The Future Digital Innovators: Empowering the Young Generation with Digital Fabrication and Making

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Abstract

So far, the implications of digital fabrication and making on digital innovation and the future of IS discipline and profession remain unexplored. This is where this study contributes and it does so by focusing on the perspective of the young generation, in whose hands the future of IS profession, indeed, lies. Digital technology has become intimately intertwined with our everyday life. New stakeholders take part in its development and innovation processes, including children. Calls for offering more in-depth technology knowledge for children have emerged within research on digital fabrication and the maker movement: children need to be educated to design, make, and build new technology. We critically examine existing studies on digital fabrication and making with children, in order to see what the potential of digital fabrication and making for empowering children to become digital innovators of the future is. Implications to IS research, practice, and education are presented.

Keywords: children, digital fabrication, making, Fab Lab, digital innovation

Introduction

Digital technology has become intimately intertwined with our everyday life, both work and leisure. The fast-paced development of digital technology also necessitates us to continuously adapt and modify our everyday doings and practices. Additionally, the advancement of digital technology has invited many new stakeholders into its development and innovation processes. Social media and web 2.0 technologies, for example, have enabled the crowd to enter the sphere of digital innovation and technology development in radically novel ways. Crowdsourcing (e.g. Majchrzak and Malhotra 2013), peer production (e.g. Benkler and Nissenbaum 2006), and cultures of participation (e.g. Fischer 2011), among others, are concepts with which researchers have tried to capture and explain this new phenomenon. However, the peers, the crowd, or the culture members discussed within this literature include mainly adult population, and usually mostly those who are also relatively competent with digital technology.

On the other hand, in information systems (IS) research, among other disciplines, it has been recognized that the digital divide, i.e. the polarization between those who have access and ability to develop their skills related to digital technology, and those who have not, is a serious concern of ours (e.g. Agarwal et al. 2009; Riggings and Dewan 2005; Srivastava and Shainesh 2015). Even more importantly, the digital divide needs to be taken extremely seriously among the young generation (OECD 2012). For children of today, it is pivotal to provide equal means to access, use, and gain benefit of digital technology. The literature base on computer, technology, and digital literacy (e.g. Davies 2011; Eshet-Alkalai 2004; Ezziane 2007) underscores the need for the young generation to understand and to be able to make informed decisions on how to utilize digital technology for different everyday life purposes. Recently calls for offering more in-depth technology knowledge for children have emerged also within research on digital fabrication and the maker movement, within which there has emerged an interest to educate children to design, make, and build new technology (e.g. Blikstein 2013; Honey and Kanter 2013).

With *digital fabrication* we refer to "translating a digital design developed on a computer into a physical object" (Berry et al. 2010, p. 168). We define 'digital fabrication' as the "making of physical digitally enhanced artefacts as well as the making of materialized objects by means of digital models. Following this definition, technologies for digital fabrication comprise physical computing technologies as well as digital production machines for printing three-dimensional objects and for cutting, shaping or milling material." (Katterfeldt et al. 2015, p. 3). '*Making'* in the context of the current study refers to "use of technological resources to build something of interest" (Chu et al. 2015, p. 11) while the *maker movement* includes hobbyists or enthusiasts dedicated on making tools or artefacts by themselves for themselves by utilizing various kinds of advancements in digital technology (Buxmann and Hinz 2013; Chu et al. 2015; Dougherty 2012).

As for the relevance and significance of the topic, nearly 700 Fab Labs have already been established around the globe (https://www.fablabs.io/) and since their launch in 2006, maker fairs have attracted over 2,3 million attendees globally, largest one in 2014 with 130,000 attendees. In 2014, 131 fairs were arranged all around the world (http://makerfaire.com/). Overall, digital fabrication is a significant trend affecting our future, being associated with the Fourth Industrial Revolution that includes developments in: "previously disjointed fields such as artificial intelligence and machine-learning, robotics, nanotechnology, 3-D printing, and genetics and biotechnology" that poses "major challenges requiring proactive adaptation by corporations, governments, societies and individuals. As whole industries adjust and new ones are born, many occupations will undergo a fundamental transformation. (…) They will change the skill sets required in both old and new occupations in most industries and transform how and where people work, leading to new management and regulatory challenges" (WEF 2016, p. 5, 8).

Digital fabrication and making are at the crossroads of the fields of science, technology, engineering, and mathematics (STEM) education as well as of the fields of software and hardware engineering (e.g. Buxmann and Hinz 2013; Christensen et al. 2015; Chu et al. 2015), where user innovators (von Hippel 1988) create digital designs with software tools and then those designs are turned into physical products (Thiesse et al. 2015). The future workforce of digital innovators is highly dependent on students interested in the STEM subjects (e.g. Christensen et al. 2015; Honey and Kanter 2013; Thiesse et al. 2015), and according to Christensen et al. (2015), hands-on STEM activities seem to be at the spotlight when encouraging the young generation towards STEM careers. However, even though schools increasingly use technology for teaching and learning and children do different activities in science or art classes utilizing technology, those activities are typically isolated and interested often mainly in completing a given task (Chu et al. 2015). Compared to those, in making activities both the actual exploratory process of making and the integrated outcome, the product, are emphasized (Chu et al. 2015) together with multiple cycles of design, which is not very typical in school context (Blikstein 2013). This gives students a wider understanding of the whole process (Chu et al. 2015), teaching them how to manage failure (Blikstein 2013) and giving an opportunity for both students and teachers to evolve from technology consumers towards technology producers (Vandevelde et al. 2015). Thus, employing digital fabrication and making, where the need for understanding different (STEM) subjects merge, as a pedagogical approach in elementary education, may increase young generations' potential to get involved with the digital innovation processes of the future (Berry et al. 2010). Hence, it seems obvious that IS research ought to be interested in digital fabrication and the maker movement.

However, in the IS literature only a couple of articles on the topic can be found. Those, on the other hand, point out that the IS discipline, indeed, should be interested in these phenomena as they will likely act as key drivers of innovation in the future and have serious implications on Information Technology (IT) industry (Buxmann and Hinz 2013; Thiesse et al. 2015). IS education should also consider integrating digital fabrication and maker spaces into the topics addressed (Buxmann and Hinz 2013). So far, however, the implications of digital fabrication and making on digital innovation and the future of IS discipline and profession remain unexplored. This is where this study contributes and it does so by focusing on the perspective of empowering the young generation, in whose hands the future of IS profession lies. Therefore, we ask as our research question "*What is the potential of digital fabrication and making for empowering* *children to become digital innovators*[1] *of the future?*" To answer this question, we have conducted a thorough literature review to see what the state-of-the-art research on digital fabrication and the maker movement targeting children is.

When looking at digital fabrication and the maker movement from empowerment perspective they are both based on doing and making by yourself: they include planning of what is to be done, actual making including decision-making in different phases of the process, as well as some reflection on how satisfactory the results are. In the heart of the maker movement is also doing what you want to do, enjoyment, and fun (Dougherty 2012; Honey and Kanter 2013). Parts of this may sometimes seem to be in contradiction with formal education. However, this kind of ideas have been highlighted in a vast body of research on children's participation carried out already for decades within a number of disciplines such as Child development, Cultural and social psychology, Environmental psychology, Human geography, Community development, Environmental education, Educational sociology, and Urban planning (Malone and Hartung, 2010). In these studies, it has been shown that children's participation in decisions that are related to their life-world leads to better decisions and services and products for children as well as enhances their personal and social skills, thus enabling them to act as full society members (Ackerman et al. 2003; Chawla and Heft 2002; Sotkasiira et al. 2010). Criteria for effective children's participation have been developed in these studies. Albeit there is a variety in the views on what constitutes effective participation – it has been defined based on the process or the outcomes (Chawla and Heft 2002) – generally there is an agreement that effective participation allows children to have a real influence on decisions and outcomes, the outcomes including both material ones as well as children's learning and competence development (Chawla and Heft 2002; Hart 1992; Iacofano 1990). The current study is inspired by the effective participation framework constructed by Chawla and Heft (2002) that posits that children are to participate in projects affecting their lives and they need to be empowered to truly affect and make decisions in these projects. Literature on digital fabrication and making will be critically reviewed against this lens as we feel that the framework echoes the values of digital fabrication and the maker movement and is therefore suitable for evaluating and further improving the use of digital fabrication and making in education.

The paper is structured as follows. First, the methodology for the literature review is presented. The next section introduces literature on digital innovation, fabrication, and the maker movement. After that, the critical analytic lens on children's effective participation that will be used for scrutinizing the existing literature on digital fabrication and maker movement is outlined. The following section discusses the findings. The last section summarizes the results and discusses their implications for IS research, practice, and education. Additionally, some limitations of this study are identified as well as a number of interesting paths for future work proposed.

Methodology

This study presents a thorough literature review that outlines the state-of-the-art research on digital fabrication and the maker movement targeting children. The literature search carried out included the following electronic databases: AIS, ACM, EBSCO, Elsevier, IEEE, LNCS, ProQuest, SCOPUS, Springer, Web of Science, and Google Scholar. It relied on Boolean search with the keywords of 'digital fabrication', 'maker', 'making', 'DIY', 'fabrication', 'fablab' in combination with 'child', 'teen', 'youth', and 'adolescent' (e.g., 'digital fabrication' AND ('child' OR 'teen' OR 'youth' OR 'adolescent')). We relied on a traditional narrative literature review (Boell and Cecez-Kecmanovic, 2014) instead of a systematic literature review (SLR). Our goal in this review was to get a comprehensive understanding of the field of digital fabrication and making with children, as is typical for a narrative literature review (Boell and Cecez-Kecmanovic, 2014),

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[1] Please note that the term innovator is used in the literature in multiple senses. Part of the literature labels early adopters of innovations as innovators (e.g. Rogers 1995; Hansen and Hallum Hansen 2005), whereas we refer to von Hippel (1988, 2005), where innovator is the one who develops the innovation, such development entailing recognizing a need, solving the problem by invention, building a solution and establishing its value in use (von Hippel 1988). Such endeavor, of course, is many times collaborative (e.g. Franke and Shah 2003). Thus, in this article, we use the term innovator loosely to refer to *people who take part in the innovation process*, involving recognizing a need, solving the problem by invention, building a solution and establishing its value in use, alone or with others.

contrasted with finding an answer to a highly specific research question, as in SLR (Boell and Cecez-Kecmanovic 2014). Narrative literature review is suitable for this kind of a new research field, in which the terminology of the field has not yet stabilized and within which, thus, "researcher's insight and contextually sensitive judgement are needed" (Boell and Cecez-Kecmanovic 2014, p. 4).

The keywords were required to be found in the abstract, keywords, or title of the article. The searches resulted in about two thousand hits in the databases (AIS: 7 hits; ACM: 27; EBSCO: 27; Elsevier: 6; IEEE: 1316; LNCS + Springer: 68; ProQuest: 0; Scopus: 9; Web of Science: 34; Google Scholar: 594), not all of them relevant ones. Thus, several hundred articles were browsed through, which resulted in the identification of 57 central articles for more thorough reading. To be included, the studies had to contain actual experiences of work with children or otherwise present either a very recent or a thorough and widely cited account of the topic. The articles that did not contain empirical data were excluded from the study, as well as very short papers and technology-focused papers (related to e.g. 3D printing) that did not report what was done with children. Publication years of the articles were not limited.

The articles were organized in Google Drive with reference information, purpose of the research, information about the research design, and how the article related to the theoretical lens utilized in this study. In this study, a subsection of 27 papers have been selected for detailed analysis and for the creation of a narrative synthesis, which, based on our theoretical lens, provides the reader a critical review of what the current situation in enabling effective participation of children in digital innovation projects is and what this implies for IS research and education (cf. Cronin et al. 2008).

Digital Innovation, Digital Fabrication, and Making of Technology

Digital innovation, the conference theme of ICIS 2016, is to be seen as a fundamental and powerful concept in the IS curriculum – as a core concept of IS education (Fichman et al. 2014). We should be educating digital innovators of the future, and by doing so, increase the legitimacy and identity of our discipline (Fichman et al. 2014). Digital innovation is broadly defined as "a product, process, or business model that is perceived as new, requires some significant changes on the part of adopters, and is embodied in or enabled by IT" (Fichman et al. 2014, p. 330). We are in this study particularly interested in enabling the young generation to start acting as digital innovators through technology making and digital fabrication. In the IS innovation literature the closest to this topic is research on user innovation, which examines the production of innovations *by* end users, as opposed to manufacturers producing innovations *for* end users.

User innovation is seen to originate from users' needs, for meeting of which they develop solutions (e.g. von Hippel 1988) utilizing digital technology (e.g. Floyd et al. 2007). However, the 'new' necessitated from such innovations may variably denote new to the 'world', 'industry', 'scientific community', 'market', 'firm' or 'customer' (Garcia and Calantone 2002). In addition, user innovation has been seen to cover both entirely new products and new features or functionality improving and refining existing products (Franke and Shah 2003; Franke and von Hippel 2003; Morrison et al. 2000). Additionally, user innovation may entail improvements in people's practices and usage patterns without advancements in technology (e.g. Hyysalo 2009; Lettl 2007). User innovation has been characterized as an iterative and collaborative process (Garcia and Calantone 2002; Floyd et al. 2007; Franke and Shah 2003; Morrison et al. 2000) and innovating users have been characterized as 'lead users' who are ahead of trends and who clearly benefit from their innovations (Franke and Shah 2003; Morrison et al. 2000). Such users also typically have in-depth knowledge of the domain (Lettl 2007), they are hobbyists in the field within which they innovate (Jeppesen and Frederiksen 2006), are open to new technologies, and have strong knowledge about technologies' capabilities and ability to explore technology (Lettl 2007; Nambisan et al. 1999).

Digital fabrication and the maker movement, on the other hand, allow ordinary people to make use of cutting edge design and construction technology (e.g. 3D printers and physical computing). They both invite people into programming, engineering, design, and innovation with technology. The point is enabling people to build, craft, and make technologies as opposed to merely using them. There is a strong agenda to build technological competence of people: encouraging them to gain enough in-depth technological knowledge to be able to design and build new technology by themselves. (Buxmann and Hinz 2013; Dougherty 2012; Eisenberg 2013; Blikstein 2013.) In the background are also open source software and hardware movements as well as the Do-It-Yourself and hacker movements and the radical developments in physical computing, digital production and personal manufacturing technologies (e.g. Akbal et al. 2014;

Bar-El and Zuckerman 2016; Blikstein 2013; Chu et al. 2015; Dougherty 2012; Giannakos and Jaccheri 2013; Katterfeldt et al. 2015; Posch and Fitzpartick 2012).

An interest to integrate making and digital fabrication into the education of the young generation has also emerged. Here, it has been pointed out that critical and constructivist educational approaches need to be followed as those underlie digital fabrication and the maker movement (e.g. Blikstein 2013; Katterfeldt et al. 2015; Stager 2013). Studies within this stream of research bring up Piaget, Papert, Dewey, constructivism, Reggio Emilia, and Montessori as originators of the ideas and the studies claim implementing practice based, experimental, unstructured, self-directed, collaborative, or design based learning as well as learning by doing and learning by making (Akbal et al. 2014; Bar-El and Zuckerman 2016; Bekker et al. 2015; Blikstein 2013; Chu et al. 2015; Iversen et al. 2016; Katterfeldt et al. 2015; Posch and Fitzpartick 2012; Stager 2013; Wardrip and Brahms 2015; Zeising et al. 2013). Schools and teachers, among other actors, have been pointed out as significant: they should educate the young generation so that they are prepared for the needs of the future; however, schools are lagging badly behind recent developments in technology (e.g. Kinnula et al. 2015; OECD 2012; Wastiau et al. 2013). Albeit programming has recently been integrated into the curricula of several European countries (Balanskat and Engelhardt 2014) and STEM education has become a hot topic in US with extensive funding programs (e.g. Buxmann and Hinz 2013), many countries are still lagging behind and teachers are in serious need of training and help (Bekker et al. 2015; Blikstein 2013; Iversen et al. 2016; Katterfeldt et al. 2015; Wastiau et al. 2013).

Even though problems prevail, significant developments have already been achieved in educating and empowering children with digital fabrication and making. The IS literature remains silent about this new trend, while this study introduces the potential of the trend to the IS community – focusing here particularly on children and their empowerment and education. Through this review, IS scholars can start considering how to integrate digital fabrication and making into IS education in all levels as well as professional practice, which is warmly recommended as digital fabrication and making offer a fascinating way to enable and boost digital innovation in the future.

Theoretical Lens

We will examine digital fabrication and making from the perspective of effective participation of children in projects affecting children's life, here particularly in digital technology projects. In the long-lasting and multidisciplinary literature base, a multitude of models have been proposed for understanding and improving children's participation and for making possible forms of participation visible to all actors, so that both adults and children can make informed choices of the degree of participation. The philosophy behind these models is that children's participation not only brings better decisions in child-related issues (Ackerman et al. 2003) but is important and worthy as itself, as it creates children possibilities for learning and development. Well known and often cited model is Hart's 'ladder of participation' (Hart, 1992) where Hart distinguishes non-participation and participation, and differentiates participation by children's possibility to affect decisions: being just an informant in the process or sharing decision-making with adults. Many similar type of typologies for participation have been presented, e.g., Franklin (1997) concentrating on who has the power in the process, very similarly to Hart (1992) and Shier (2001). Chawla (2001) tries to show different nuances in participation by describing different forms of participation that are not necessarily mutually exclusive, children moving between the forms of participation depending on their level of involvement and degree of personal initiative. Treseder (1997), then again, sees that some types of participation are more appropriate to certain type of settings. Moreover, Thomas (2007) highlights that we should understand the difference between the two types of 'participatory' activities: activities where 'children engage in conjointly with adults' and children's autonomous activities.

The models have also received criticism, e.g. for their sequentiality, implicating that one form of participation is better than the other, and for their hierarchical nature (Reddy and Ratna, 2002; Kirby and Woodhead, 2003; Malone and Hartung, 2010). These models, moreover, do not provide practical tools for projects to plan for children's participation beforehand or to evaluate it afterwards. As the process of participation can be just as important as the outcome of a project (Percy-Smith and Thomas, 2010), measuring just the results after the project has ended is somewhat limited. Thus, different frameworks for both monitoring the project during its course and for evaluating the impact of a project or service and children's participation in it have also been created, especially for the use of larger-scale initiatives aiming at making changes in community practices (Sinclair, 2004; Johnson, 2010). Chawla and Heft (2002, p.

204) present criteria developed particularly for project planning purposes, to help projects to take into account different facets of children's participation, trying to describe "common features of meaningful forms of participation" (see Table 1).

Conditions of Convergence
Whenever possible, the project builds on existing community organizations and structures that support children's participation.
As much as possible, project activities make children's participation appear to be a natural part of the setting.
The project is based on children's own issues and interests.
Conditions of Entry
Participants are fairly selected.
Children and their families give informed consent.
Children can freely choose to participate or decline.
The project is accessible in scheduling and location.
Conditions of Social Support
Children are respected as human beings with essential worth and dignity.
There is mutual respect among participants.
Children support and encourage each other.
Conditions for Competence
Children have real responsibility and influence.
Children understand and have a part in defining the goals of the activity.
Children play a role in decision-making and accomplishing goals, with access to the information they need to make informed decisions.
Children are helped to construct and express their views.
There is a fair sharing of opportunities to contribute and be heard.
The project creates occasions for the graduated development of competence.
The project sets up processes to support children's engagement in issues they initiate themselves.
The project results in tangible outcomes.
Conditions for Reflection
There is transparency at all stages of decision-making.
Children understand the reasons for outcomes.
There are opportunities for critical reflection.
There are opportunities for evaluation at both group and individual levels.
Participants deliberately negotiate differences in power.

Table 1. Characteristics of Effective Projects for Children's Participation (Chawla and Heft 2002, p. 204)

Chawla and Heft (2002) divide the criteria into five areas: 1) conditions of convergence, i.e. project establishment related issues where it is emphasized that one should rely on and utilize as much as possible the existing structures, settings and interests; 2) conditions of entry, i.e. accessibility and inclusion related issues as regards who will be involved in the project, how the participants are recruited, how easy access is enabled and whether participation is voluntary; 3) conditions of social support that emphasizes respect for the human being in the sense of making children feel valued and accepted as well as ensuring mutual respect and support among the participants; 4) conditions for competence, i.e. giving children genuine possibilities to make and impact decisions and ensuring that there emerges both material outcomes that the children influence and gradual development of children's competence; and 5) conditions for reflection, i.e. increasing transparency in decision-making and as regards power relations through open dialogue and supporting critical reflection and evaluation thorough the project.

Chawla and Heft (2002) note that the criteria are meant for iterative planning of projects, rather than sequential, even though the criteria are presented in sequential order. Especially reflection of the results can be connected with the ideal of participation: who are better able to evaluate the results than the ones whose lives the decisions and the outcome affect? (Chawla and Heft 2002.) Originally monitoring and evaluation was typically performed by external consultants, trying to be objective and producing quantitative results, but due to criticism, participatory approach has gained more footing also for planning, monitoring and evaluation phases of projects, not only for the implementation of them (Johnson, 2010).

We argue that this kind of criteria would be beneficial with adult participants in any kind of participatory project, but it is especially useful with more vulnerable user groups, like children, when their empowerment and education are targeted at. We maintain that the criteria make visible a number of important considerations to be taken care of when empowering children to become digital innovators of the future, in this case through digital fabrication and making. Hence, next we utilize the criteria presented by Chawla and Heft (2002) on children's effective participation in our critical review of the literature on children, digital fabrication and making.

Findings

Table 2 summarizes the findings of our critical literature review, with some central references. Afterwards, the findings are discussed in more detail.

Conditions of Convergence

The literature on effective participation of children posits that projects affecting children's lives and thus including children as participants should rely on and utilize as much as possible the existing structures, settings, and children's own interests (Chawla and Heft 2002). The digital fabrication and making related literature addressing children seems to be well in line with this. The projects have been organized in schools (Akbal et al. 2014; Bekker et al. 2015; Blikstein 2013; Fitton et al. 2015; Giannakos and Jaccheri 2013; Katterfeldt et al. 2015; Smith et al. 2015; Vasudevan et al. 2015), libraries (Bar-El and Zuckerman 2016; Litts 2015; Telhan et al. 2014), or museums (Litts 2015; Wardrip and Brahms 2015) that are considered as natural places for children to enter into and work in – schools in particular. Additionally, the digital fabrication and making projects seem to advocate strongly children's own interests. Also with adults, these projects are usually initiated by the ideas people bring to the lab (Posch and Fitzpatrick 2012), in which the idea is then worked on. Many studies have indeed implemented this idea with children (e.g. Akbal et al. 2014; Bar-El and Zuckerman 2016; Blikstein 2013; Giannakos and Jaccheri 2013; Litts 2015; Posch and Fitzpatrick 2012; Posch et al. 2010; Pucci and Mulder 2015; Vasudevan et al. 2015). Here, it is emphasized that kids are free to choose what to do and the work is about making personally meaningful creations (Bar-El and Zuckerman 2016; Katterfeldt et al. 2015). However, not all the reviewed studies adhered to this ideal: there are several studies in which researchers or teachers generated a topic for children to work on (Bekker et al. 2015; Blikstein 2013; Chu et al. 2015; Fitton et al. 2015; Katterfeldt et al. 2015; Smith et al. 2015). With a predefined design topic to start with, the original idea of making of technology purely based on people's interests and needs gets lost. On the other hand, the literature maintains that when teaching children digital fabrication and making there is not necessary any initial idea and interest in children in which case it is very valuable to have an assignment or a design brief to begin with as well as a well-planned design process guiding the work (e.g. Smith et al. 2015). For example, in project-based learning experiments the project is organized as an extracurricular activity explicitly designed for learning purposes with different combinations of specific training sessions, following with more or less structured hands-on activities (Durães 2015). Pucci and Mulder (2015) found out that raising young people's interest towards 3D printing with personalized key chains was far from successful when aiming specifically for active involvement and personal empowerment. Instead, a more incremental approach worked better, allowing the young people time to accept the new concepts and technologies and to learn to view themselves as competent co-creators. (Pucci and Mulder 2015.)

Effective participation	Digital fabrication and making	Key references
Conditions of Convergence	Organized in schools, libraries, museums – natural places for children to enter into and work in. There is also a high emphasis on children's own interests and needs as a starting point of making and fabrication. However, several studies have also relied on researchers' or teachers' ideas instead of children.	Bar-El and Zuckerman 2016; Bekker et al. 2015; Blikstein 2013; Katterfeldt et al. 2015
Conditions of Entry	Organized in schools, libraries, museums – easy to access, even compulsory places for school-aged children, or public drop-in places with easy entrance. However, in some studies, whole classes involved without discussion about children's voluntariness to participate.	Bar-El and Zuckerman 2016; Blikstein 2013; Christensen et al. 2015; Katterfeldt et al. 2015
Conditions of Social Support	Respect for the human being not explicitly emphasized, whereas collaborative, communal, and peer-to-peer learning and sharing emphasized a lot. In some studies reported that some adult facilitators better equipped for the job than others or children find it difficult to collaborate.	Bar-El and Zuckerman 2016; Blikstein 2013; Chu et al. 2015
Conditions for Competence	Graduated development of competence a pivotal goal: building children's design, technology, engineering, and innovation competence. Preparing children for the future, giving them skills, knowledge, and facilities to continue the work also by themselves. Tangible outcomes essential. Children ideate and implement their own projects, making the necessary decisions and setting the goals. Facilitators (adults, teachers) available for assistance in some cases as well as peer support. Support for children's digital fabrication and making activities considered in some studies a lot. However, in some studies lack of assistance brought up as well as teacher or researcher driven projects reported, where children merely executed adult predefined tasks. Some emphasize that a structured design brief driven process is essential for children, adults guiding the work.	Blikstein 2013; Chu et al. 2015; Durães 2015; Katterfeldt et al. 2015; Pucci and Mulder 2015
Conditions for Reflection	Children allowed to act as decision-makers in their own projects; however, not all studies allowed children this position. Moreover, critical reflection and evaluation not emphasized, albeit few studies explicitly emphasized this type of activities, too. Power differences among adults and children paid no special attention to, albeit some studies emphasized the need to reduce adults' role in these kinds of activities.	Bar-El and Zuckerman 2016; Bekker et al. 2015; Giannakos and Jaccheri 2013; Smith et al. 2015

Table 2. Summary of the Findings

Conditions of Entry

The literature on effective participation of children emphasizes accessibility, inclusion, and voluntariness in projects with child participants (Chawla and Heft 2002). The literature on digital fabrication and making is again quite well in line with this. The literature highlights accessibility and inclusion of children: the work is organized in schools, libraries, and museums that are easy to access and often free for children to enter into (Akbal et al. 2014; Bar-El and Zuckerman 2016; Bekker et al. 2015; Blikstein 2013; Fitton et al. 2015; Giannakos and Jaccheri 2013; Katterfeldt et al. 2015; Litts 2015; Smith et al. 2015; Vasudevan et al. 2015; Telhan et al. 2014; Wardrip and Brahms 2015). The studies also advocate organizing the work in open, public drop-in places or 'third places' within which participation is entirely voluntary (Bar-El and Zuckerman 2016; Blikstein 2013; Posch et al. 2010). However, some studies have organized the work in universities' Fab Labs that clearly are not places easy to access for children (e.g. Chu et al. 2015; Posch and Fitzpatrick 2012). Moreover, in the context of school, participation in some projects has been voluntary so that the participating children have chosen the take part in choice subject courses or extra-curricular activities (Katterfeldt et al. 2015; Vasudevan et al. 2015), whereas in other projects the work has been integrated into the schoolwork of students and it is not very clear whether their participation has been entirely voluntary (e.g. Bekker et al. 2015; Fitton et al. 2015; Giannakos and Jaccheri 2013). This, again, seems a bit contradictory to the ideals of digital fabrication and making, whereas it can be argued to be well justified if this work is considered to be part of the curriculum of the children. However, when considering children's interest towards STEM careers, there are studies which show that after few weeks of experimental compulsory school assignment, children without voluntary involvement do not think as positively about STEM careers as children who voluntarily participate in after-school programs (Christensen et al. 2015). Yet, Pucci and Mulder (2015) suggest a network approach where schools and Fab Labs are nodes of a co-learning community for the 21st century skills.

Conditions of Social Support

The literature on effective participation of children emphasizes also respect for the human being in the sense of making children feel valued and accepted as well ensuring mutual support among the participants (Chawla and Heft 2002). This is less discussed aspect in the literature on digital fabrication and making. Quite recently, Pucci and Mulder (2015) highlighted specifically the empowering nature of digital fabrication in education concerning underprivileged students. However, most of the studies do not touch upon the issues expect for underscoring the collaborative, communal, and peer-to-peer learning and sharing involved in digital fabrication and making (Bekker et al. 2015; Blikstein 2013; Posch and Fitzpartick 2012; Posch et al. 2010). Such collaborative and communal learning, making and sharing includes the peers as well as many kinds of adults as participants. Many studies highlight that there should be adult facilitators available for help (Bar-El and Zuckerman 2016; Bekker et al. 2015; Blikstein 2013; Fitton et al. 2015; Litts 2015). Teachers are even trained specifically for STEM content in order to better support and facilitate children's tasks (Christensen et al. 2015). Peers are considered to be a valuable resource, too (Blikstein 2013; Chu et al. 2015; Giannakos and Jaccheri 2013; Katterfeldt et al. 2015; Litts 2015; Posch and Fitzpartick 2012; Posch et al. 2010; Vasudevan et al. 2015; Telhan et al. 2014). The community aspect is highlighted: it is important to support community building with like-minded young makers (Bar-El and Zuckerman 2016; Blikstein 2013). All this indicates that at least support from adults and other child participants is emphasized in these studies, although the respect for the human being is not otherwise explicitly addressed. Then again, one can say that even problems in this respect are reported: some studies report that some adult facilitators were better equipped for the job than others - some were thanked but others were not (Bar-El and Zuckerman 2016), and some children also found it difficult to collaborate among themselves (Smith et al. 2015).

Conditions for Competence

The literature on effective participation of children places a lot of emphasis on this condition, which is about giving children genuine possibilities to make and impact decisions and about ensuring that both child-influenced material outcomes and outcomes in the sense of gradual development of competence emerge as a result (Chawla and Heft 2002). In the literature on digital fabrication and making this condition is realized very well. First of all, in the reviewed literature the development of children's competence is a pivotal goal: the studies aim at building children's design, technology, engineering, and innovation competence (e.g. in Bekker et al. 2015; Blikstein 2013; Chu et al. 2015; Durães 2015; Katterfeldt et al. 2015; Pucci and Mulder 2015; Smith et al. 2015). Preparing children for the future in the sense of giving them skills, knowledge and facilities to continue the work also by themselves is also occasionally brought up (Bar-El et al, 2016; Blikstein 2013; Chu et al. 2015; Katterfeldt et al. 2015; Litts 2015; Posch and Fitzpatrick 2012; Pucci and

Mulder 2015). These studies wish to nurture a maker mindset and identity in children, so that they feel capable to make, like to make and want to make also in the future (Chu et al. 2015; see also Katterfeldt et al. 2015; Litts 2015). The projects mostly emphasize tangible outcomes as essential, too. Creation of such is almost unavoidable in digital fabrication and making projects, while some studies also emphasize creating outcomes that the children can to take home with them (Chu et al. 2015; Posch and Fitzpatrick 2012), which has not been possible or even considered in all the projects.

Digital fabrication and making are driven by the ideal of people being empowered to make their own tools. This empowerment aspect was evident also in the reviewed literature addressing children: the involved children had a lot of power in the sense of ideating and implementing their own projects (e.g. Akbal et al. 2014; Bar-El and Zuckerman 2016; Blikstein 2013; Giannakos and Jaccheri 2013; Litts 2015; Posch and Fitzpatrick 2012; Posch et al. 2010; Pucci and Mulder 2015; Vasudevan et al. 2015). In some cases, however, adults set the project goals or directed the work according to a predefined plan (Akbal et al. 2014; Bekker et al. 2015; Chu et al. 2015; Durães 2015; Fitton et al. 2015; Smith et al. 2015; Vasudevan et al. 2015). Additionally, adult facilitators were available, giving guidance and instructions (Bar-El and Zuckerman 2016; Bekker et al. 2015; Blikstein 2013; Fitton et al. 2015; Litts 2015). Many studies discuss how to support digital fabrication and making activities of children even better and propose suitable processes, methods, and tools for the purpose (Bekker et al. 2015; Blikstein 2013; Durães 2015; Katterfeldt et al. 2015; Litts 2915; Smith 2015; Zeising et al. 2013). Such studies propose for example a design process to be followed with the following main activities: (1) design brief, (2) field studies, (3) ideation, (4) fabrication, and (5) reflection (Smith et al. 2015). However, future work on how to truly invite children into digital fabrication and making is still needed, as the studies identify problems in their work with children: lack of assistance, problems in collaboration, and an overall lack of understanding of digital fabrication process and tools (Bar-El and Zuckerman 2016; Blikstein 2013; Smith et al. 2015). Another unclear aspect concerns the extent to which it is meaningful to teach digital fabrication and making with teacher- or researcher-driven projects, where children execute tasks predefined by adults. On the other hand, some studies point out that it is absolutely necessary to have a structured design process driving the work (Bekker et al. 2015; Smith et al. 2015). Considering the curricula from the STEM career and competence point of view, it seems that more structured, project-based learning process leads to better learning results (Durães 2015).

Conditions for Reflection

Finally, children's effective participation also requires that there is transparency in decision-making and differences in power are openly negotiated (Chawla and Heft 2002). Moreover, projects should invite children into critical reflection and evaluation of the progress and the outcomes of projects thorough the projects (Chawla and Heft 2002). These are issues that the digital fabrication and making literature is not at its strongest. In many studies children have been allowed to act as decision-makers in their own projects, as mentioned, but some studies have not allowed children this position, but instead invited children to take part in more or less adult-initiated and -driven projects (Akbal et al. 2014; Bekker et al. 2015; Chu et al. 2015; Durães 2015; Fitton et al. 2015; Smith et al. 2015; Vasudevan et al. 2015). Moreover, critical reflection and evaluation have not been emphasized in these studies, except for few studies that have explicitly emphasized this type of activities, too. In some studies, interviews or surveys have been used to collect feedback from children (Chu et al. 2015; Giannakos and Jaccheri 2013; Posch and Fitzpatrick 2013). In some studies, reflection or evaluation have been even an explicit step in the design process (Bekker et al. 2015; Fitton et al. 2015; Smith et al. 2015). The reflection phase has involved peer presentations and evaluation of own and others' designs, viewing other children as clients (Bekker et al. 2015) or extensive iteration and argumentation of the own design solution (Smith et al. 2015). However, deliberate negotiations of differences in power have not been brought up in these studies, albeit the basic idea is to empower the power weak to build and make their own technology. Though, some studies emphasized the need to reduce adults' role in these kinds of activities (Bekker et al. 2015; Giannakos and Jaccheri 2013) and considered even providing guidance for teachers to adopt a new role of a coach or a facilitator (Bekker et al. 2015). One study included children acting as facilitators for other children and considered it to be very important to nurture a unique community of young makers in a space managed by kids for kids (Bar-El and Zuckerman 2016).

Concluding Discussion

This paper inquired *the potential of digital fabrication and making for empowering children to become digital innovators of the future*. This was studied through analyzing previous studies conducted with children in relation to digital fabrication and making, using a lens of effective participation of children proposed by Chawla and Heft (2002). In the following, the main results are summarized and their implications for research and practice are discussed, ending with discussing limitations of the study and paths for future work.

Summary of the Results

Our aim for this study was to make visible for the IS community the current literature and used practices in digital fabrication and making with children as well as to critically review those from the point of view of enabling effective participation of children in digital innovation projects. Later in this section, we will consider how this understanding can be used for informing IS research, practice and education.

In our critical analysis, we found out that the current literature on digital fabrication and making is very well in line with the theoretical lens we utilised: Regarding conditions of convergence, i.e., relying on and utilizing the existing structures and children's own interests, most of the studies have these as their starting points. Existing settings have been extensively relied on when establishing the maker spaces. Moreover, especially children's own interest in the project topic has been seen important. However, some studies maintain that a well-planned design process for guiding children's work is needed as well as some pre-planned assignment, in case children do not have their own design ideas (e.g. Smith et al. 2015).

Regarding conditions of entry, i.e., accessibility, inclusion, and voluntariness in such projects, integration of Fab Labs or other kind of maker spaces with schools (e.g. Pucci and Mulder 2015; Smith et al. 2015) or public drop in places (Bar-El and Zuckerman 2016; Blikstein 2013; Posch et al. 2010) ensures accessibility for children. Children's voluntary participation has been emphasized and it has also been shown to produce better results in the sense of increased interest in STEM careers (Christensen et al. 2015). In schools, such projects can also be offered as choice subjects or extra-curricular activities, hence relying on voluntary participation of children (e.g. Katterfeldt et al. 2015; Vasudevan et al. 2015). However, it was not clear whether children's participation was entirely voluntary in all the reviewed studies.

Conditions of social support, moreover, were not addressed much in the studies. However, the importance of collaborative, communal, and peer-to-peer learning and sharing (Bekker et al. 2015; Blikstein 2013; Posch and Fitzpartick 2012; Posch et al. 2010) were underscored, and the need for adults and peers to support and facilitate the work were brought up.

Conditions for competence, i.e., children having a real possibility to make decisions and the project resulting in both material and learning related outcomes, were emphasized in the studies. Children acted as influential decision-makers, producing material outcomes that also resulted in gradual development of competence in design, engineering, technology and innovation. The work processes need more development, however. It seems that a structured, project-based learning process leads to better competence development (Durães 2015) as well as a structured, systematic design process with a design brief (Bekker et al. 2015; Smith et al. 2015). Some of the projects were teacher- or researcher-driven, which may affect learning outcomes. The influence of this on both the material outcomes and children's competence development requires future studies.

Finally, the conditions for reflection, i.e. transparency in decision-making, open negotiation of differences in power, and critical reflection and evaluation of the progress and the outcomes, were the most lacking criteria. We argue that reflection and evaluation of both the process and the outcomes should be an explicit phase in the process, as already was in some studies (Bekker et al. 2015; Fitton et al. 2015; Smith et al. 2015). Moreover, we maintain that the existing power relations between adults and children should be openly and critically addressed (cf. Chawla and Heft 2002), also in digital fabrication and making projects.

Implications for IS Research

This study guides IS research at several crossroads. It connects several generations as it guides us, adult scholars, to consider children, the future IS scholars and IS practitioners, who need to be educated and empowered to become such. The study also combines theories from a variety of disciplines to understand and enable digital innovation: it relies on insights from the disciplines of Child development, Cultural and social psychology, Environmental psychology, Human geography, Community development, Environmental education, Educational sociology, and Urban planning (Malone and Hartung, 2010) as well as from Human Computer Interaction, Education, Design, and Innovation to make sense of and enrich our understanding of an IS phenomenon. We argue that we bring the IS discipline to a new and unchartered territory that is relevant both for academia, for IT industry, and for IS education. This paper opens up the debate of the unfamiliar possibilities ahead as regards digital fabrication and making in fostering digital innovation. In addition, this paper wishes to challenge the assumptions as regards how digital innovation is to be nurtured. We argue that the focus should be moved from organizations to passionate individuals and their communities, and that the individuals should be educated and empowered from an early age to be prepared to truly act as digital innovators of the future.

This study broadens the understanding of IS research field of digital innovation by introducing the potential of digital fabrication and making. Digital fabrication and making clearly advocate digital innovation of a sort; they contribute most obviously to the innovation of new, digitally enhanced physical products and have a close relationship to user innovations. User innovations are often products as well (cf. Franke and Shah 2003; Franke and von Hippel 2003; Morrison et al. 2000), but they can also be new features improving existing products or new practices (Hyysalo 2009; Lettl 2007). Digital innovations include also new business models (Fichman et al. 2014). We think that digital fabrication and making may result in novel usage practices or business models, too, but their main focus is not in the creation of such. In line with the user innovation literature, digital fabrication and making assume people have a problem and an interest to solve it. Personally meaningful innovations are to be created. In both cases the innovation originates from users' own needs and interests for meeting of which technology is utilized in creative ways (cf. von Hippel 1988; Floyd et al. 2007). Digital fabrication and technology making as well as user innovation seem to rely on iterative and collaborative processes (cf. Garcia and Calantone 2002; Floyd et al. 2007; Franke and Shah 2003; Morrison et al. 2000) and the innovating users have or are to gain in-depth technology knowledge during the process (cf. Lettl 2007; Nambisan et al. 1999). The literature on digital fabrication and making have not discussed the importance of users' domain knowledge (cf. Lettl 2007; Jeppesen and Frederiksen 2006), whereas one could assume that domain knowledge and strong interest are significant drivers also in digital fabrication and making. Digital fabrication and making highlight also the importance of enjoyment and having fun (Dougherty 2012; Honey and Kanter 2013) – which probably should be nurtured in user innovation processes as well.

All in all, this paper has identified a critical blind spot in IS innovation research that other researchers are welcomed to shed some more light on. IS literature has already hinted that digital fabrication and making may act as significant drivers of innovation and entrepreneurship in the future (Buxmann and Hinz 2013; Thiesse et al. 2015), while IS researchers interested in user or digital innovation are now warmly welcomed to take a look at the current practice in digital fabrication and making communities and consider what could be learned from there to nurture or augment IS innovation practices.

Another blind spot in the IS literature concerns children – a growing technology user group of whom the future IS scholars and IS practitioners are to emerge. This study highlights the importance of empowerment, participation and education of children as regards design, engineering, technology, and innovation. The IS literature should be interested in this topic as digital divide is a concern of ours, too (Agarwal et al. 2009; Riggings and Dewan 2005; Srivastava and Shainesh 2015) and in today's world technological literacy (Davies 2011; Eshet-Alkalai 2004; Ezziane 2007) and competence (e.g. Blikstein 2013) are essential for children – such are significant also for the future workforce (Christensen et al. 2015; Thiesse et al. 2015) – including the IS profession. There is no existing research in the IS field on the topic, while the existing, very multidisciplinary literature on children's participation was used as a sensitizing device in this study. This vast literature base enabled us to critically review the state of the art of educating children in digital fabrication and making. The lens we adopted enabled us to appreciate many features of digital fabrication and making as educating and empowering children, but it also enabled us to point out shortcomings and limitations related to which future work is needed. We argue that the theoretical lens used in the study on effective participation of children by Chawla and Heft (2002) can be utilised as a practical tool when planning and implementing digital fabrication and making projects with children (see also Iivari et al. 2015), which is something we wish also IS scholars start doing. Moreover, we argue that the framework is not only useful with children but with any project where the framework values match the project goals and intentions. The framework could be used by empowerment or inclusion seeking IS researchers to plan, monitor, and evaluate their projects with any kind of participants. Especially it would be useful if working with vulnerable or underserved participants, e.g. with children, patients, immigrants, or participants in developing countries. The criteria highlight accessibility, voluntariness, inclusion, social support, decision-making power, tangible outcomes, development of competence, negotiation of power relations, and critical reflection and evaluation of the process as well as the outcomes. All this should be valuable for projects including solely adults, too.

However, we also want to highlight that the criteria discussed by Chawla and Heft (2002) are by no means all-encompassing. For example, motivation to participate, definitely an important element of any collaborative project, has not been emphasized specifically in these criteria. Yet, there are several characteristics which in one way or another touch upon motivation of the participants, e.g. whether the project is based on children's own interests, whether children can freely choose to participate, or whether they take part in defining the goals of the activity. There are different motivation theories available which could be used to extend the criteria and thus enhance our understanding of children's participation even further. Self-Determination Theory considers participants' intrinsic or extrinsic motivations to participate to be significant, as participants may either have a personal interest in the activities (intrinsic motivation) or they may be motivated by a possible reward from the project, such as a prize or recognition from the adults (extrinsic motivation) (Deci and Ryan 1985). Many of the issues discussed above point to the significance of children having intrinsic motivation (Ryan and Deci 2000) to participate, i.e. when they do something inherently enjoyable, they also e.g. associate it with possible future career plans. On the other hand, if such projects are considered very valuable learning-wise, it might even be necessary to include these projects as compulsory studies for all, therefore making it impossible to rely on children's intrinsic motivation only and necessitating considerations of how to foster "active and volitional" forms of extrinsic motivation in children, by providing a good rationale for taking part in the activity to ensure successful learning experience (Ryan and Deci 2000). In this respect, the criteria for children's effective participation (Chawla and Heft 2002) can also be of help as they support e.g. autonomy of children, which has been found to have a positive effect on internalization (Ryan and Deci 2000). Then again, when interpreted from the Cultural-Historical Activity Theory point of view (e.g. Hyysalo 2005) there are both personal (e.g. culturally mediated desire for recognition) and collective motives to participate and the object of any activity system "connects the actions of the various participants under the same motivating whole" (Hyysalo 2005, p. 21). When digital fabrication and making projects with children are conducted in educational settings for example, they inherit some of the specific practices related to learning theories used (e.g. constructivism) and built-in motives and goals for participating in educational activities in general. Going into the motivation theories more deeply is beyond the scope of this paper, however.

Implications for IS Practice

We argue that this study addressed a highly valuable topic for IS practice. Digital fabrication and making offer interesting possibilities for the IT industry (Buxmann and Hinz 2013; Thiesse et al. 2015). They enable user innovation and user entrepreneurship (Buxmann and Hinz 2013; Thiesse et al. 2015), while they can also be utilized in corporate settings to boost digital innovation. IS practitioners can consider building some sort of maker spaces in which they can together with their peers experiment with new ideas and have fun in doing so (cf. Dougherty 2012). The maker mindset or the user innovator mentality might be valuable also in corporate settings. With the help of this study, IS practitioners can start considering how to nurture this type of mentality, mindset as well as practice in their workplace.

Another important practical implication are the novel business opportunities offered by digital fabrication and making technologies and practices. There already are companies providing digital fabrication and making tools, also such that are targeting children, schools and education, whereas definitely numerous unexplored business opportunities and models still remain. For example, there is a possibility of extending companies' business ecosystem to include users ideating, designing, developing, and manufacturing new digitally enhanced physical products to serve the ecosystem. IS practitioners should start considering these possibilities for their companies.

Finally, this study should be helpful for IS practitioners working with users. The criteria of Chawla and Heft (2002) target specifically children, but the criteria should be valuable also when working with adult users, especially with vulnerable or underserved ones, but also more generally with the adult population.

Practitioners can use the framework for planning user participation as well as for monitoring and evaluating their projects. The framework values e.g. inclusion, accessibility, voluntariness, respect for the human being, true decision-making power for users, users' learning and equality in power. All this is very valuable in user participation, while practitioners can consider how much emphasis each of the criterion requires and which of them deserve less attention. In community informatics context as well as with vulnerable or underserved users, all these criteria may be very significant.

Implications for IS Education

Children are increasingly being educated and empowered to design, make, and build new technologies; digital fabrication and making is already entering the primary school and beyond. These practices may be further improved by being informed by and by following the ideas from effective participation discussed in this paper, i.e. considering specifically the characteristics of children's meaningful participation; the conditions of convergence, entry, social support, competence, and reflection.

This paper has several implications for IS education. First, we need to take this current trend in digital fabrication and making seriously and start to widen IS students' understanding about the diversity of the empowered stakeholders and participants involved in IS and digital innovation in the future. In IS education, students might consider new processes and practices of participation further towards co-learning communities of future digital innovations. In addition, IS students may experiment with digital fabrication and making themselves as part of their curriculum. As digital innovation has already been seen as a core concept and subject in IS education (Fichman et al. 2014), we could learn from STEM education and research experiences and raise students' interest towards STEM subjects in general by increasing innovative hands-on digital fabrication and making activities in the curriculum (Christensen 2015). Here, enjoyment and fun brought by digital fabrication and making (Dougherty 2012) might also open IS students' minds about the potential of advanced technologies as well as provide them in-depth knowledge about new technologies' capabilities based on their own explorations similar to innovating users'. In such courses, one should rely on critical and constructivist educational approaches that underlie digital fabrication and the maker movement (e.g. Blikstein 2013; Katterfeldt et al. 2015; Stager 2013): practice based, experimental, unstructured, self-directed, collaborative and design based learning as well as learning by doing and learning by making should be integrated into such courses.

Furthermore, in addition to adults and workforce in general, IS education should pay more attention to the young generation who should become interested in IS and digital technology and pursue such careers. The future workforce of digital innovators is highly dependent on students interested in the STEM subjects and hands-on STEM activities seem to be at the spotlight when encouraging the young generation towards STEM careers (e.g. Christensen et al. 2015; Thiesse et al. 2015). IS education should consider contributing to the education of this workforce early on. We should consider how to raise the interest in IS and digital innovation among the children of today and how to prepare them for the needs of the future. Schools are often lagging badly behind recent developments in technology (e.g. Kinnula et al. 2015; OECD 2012; Wastiau et al. 2013) and thus we cannot assume that schools alone are capable of educating the young generation as regards digital technology and innovation. Instead, we need to acknowledge that teachers are in serious need of training and help (Bekker et al. 2015; Blikstein 2013; Iversen et al. 2015; Katterfeldt et al. 2015; Wastiau et al. 2013) and we should consider how to help them in this important endeavor. If voluntariness, i.e. children's intrinsic motivation to participate in the projects seems to produce better results in relation to increased interest in STEM education and careers (Christensen et al. 2015), integrating e.g. Fab Labs in schools (e.g. Bliksten 2013; Smith et al. 2015) provides possibilities for children's autonomous activities (cf. Thomas 2007) and children have more possibilities to get interested in; after all, you cannot be interested in something you don't even know to exist. This also provides possibilities for utilizing aspects of extrinsic motivation related to learning, e.g. by children getting recognition from their peers or teachers, especially when combined with more formal teaching. We encourage combining of both types of participation: voluntary activities, based on intrinsic motivation, where children work based on their personal interest in the topic, as well as adult-led activities, planned to create meaningful extrinsic motivation in children (cf. Ryan and Deci 2000). Moreover, we encourage the educators to look at the activities also from the viewpoint of collective activity systems (cf. Hyysalo 2005); what would be the purposeful, shared project goals towards which the orchestrated interests of each individual participant might be directed. In practice, for example, this might involve building a 3D board game where each participant has a section of their own based on their own interest and capabilities.

Limitations and Paths for Future Work

There are several limitations that need to be taken into account. Although the literature review covered a wide variety of databases and forums, there still might be some lacking. At this point, it was not possible to carry out a systematic literature review as there seemed to be no consensus on terminology, at least yet. In a couple of years, a systematic literature review on the topic may be warranted. Despite the limitations of the current search, we succeeded in finding a good number of empirical studies dealing with the topic. On the other hand, we focused on children and their empowerment and education in digital fabrication and making. Another literature review could be carried out addressing university level education or adult population in general. It would also be interesting to examine the situation in different countries and cultures – it seems that the maker movement (http://makerfaire.com/) and Fab Labs (https://www.fablabs.io/) have already spread out all over the globe, while it might still be possible to observe interesting differences in emphasis, capabilities and actual practices in different contexts. We also wish to point out that the framework of Chawla and Heft (2002) strongly focused our attention to certain aspects in digital fabrication and making – that we indeed feel strongly about and consider significant – but at the same time many other aspects were left out. Very interesting aspect to study further that we addressed only lightly in this study would be participants' motivation and how it affects project results. A study focusing on the variety of practices and tools already in use in digital fabrication and making education could also be carried out to offer even more practical guidance for the future utilizers of these results. Moreover, although our study strongly emphasized children's empowerment as something to be strived for, we do acknowledge that future work is needed to scrutinize this complex concept and the means by which to realize it in practice. However, despite these limitations we feel that we succeeded in guiding the IS community at several crossroads, where a fascinating yet unchartered territory was pointed out as regards fostering digital innovation.

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