment may be practically pursued, and the challenges that arise from doing so, we now turn to our case study.

5 CASE DESCRIPTION AND METHOD

The FabLab@School project combines participatory research and community development [23]. Through long-term engagement with diverse stakeholders including students, teachers, lab leaders, and local and national policy makers, we have explored the core challenges and potentials of integrating digital technologies into real-life educational contexts. The cornerstone of the project has been an inclusive participatory process intersecting the agendas between our research project and a regional development project. This has been conducted through a series of collaborative events and research activities inviting stakeholders to co-develop the research agenda, visions and implementation of the project. It involved researchers working closely with students and teachers in educational environments to support their roles as agents and protagonists [35] in explorations of possible educational agendas. Moreover, it involved constant attention to the infrastructuring of local, regional and national networks and agendas for digital technology in education [50]. Organizing an inclusive PD process around the educational aspects of digitalization has provided a focus not only on the development of new teaching practices but also on the learning outcomes and organizational changes for diverse stakeholders in the project. These dynamic real-life organisational settings have allowed us to maintain, rather than reduce, the complexity of understanding and producing sustainable educational practices. In this way, the project has served as a way to explore and mature CE as a PD approach to digital technology and design in education, which may support current developments in society.

5.1 FabLab@School: Digital Fabrication in Education

The FabLab@School research project (2013-2017) was carried out by the Child Computer Interaction Group, Aarhus University, in collaboration with four municipalities in the Eastern region of Jutland, Denmark. Based on the global FabLab@School concept developed at Stanford University, the Danish project added a strong Scandinavian PD approach to the STEM-oriented focus on constructivist maker technology in education [15]. The objective for the research project was to explore and develop the concept of (digital) design literacy, coining the technological aspects of digital fabrication and literacy with a PD approach into the educational domain. The target group was upper primary and lower secondary schools with students of 11-15y within newly established subjects such as FabLab, craft and design, but also in interdisciplinary teaching contexts. The research explored the central qualities and dynamics of design literacy for children, and how this core competence could be scaffolded through constructive and critical processes of digital design.

The project was established in conjunction with the introduction of a cross-curricular focus on innovation, entrepreneurship and digital technology in the Danish school system in 2014. Local teachers and schools had almost no experience in facilitating learning processes connected to digital fabrication and design. Hence our role as researchers was to establish a framework for co-investigating an emerging field with the stakeholders, relating to the broader political objectives of developing a sustainable and scalable educational initiative. The project has scaled considerably in the four years of its existence. From involving 12-15 so-called FabLab schools across three municipalities in 2014, the number of schools has risen to 46 in 2016, with more than 1,100 teachers and 11,000 students included in the project by 2017. Central labs have been established in each municipality with numerous unique labs set up in local schools. The project has established academic and cross-sector networks, including through a biennial European conference and an annual national conference around emerging technologies and design thinking in educational practice, bridging international research and practice with policy makers, school management, consultants, etc. Based on the project, a research-based training programme at university level has been established for developing the teachers' competences. In a Danish context, the project now extends to all levels of authority from local school level to governmental advisory boards, where experiences and outcomes from the project provide input to national curriculum development and policy making on new IT subjects. The project has been highlighted in several contexts as an ideal collaborative model of academic research for societal benefit, and the academic founders of FabLab@School recognize the Danish project as the largest of its kind globally, and a possible working model and living lab for other FabLab oriented projects.

5.2 Research design

Our research has been driven by an interdisciplinary approach to research-through-design, in which we combined qualitative social research with design experiments and a survey study [51, 58]. Based on initial ethnographic research, we studied the students' creative processes when engaged in digital fabrication experiments in the schools. Insights from these studies fed into the development of a series of design experiments with students and teachers in two schools [51]. In parallel, we conducted a baseline survey (1,150 students) assessing students' level of digital literacy and design competence across age (11-15y) and schools (50 urban and suburban) in the Eastern region of Jutland, Denmark. The baseline survey was followed up by an end-line survey (450 students) and 11 interviews in which 22 students in pairs of two engaged in a dialogue with a researcher about the questions in the survey.

The aim of the research study and design experiments was to examine how elements of design thinking and digital fabrication could provide students with new learning possibilities, based on an integrated approach to technology, design and societal challenges. The design experiments were conducted by researchers in two schools, in which we as researchers facilitated a design and digital fabrication course in four 7-grade classes over an eight-week period (Fall 2014). Based on our results, a second participatory research experiment was carried out with 8 primary school teachers focusing specifically on teacher experiences and challenges when teaching digital fabrication and design processes (grades 4-9) [52]. The end-line survey and semi-structured interviews with students together provided insights into the developing competences of students in the FabLab schools and control schools, which facilitated the development of a framework of archetypical students and schools when working with design and digital fabrication (see [50] for the framework and [20] for survey methodology and analysis).

The ethnographic studies and design experiments with students and teachers generated various kinds of data: video recordings and field notes from following groups of students through the duration of the course; follow up interviews targeting their experiences and learning outcomes from the process; video recordings of the teachers' collaborative work, design materials created through workshop activities, online diaries and field notes generated by the teachers, as well as follow up interviews about their experiences and challenges from the process. Video data and interviews with the students from the design experiments were logged and transcribed with a focus on their engagement with the design challenge, process and technologies, and their experienced competences and learning outcomes from the process.

Our interdisciplinary research approach combines design theory with anthropological research and design experiments, which allows us to triangulate between different types of qualitative and quantitative data, and design interventions [31, 53]. Especially when researching and designing potential futures with children and diverse stakeholders in complex networks and organisations, we find such a hybrid approach useful for developing knowledge through long-term engagement. All stakeholders were involved through contractual agreements with the FabLab project. For students' engagement in the survey, research and experiments, direct consent was given by all students and their parents prior to the research, with the possibility of withdrawing consent at any time in the process.

6 A PD APPROACH TO DIGITAL FABRICATION IN EDUCATION

In the following, we describe the approach we developed through the FabLab@School.dk project to demonstrate how a CE approach

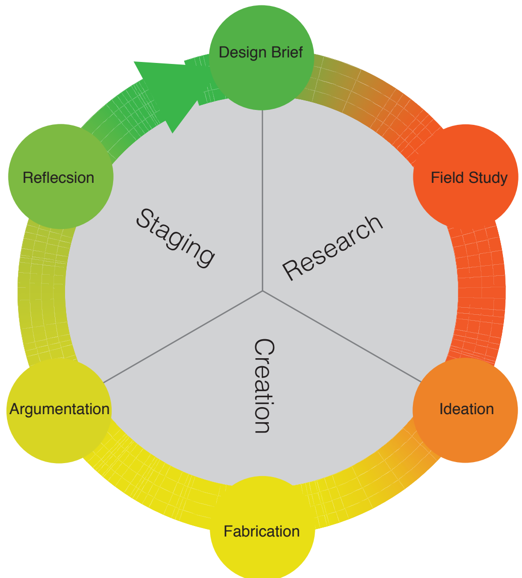

Figure 1: A structured process model for digital technology in education.

may unfold in practice. We will describe the activities and progression in our process to highlight the qualities of CE in an educational setting. The CE approach addresses how we might enable students (and educators) to develop critical and nuanced understanding about digital technology, and provide them with the skills, competences and 'Bildung' for engaging in creating change for a digitalized society. The CE approach is operationalized in a design process that we developed through the project. The design process model (Fig. 1) emphasizes the entire process, from research, ideation, and mock-up creation to the initial presentation of a prototype, argumentation for design ideas and reflections on the learning outcomes and possible societal impact of the ideas.

The design process contains six main activities, each including several sub-activities: (1) design brief, (2) field studies, (3) ideation, (4) fabrication, (5) argumentation and (6) reflection. The activities support students' and teachers' ability to work through an explorative design process while gaining an understanding of the potential value for design thinking in learning processes. The model is comparable to other generic design process models but integrates several dimensions that are central for the educational context. Importantly, the model can be used both as a tool through which students engage in cultural production by producing novel digital artefacts and solutions for meaningful practices - coding (moving clockwise in the model). Here, the framework allows students to acquire and develop a set of design skills and competences through reflection, synthesis and hands-on design work towards co-creating intentional change. Reversely, the framework can be used for critically examining and understanding how meaning and intentionality are encoded into digital artefact and practices that impact upon our everyday lives - decoding (moving counter clock-wise in the model). Here, students analyse, explore and hack existing designs in terms of their significance for personal use, cultural practices and society at large. As such, the model can be used as a reflective tool for developing children's 'Bildung' and agency as critical co-creators of future technology.

Our initial ethnographic studies showed a strong focus by students and teachers on the digital technologies themselves, a focus in which technologies were perceived as 'completed objects', which could be 'applied' to ad hoc ideas rather than developed or integrated in an exploratory process [51]. Students' technological skills and literacies were very superficial and largely detached from personal agency or societal concerns. Instead of providing students with technical training and computational skills, however, the design process model provided a critical and reflective approach to design and programming as part of interconnected and complex processes. In this way, CE as embedded in the process model emphasizes issues related to personal and societal consequences of digitalization. In the following, we will describe the activities (two-by-two) in the process model in more detail to illustrate the qualities of the CE approach.

Design Brief and Field Studies: The initial activities engage students in a contextual approach for working with real-life challenges and the development of possible futures. The model emphasizes critical engagement with the design challenge, framing and prioritizing the focus from a larger field of possibilities. Based on an initial understanding of the design problem, students move through research and field studies to explore relevant contexts and user groups, and generate empirical data and insights for the following activities of ideation and fabrication. Important learning aspects of these activities are exploring and prioritizing particular aspects and issues of a complex situation, using one's prior knowledge, values and appreciative system to ask questions and engage in a process of framing and reframing both problem and solution. In Computational Thinking, we see a tendency not to emphasize the contextual aspects of this type of problem setting and knowledge production (complexity, framing and reflexivity) as part of the process, but to treat problems as 'found' or predefined prior to the technological exploration. In this way, a CE approach includes the ability to address emergent personal and societal problems and the ability to explore, analyse and synthesize relevant forms of cultural production in response to these.

Ideation and Fabrication: Ideation and Fabrication cover activities that are often referred to as sketching, conceptualizing, mock-up, prototyping, implementation and testing. Here, focus is placed on the students' ability to externalize visions and ideas in ways that allow them to further explore and transform these into working concepts. As mentioned, PD has a wealth of tools and techniques that allow for the collaborative exploration and communication of ideas and possible futures (e.g. [16, 17]). These activities challenge students to transform abstract ideas into tangible representations and scenarios, meaningfully connected to the framed challenge, and to work with the integration of diverse analogue and digital materials. The availability of diverse design materials in these activities help to shift students' views of technology from (consumer) digital objects towards means and opportunities for creating alternative solutions. The fabrication activities cover the computational practices of iteratively testing and debugging, remixing, abstracting and modularizing as described by Brennan and

Resnick [18]. In their perspective, students learn to work with making and problem solving, and ways of using computation as media for designing and self-expression (rather than consumption) [18, p.12]). These are technical skills and competences that are necessary for working creatively with technology. In addition, CE emphasizes the intentionality encoded into the artefacts and solutions, as well the collaborative learning potentials that these activities can contribute to the educational context. Thus, ideation and fabrication combine hands-on and mind-in activities for students to iteratively and collaboratively explore design ideas, fabricate new technology and judge the relevance of specific digital solutions.

Argumentation and Reflection: The final two activities of argumentation and reflection are central to our focus on CE as they cover the ability to develop arguments and reflections about the artefacts and outcomes of the design process. Students present their work and receive feedback from peers and external partners, communicate and test the intended use of the artefacts, and develop a language about their decisions and priorities through the process. Based on these collaborative and real-life activities, students may modify and develop their products and refine their arguments in relation to requirements or knowledge created about the problem, users, technological constraints, etc. The final activity involves collaborative and personal reflections on the learning outcomes of the iterative design process, the creative work with technology and complex problem solving. The focus is not on formal assessment of students' instructional learning, production of aesthetic objects or computational skills. Instead, qualitative indicators of the students' development of design ability, digital literacies and reflective understanding of work with digital technology and design as interconnected practices are emphasized. That is, focus is on students' constructive learning process and 'Bildung', and their ability to judge the relevance and impact of technological solutions for specific people, contexts and concerns. It is important again to note that students and teachers may move in both directions in, and also across, the model. As such, teaching activities need not necessarily be arranged around a structured design case, and can potentially be initiated in any phase of the framework. Students can analyse existing technology by asking how a given design reflects a particular framing and what it can potentially mean for its users. In this way, the model supports many different ways of exploring how intentionality is expressed in technology and its possible effects in the world.

Whereas CT has its primary focus around the activities of ideation and fabrication, our framework extends the focus to CE as something that not only provides students with technical skills and computational understanding but which gives them agency to investigate and co-create meaningful futures. These alternatives are based on knowledge and insights framed by and through initial explorative activities. Moreover, the latter activities of argumentation and reflection provide an ideal context for articulating meaning and intentionality in the students' artefacts and, further, to reflect on their personal and societal impact, as well as students' developed skills, competences and 'Bildung' relating to digital technology and design.

In the FabLab@School project, the design process model became an iconic representation of this approach which encompassed the complexity of working with and understanding digital technologies at various levels of abstraction. The use and integration of the model into the schools' educational practices became fundamental in developing more critical and reflective approaches, and a common language of digital technology for both students and teachers. In this way, our participatory approach to developing design and technological literacies helped transform conceptions of technology and primed the development of new educational practices and digital cultures in the communities.

7 CHALLENGES FOR COMPUTATIONAL EMPOWERMENT (FOR ALL)

In the FabLab@School project, we set out to measure indicators of the students experienced their progress in relation to digital technology and design competence. Comparing the students' relationship to digital technology in the baseline survey (2014) and end-line survey (2016), results indicated that students had developed their skills, competences and 'Bildung' in comparison with other students outside the initiative (control groups) in relation to three main points. (1) *Students had improved their understandings and self-perceived knowledge of concrete digital fabrication technologies* from 3D printers to electronic devices, microcontroller boards, text-based programming, and block-based/visual programming. (2) *Students had gained hands-on experience with a range of digital fabrication technologies*, providing them with experience working with technologies in developing own ideas in an educational setting. (3) *Students found the work with digital fabrication technologies motivating*. Although there was variation in the responses, on average students agreed that the work with digital fabrication in their schools had been interesting and useful for their futures. On an overall level, the results indicated that, (4) *the FabLab@School.dk project had initiated design literacy among students*. In schools where students used a wide range of technologies, had developed their own ideas through a structured process around the design model, and using a diverse range of digital technologies, students' responses indicated that they had on average become better at imagining change with technology, at working creatively with technology and complex problem solving, at understanding how new technologies were developed, and at understanding how technology affects our lives. In this way, the project initiated the development of new digital competence and skills among some students, while the results also indicated the need for a strategic long-term effort to have a sustainable societal impact.

Based on a cross-analysis of the survey results and 11 qualitative interviews with 22 pairs of student following the same survey, we developed a framework of five archetypical student categories found within the schools. The five categories identified types of student engagement and learning with digital technology and design, scaled according to performance, reflection and interests, and which revealed interesting challenges to CE in education. The five categories were identified as follows:

(1) The Design Competent
(2) The Technology Interested
(3) The Well-Schooled
(4) The Undecided
(5) The Not (Yet) Motivated

The Design Competent could be characterized as the ideal student category, demonstrating how the systematic engagement with complex problem solving over time developed the language, repertoire and skills among the students. This approach developed their ability and judgement to address diverse personal and societal challenges connecting approaches to design with new-found conceptions and abstractions of technology. The category was relatively small, mixed gender, and from a few schools who had worked systematically with the integration of both design and digital fabrication in and across several subjects. Students were taught how to manage and structure the design process in order to develop a relevant outcome to a design brief. As a male student explained, they would work from a specific challenge and use the model to structure their work: "*other students who don't have this approach lack the structure, and the step by step* (...) *of starting a project, and knowing what the outcome is, and what it takes to create a good product.*" The Design Competent have developed central CT skills through engagement with a diverse set of technologies. In addition, they can extend and connect these competences to a wider context of personal and societal concerns. That is, they were developing a design ability to reflect on complex societal challenges through a structured and systematic approach to digital technology.

The Technology Interested had a different approach. They were often addressed as tech-nerds or Digital Natives by their teachers and co-students, and were highly motivated for working and tinkering with technology. They were interested in the technical aspects per se rather than the complex challenges, contexts or processes surrounding it. The focused attention on the technology affected their interest and ability to collaborate with less-competent peers as they preferred to work with fewer, like-minded peers. They enjoyed the hands-on fabrication process and would invest substantial time and effort both inside and outside of school. A male student explained: "*I like being in the FabLab and makerspace, instead of school work where you have to make paper sheets, cos it's more fun to tinker with things and make them work, and if they don't work then to fix them*" (...) "*Sometimes I watch something on YouTube, but sometimes I also just tinker and try out some code.*"

They were less motivated for the non-technical activities of the design process and even mock-ups were found boring; hence, ideas of developing relevant or sustainable solutions rather than merely technical artefacts were not priority. These students match the core of Brennan and Resnick's [18] focus on CT, of coding, tinkering, testing, debugging, etc., being engaged and self-motivated by the opportunities for self-expression that the digital technologies afforded. Students were all-male and also few in number. Their interest and motivation in CT formed a vast potential for their own engagement and agency in societal development of technology, especially if coined with a broader focus on CE as argued in this paper.

The Well-Schooled were skilled and ambitious students in the traditional educational competences (e.g. reading, writing, mathematics, language, physics at the core of STEM education). They understood the societal and personal importance of technology at an intellectual level. They understood the design process and approach to working creatively with digital technology. However, they did not clearly connect the hands-on digital experiments with other curriculum based school subjects, which they valued higher. The students engaged with the activities presented by the teacher but not necessarily consider using the acquired competences beyond the school, unless they supported them as high-performers in other (measured) fields. Opposite the Technologically Interested, they performed higher in the reflective activities connecting different levels of abstraction but were sometimes reluctant to engage in hands-on activities of trial and error with the diverse analogue materials. These, mostly male, students had ideas of becoming lawyers, working in business, and other classic disciplines. Further, while they performed well in many tasks connected to CT, their efforts towards CE are not likely to be sustained beyond the classroom into potential societal developments.

The following two categories were mixed but dominated by girls, and particularly **The Undecided** was a relatively large group. For reasons of personal interest or specific learning contexts, they were not convinced by the relevance or potential of teaching technology and design. Our results, however, showed that they might relatively easily be motivated and engaged given the right framing and support. Several students were critically engaged in social media and discussions of personal data, internet and security in their private spheres. However, they experienced the FabLab activities, as framed by their teachers, as a series of random two-hour technical problem-solving activities with no personal or societal relevance. Here, the teachers' framing of the activities as technical or computational exercises became obstacles for the students' motivation and engagement with the technologies. Other students had keenly worked through a few design processes, and were engaged over time through a more long-term strategic approach. In their experience, technology was mostly for the boys, and the activities often focussed too much on technology. For them, digital fabrication was part of school work and something they tended to forget after the fact. The research showed a potential interest from the students in technology and design related activities and concerns; however, it also indicated a necessary focus away from CT towards a pedagogical effort and scaffolding of socio-technical matters in order to include female students.

The Not (Yet) Motivated found it difficult to find motivation for using and understanding digital technology in a school context. Their design experiences were based on following teacher instructions, and they saw few connections between this use of digital technology in the classroom and the societal developments around them. Again, the teachers' impact for the students' experiences was evident, as they described the FabLab teaching as tedious, repetitive and passive. Interestingly, they requested more exploratory projects and independent hands-on activities, rather than following technical instructions. One girl phrased it this way: "*I like it when we make experiments in physics. But this stuff with electronics doesn't really interest me.*" A second girl (same interview) added: "*I'd also like more experiments and stuff. I mean, I like working with the computer, but I like to be more practical, to get out and do things.*" The students did not experience the potential of working through the design process model or being empowered agents through engagement with (simple or) complex challenges. In this case, neither personal, societal nor technical agendas of CT or CE were actualized by the educational and pedagogical context, indicating the need for a substantial effort from school and policy level.

As is visible from the diverse categories of students, they are motivated and engaged for different reasons. Assuming that digital literacy comes naturally to younger generations is to ignore the complexities of the educational situations, the influence of the students' personal interests, and the impact of the teachers' competences on their learning. While the first three student categories appear well prepared for a digitalised society, they have different educational needs in terms of integrating technological skills and competences with creative and reflective approaches to a digitalised society.

The framework of five archetypical student categories reveals several challenges for a CE approach digital literacy:

- How do we engage all students in teaching activities around computational empowerment?
- How do we address the individual motivation factors in each of the five groups?
- How do we scaffold structured engagement with societal challenges and digital technology?
- How do we develop measures and learning goals for the illusive development of 'Bildung'?

8 TOWARDS A PD AGENDA OF COMPUTATIONAL EMPOWERMENT

We have proposed CE as a PD response to challenges related to digitalization of society and the emerging need for digital literacy in K12 education. PD has the potential to drive a CE agenda in education as it re-accentuates the empowerment agenda from PD projects deriving from the labour market 30-40 years ago. As we claim here, PD has the grounding perspective, and the methods, techniques and practices to empower students to engage in the design of a digitalized society. Our research in the Fablab@school project indicated that a PD approach to digitalization (as illustrated through the design process model) provides students with computational skills and competences to reflect on the role of digital technology in relation to self, others and society. However, we experienced great diversity in the students' *motivation*, *engagement* and *reflection* towards digitalization and, therefore, much research and development is needed to fulfil the ambitious goal of empowering every student in relation to digital technology. Our research indicated that Danish students fall within five categories in their relation to digital technology. The design competent, the technology interested, the well-schooled, the undecided, and the not (yet) motivated. These broad categories may vary significantly from country to country and from culture to culture. Nevertheless, our categorization demonstrates that many questions need to be addressed for CE to be effectually realized within formal education.

So, is PD a fruitful approach for furthering a CE agenda? In the first part of this paper, we provided three reasons that support PD's candidacy to drive a CE agenda challenging the idea of teaching children programming as a means of preparing them for a digitised society. Here, we will turn the perspective and critically review PD's chances of succeeding in this endeavour by outlining three challenge that PD must address.

First, CE is not the first grand agenda to be suggested at PDC and the track record so far does not unequivocally reflect success. The agenda in early projects was to promote more democratic processes of technology design and give workers a voice in the development and organization of work. Some years later, Shapiro [48] proposed another agenda, arguing for PD's collective engagement in the development and procurement of large scale public IT systems (see also [1]) based on the observation that the failure rates were unreasonably high and that this could be rectified if PD principles were applied. The success of these two agendas is at least contestable. The high failure rate within the public sector in terms of the development and procurement of large IT systems has arguably not been improved significantly, nor has this agenda received substantial and systematic attention from the PDC community. It may be argued that participatory practices have, in fact, become commonplace in many development projects, design agencies and in the innovation department of companies, and that PD can take some credit for this development. Yet, it is doubtful if the widespread use of participatory practices have in fact brought about more democratic processes or empowered marginalised groups on a wide scale. In 2014, Ehn [26] took stock of PD's achievements, from the 1970s democracy at work to the digital Bauhaus and design things. While Ehn found traces of PD's impact, his keynote presentation acknowledged the melancholic undertone of 'utopias lost'. In sum, it might be argued that PD's track record of engaging with large societal agendas does not unequivocally speak to its favour.

Second, if PD is to engage with a CE agenda and take on the responsibility of empowering children in a digitised society, PD will likely be required to document its merits to people and policy makers outside PDC. Documenting the outcomes and effects of PD efforts has not played a major part in the PD literature [15]; further, while researchers and practitioners may argue that evidence of PD merits can be found in PDC research papers, it would prove difficult to produce documentation that would convince policy-makers to opt for a PD approach. More rigorous documentation practices are needed and a commitment to articulating results in a way that is accessible for people outside of the community. While the PD literature on these issues is sparse, there are examples such as Hertzum and Simonsen [32] and Bossen et al. [14] which demonstrate how PD achievements can be documented and assessed.

Third, while the PD literature is rich on examples of local projects with small ground of users, the literature is sparser in terms of how initiatives are scaled to, for example, a national level. For CE, there is an obvious challenge of scaling, both in terms of scaling local initiatives in schools to a broader context and scaling larger initiates to local circumstances.

9 CONCLUSION

We have proposed CE as a concern for how children are empowered to make critical and informed decisions about the role of technology in their lives. CE shifts focus from programming skills as an end in themselves towards providing children and young people with the means necessary to engage actively in technological development. Our empirical findings demonstrate how a CE approach in K12 education improved children's understanding of digital technology and simultaneously initiated a nascent design literacy among students. By emphasizing computational empowerment as a vision for technology education, we repurpose the scope of current technology education (such as CT) from one of providing children with STEM competences to one of empowering children to live meaningful lives in a highly digitalized world, providing them with the means and competences necessary to actively engage in co-constructing the future. We have provided three reasons why PD has the potential to drive this CE agenda. Firstly, PD has a track record of responding to the introduction of technology by emphasizing the need for learning, skill-development and empowerment. Secondly, PD has a substantial catalogue of methods, techniques and practices not only for co-designing technology but for supporting learning. Finally, PD has a relatively well-developed discourse for articulating how complex challenges, such as that of CE, require work across political arenas and involvement of diverse stakeholders. We have applied CE in a three-year research project and found that computational empowerment can be pursued systematically through a design approach. However, as discussed, significant challenges remain in relation to the differences in motivation, engagement and ability to reflect among different types of students.

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