Guidelines for Empowering Children to Make and Shape Digital Technology – Case Fab Lab Oulu

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Abstract: Digital technology design and making skills are seen as important '21st century skills' that children need to learn to become future changemakers, i.e., to manage and master in the current and future technology-rich everyday life. Fab labs (digital fabrication laboratories) are one example of non-formal learning environments where school teachers bring children to work with projects on digital technology design and making. Even though the value of fab labs in such endeavors has been acknowledged, the potential of fab labs in empowering children to make and shape digital technology remains poorly explored. This study scrutinizes the current theoretical understanding on empowerment related to design and making and relates that on empirical data of practical work done with children in the fab lab of University of Oulu. Based on that we offer theory and practice-based guidelines for practitioners who wish to empower children to make and shape digital technology in the context of non-formal learning and fab labs. These guidelines should be useful for teachers when planning and implementing children's work in fab labs as well as for fab lab personnel who help children to conduct their projects, with special emphasis on school visits to fab lab premises.

Keywords: Fab Lab, Digital Fabrication, Making, Non-formal Learning, Empowerment, School, Children, Pupils, Teachers, Facilitators, Instructors

1. INTRODUCTION

Our society and everyday life are becoming extensively permeated by digital technologies, and it is hard to see many future occupations that have not been affected by digitalization. Access to technology and ability to benefit from its use (Iivari, Kinnula, Molin-Juustila, & Kuure, 2018; OECD, 2012; Warschauer, 2002), as well as skills and capabilities to innovate, design, program, make, and build digital technology (Blikstein, 2013; Iivari & Kinnula, 2018; Iivari, Molin-Juustila, & Kinnula, 2016; Iversen, Smith, & Dindler, 2017) are all seen as pivotal for children to manage and master in the current and future technology-rich everyday life. Children's education needs to respond to this – children's education should empower them to make and shape digital technology in addition to using it in meaningful ways (see e.g. Iivari & Kinnula, 2018; Iivari et al., 2016; Iversen et al., 2017).

Various kinds of actions and developments have already emerged around the topic. Schools and teachers around the globe are facing the challenge of educating children to

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meet these needs of the future digitalized society and workforce. Even if impressive developments have taken place, such as the FabLab@school.dk project (Iversen, Smith, & Dindler, 2018) there still is an acute need to develop children's education in this respect (e.g. Kinnula, Laari-Salmela, & Iivari, 2015; Smith, Iversen, & Hjorth, 2015). In addition to schools and teachers, significant work has been undertaken in the informal and non-formal learning (see e.g. Eshach, 2007) for the differentiation) contexts: Makerspaces, fab labs and different kinds of computer or coding clubs have started to offer children digital technology skills and competencies (e.g., Bar-El & Zuckerman, 2016; Chu, Quek, Bhangaonkar, Ging, & Sridharamurthy, 2015; Katterfeldt, Dittert, & Schelhowe, 2015; Litts, 2015; Posch, Ogawa, Lindinger, Haring, & Hörtner, 2010; Weibert & Schubert, 2010). However, their potential in empowering children to make and shape digital technology remains poorly explored so far.

This study addresses particularly fab labs as a promising site to offer children digital technology skills and competencies. Fab labs ((Digital) Fabrication Laboratories) are communal, small-scale digital fabrication and innovation platforms with a mission to popularize processes of turning something digital to a physical object or a functional device. They originate from MIT's outreach program (Gershenfeld, 2012). There are certain criteria for fab labs, set by the Fab Foundation[1]: 1) there is a public access to the fab lab; 2) the fab lab subscribes to the fab lab charter, a basic rule set for all fab labs; 3) it shares a common set of tools and processes with other fab labs; and, 4) it participates in the larger, global fab lab network. While fab labs are paving the way for third digital revolution of digital to physical and ubiquitous fabrication of programmable materials, the value of fab labs comes more of learning the processes than of the actual outcome of the processes (Gershenfeld, Gershenfeld, & Cutcher-Gershenfeld, 2017). Fab labs are sometimes described as places to learn, mentor, play, create, and innovate, not to forget communal co-working.

In this paper we ask as our research questions: What is the potential of fab labs in empowering children to make and shape digital technology? What kind of best practices, limitations, or challenges can be identified? Inspired by a study by Kinnula and Iivari (2019), we address empowerment of children to make and shape digital technology by relying on a framework proposed by Chawla and Heft (2002) that considers how to enable children's effective, genuine participation in projects of various kind. We apply the framework in the context of fab labs. To answer our research question, we examine data from a collaborative workshop conducted with University of Oulu Fab Lab personnel who regularly work with children. In the workshop, we collaboratively discussed the framework on empowerment of children and reflected on how it has been realized in the fab lab when working with children. Based on the insights generated, we develop guidelines for practitioners working with children and their digital technology education in the context of non-formal learning and fab labs. These guidelines should be useful both for teachers and facilitators when planning and implementing children's projects in fab labs, with special emphasis on school visits to fab lab premises.

The paper is structured as follows: The next section introduces the theoretical background and related research. Then we describe our research methods and present our findings from our data analysis. After that we propose practical guidelines on what kind of aspects different actors working with children in the fab lab environment should consider when they aim at empowering children with digital technology. In the last section we conclude the paper and discuss limitations and future research possibilities.

2. Empowering Children with Digital Technology

[1] https://www.fabfoundation.org

Empowerment is a complex concept discussed within numerous disciplines, and, as a result, there is a variety of meanings associated with it (Kinnula et al., 2017). In this paper, by empowerment of children to make and shape digital technology we mean children's perceived competence, impact, meaningfulness, and choice around making and shaping digital technology (Spreitzer, 1995; Thomas & Velthouse, 1990); we acknowledge however that there are other views of empowerment of children in this context as well, see e.g. Kinnula & Iivari (2019) and Kinnula et al. (2017).

Children's empowerment has been considered in different fields and for different purposes. In this paper, we rely on the framework by Chawla and Heft (2002), following the study by Kinnula and Iivari (2019). Chawla and Heft (2002) outline a number of criteria for genuine, effective participation of children (see Table 1). In their framework, they highlight the following aspects: 1) children's participation should be meaningful to participating children; 2) their participation should have actual impact on the results; 3) their participation should lead to their competence building; and 4) children should have a choice to decide whether they participate or not. The criteria are grouped under five conditions that need to be respected when working with children. These criteria align very well with literature on empowerment ((Thomas & Velthouse, 1990), see also Spreitzer, 1995) and hence we interpret them as criteria for empowerment of children.

Conditions of Convergence	**Conditions for Competence**
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.	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 gradual 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 of Social Support	**Conditions for Reflection**
Children are respected as human beings with essential worth and dignity. There is mutual respect among participants. Children support and encourage each other.	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. Criteria for empowerment of children (Chawla & Heft, 2002, p. 204)

In their paper, Kinnula and Iivari (2019) critically consider these criteria and propose a set of questions to ask when aiming at empowering children to make and shape digital technology. However, the questions have not been empirically evaluated with practitioners. That is where this study contributes.

The topic of empowerment of children to make and shape digital technology has been acknowledged as significant in Child Computer Interaction (CCI) research long ago (see Read & Markopoulos, 2013). Druin and her colleagues have already for decades argued for including children into technology design process as design partners, i.e., as equal participants to adults, having valuable expertise on what being a kid entails that should be utilizable in the design process (e.g. Druin, 2002; Druin et al., 1999). Druin's work has been inspired by the Scandinavian tradition of Participatory Design and along these lines, many researchers have developed the ideas further. For example, Iversen and colleagues (2017) have argued for inviting children as protagonists in relation to technology: children are to critically reflect on technology and its role in our everyday life and practices as well as to take an active role in shaping technology development. Iivari and Kinnula (2018), along these lines, have considered what such protagonist role adoption entails. They, additionally, have considered how well the context of school enables genuine participation of children (Iivari & Kinnula, 2016) as well as the ways by which they have managed to empower children in technology design (Kinnula et al., 2017). Discussion on empowerment of children strongly relates with ethical issues and values driving or underlying our work with children. Indeed, CCI research has already brought up ethical issues and the importance of values shaping design work with children (e.g. Iversen, Halskov, & Leong, 2010; Iversen & Smith, 2012; Kinnula & Iivari, 2019; Kinnula, Iivari, Isomursu, & Kinnula, 2018; Read, Fitton, & Horton, 2014; Read, Horton, Fitton, & Sim, 2017; Read et al., 2013; Van Mechelen et al., 2014).

This study will particularly scrutinize fab labs as a site for design and making projects. Studies have already examined children's design and making activities in fab labs (Blikstein & Krannich, 2013; Iivari & Kinnula, 2018; Iivari, Kinnula, & Molin-Juustila, 2018; Iversen, Smith, Blikstein, Katterfeldt, & Read, 2016; Katterfeldt et al., 2015; Posch & Fitzpatrick, 2012; Posch et al., 2010; Pucci & Mulder, 2015). However, the specifics of fab labs in helping or hindering empowerment of children as regards digital technology have not been explored so far. This study provides valuable insights on the particularities of fab labs as such a site.

3. METHODS

This exploratory study has been conducted in Finland, in the context of University of Oulu Fab Lab ("Fab Lab Oulu"), which is equipped with a large toolset (e.g. a laser cutter, a sign cutter, a precision Computerized Numerical Control (CNC) milling machine, a large-scale router-type milling machine, 3D-printers, a computerized embroidery machine, computers, electronic workstations, and communication devices for video conference). Working in fab lab supports distributed education and knowledge sharing (Ylioja, Georgiev, Sánchez, & Riekki, 2019). Most of the processes are easy enough for almost anyone to learn, and the majority of fab labs in Nordic countries, and also in Oulu area, are in schools and educational institutes. Fab Lab Oulu is open to everybody but one of its core goals is to get the local school community familiar with it: to create a community of school teachers, pupils, and university researchers around the fab lab, and attract new students to the technical faculties of the university.

Regarding community building, Fab Lab Oulu started collaboration with the local schools right after it opened with the model of acting as a 'super node' for the schools of the area. The aim is to familiarize teachers and pupils with basic processes and support their projects with the equipment set of Fab Lab Oulu. This model permitted the local schools to start their own makerspaces, where they can do large part of their Making projects. When the resources of the schools are not adequate to finalize the project, they can visit the super node. Regarding attracting new students, we believe that seeing a tangible outcome of one's work is highly motivating; We strongly believe that becoming familiar with simple manufacturing tools and processes, throughout the realization of different design and Making activities, makes it more likely that pupils consider related studies as one possible option for their career choice.

For the purposes of this study, two of the authors conducted two workshops involving five researchers somehow working with Fab Lab Oulu, with varying overlapping backgrounds (Cultural Anthropology/Information Systems/Human-Computer Interaction/Computer Science Engineering/Electrical Engineering) and roles (fab lab director / fab lab manager / fab lab instructor / coordinator for education related activities in the fab lab / part time researcher / researcher organizing research projects in collaboration with local schools and the fab lab). The researchers altogether have over 30 years of experience working with children. Four of the participating researchers are authors of this paper.

The first workshop pre-reading material included a framework on empowerment of children (see Kinnula & Iivari, 2019) as well as definitions of formal/non-formal/informal learning. In the 3-hour-workshop, we followed an agenda based on different parts of the framework. The focus was on the framework's conditions for meaningful and impactful participation. We collaboratively reflected on the current practices, goals, and values of Fab Lab Oulu and its personnel in relation to the framework on empowerment of children to understand how it has been realized in Fab Lab Oulu when working with children, asking ourselves the reflective questions provided in the framework. All five researchers participated this workshop. The workshop was audiotaped and one of the participants wrote down extensive, reflective notes of the discussions. The notes were shared between the participants.

Between the two workshops, data analysis continued. First, one of the researchers sorted out the discussion content to extract main insights from the framework on empowerment of children and shared this with the rest of the research team. Afterwards, the research team members individually concretized, clarified and extended the insights. This collaborative process resulted in a summary, addressing all conditions in the empowerment framework, proposing aspects for all fab labs to follow when preparing activities with schoolchildren. Those insights were then used to define a set of guidelines, divided into different phases, that could be useful for anyone trying to organize any kind of educational activity for schools in a Fab Lab environment.

In the second workshop (1,5 hours) three of the participants collaboratively discussed the results gained and reflected on them critically, and further refined their presentation and relation to each other.

4. FINDINGS

In the following sections we discuss our findings on how the framework on empowerment of children has been realized in the work of Fab Lab Oulu. Our findings are structured according to the conditions presented by Chawla and Heft (2002) and related reflective questions, presented by Kinnula and Iivari (2019). Insights based on our findings are presented later in the discussion section of the paper as practical guidelines on what kind of aspects different actors working with children in the fab lab environment should consider when they aim at empowering children with digital technology. Before moving on to the findings, it needs to be noted that we recognized that Fab Lab Oulu has organized multiple type of educational activities involving children of different ages, with different goals and formats. We realized that the goal and format of the activity are important when studying children's empowerment using the given framework: different things as regards empowerment of children become emphasized and realized in different types of educational activities. We divide the activities into three types, each having implications on the empowerment of children, discussed later on:

Short term activities. These are usually about two hours long school visits or even shorter, aiming to give pupils basic understanding of what happens in the digital fabrication process: first they design a simple object with computer (piece of jewelry, sign for their room, a keychain or such, using a 2D vector graphics software) and then use a machine to fabricate a physical object (in this case by using the laser cutter). We provide a guided tutorial, explaining step-by-step and with real time support how to utilize different software functionalities to build the object. Children must follow the given steps. They do not do significant creative work; all designs look similar. Finally, we cut the design by using the laser cutter. We show the cutting process to children, but they do not intervene in the full process. They perform some simple actions such as setting the origin or starting the machine. Children work individually or in pairs.

One day activity. During this activity, pupils learn basics of one concrete digital fabrication process, for instance, laser cutting, vinyl cutting, 3D design or introduction to electronics. The activity starts with a guided tutorial on how to use the software tool but, afterwards, pupils must work on their own project. The instructor usually defines a problem or certain functional/design conditions that the project must implement. Children work on their own with the support of instructors. During the fabrication process, children are taught how to use the machines. If they need to go through a second or third iteration, they can use the machines on their own. Work in small teams is encouraged.

Longer term activity. In this category, children typically work in 5-10 days long projects where they must use different digital fabrication processes. In case of a school group, requirements for the project are usually set by the teacher. In other cases, the fab lab instructors set the requirements for the project. Children work with total freedom and they need to make their own decisions. Instructors, acting mainly as facilitators, provide support to children when needed: they explain processes and point children to online material and tutorials for more information. Outcome of the project is a tangible object that involves usage of different digital fabrication processes at the same time. Usually children work in teams of several members.

4.1 Conditions of convergence

The conditions of convergence emphasize that one should utilize aspects from children's existing life world as much as possible when aiming at empowering them. In our workshop, several interesting observations were raised around this.

The first reflective question in the framework on empowerment of children asks, **is it easy and natural for children to participate?** The local instructors agree that Fab Lab Oulu is not the type of place that the average child is familiar with: It is located at university campus and for children visiting our fab lab for the first time, it is commonly the first time they visit university premises as well. It is also a space full of people working on their own projects and with lots of unfamiliar noisy machines. The activities carried out at fab lab might look somewhat chaotic to children.

Differences between structure of the activities can also cause confusion to the pupils: Most activities carried out at fab lab are semi-structured or totally unstructured (with the exception of short-term activities). This can be a radical change for children who are familiar with more structured activities in their classes. Sometimes they might feel a little bit lost, without knowing how to continue. In general, our Fab Lab instructors observe that children, no matter the age, seem to be used to very guided activities and find it difficult to search information by themselves. Hence, it is important for instructors to follow the general atmosphere and act when there is a clear decrease of engagement. This can be challenging to the instructors who often lack pedagogical background and do not know the children, their strengths and weaknesses.

Despite these differences, we have noticed that pupils often adapt quite easily to the new environment. Especially the older pupils (ages 13-18) seem to value the freedom of the work. The new Finnish National Curriculum for education (NCBE, 2014) also promotes project-based learning. Hence, pupils are becoming more familiar to fab lab learning style. Thanks to the dissemination work made at Fab Lab Oulu and the growing interest of the local school community in STEAM pedagogies and digital fabrication (Sánchez Milara et al., 2019), the schools are also gradually integrating digital fabrication into formal education as another educational technology asset. Some of them have their own makerspaces as well. Thus, many of the pupils from those schools are already familiar with the basic concepts, processes and machines. For those children, fab lab is not as intimidating environment as might be for those who come to a fab lab for first time.

Even though pupils get familiar with fab lab in their school projects, our instructors have noticed that children very rarely return to fab lab to work on their own project. We have not explored yet the reasons, but as pupils visit fab lab as part of their schoolwork, we assume that they associate fab lab with school and not with an activity that they can do during their free time. So, organizing voluntary activities outside school environment might help children see digital fabrication also as a hobby.

The second question regarding conditions of convergence is, **are existing organizations and structures supporting children's participation relied on?** Fab Lab Oulu seldom organizes activities for children if a learning institution has not applied for it beforehand. Schools usually initiate the process by informing the fab lab staff that they would like to visit and giving information about group size and age of participants. During 2018 Fab Lab Oulu hosted around 1000 5-18-year-old pupils.

One aspect that our instructors remark is that teachers stay at fab lab during the activities but act just as observers and rarely intervene. It seems that teachers feel they do not master the topic, and hence they should step back. The instructors, then again, like to keep their facilitator or instructor role. In line with Laru and colleagues (2019) and Pitkänen and colleagues (2019) we believe that when working in fab lab is part of school activity teachers should be the ones designing the learning activity, including learning outcomes, didactics, and pedagogies. To that end, teachers should become aware of the fab lab potential and have certain knowledge of the processes. Fab Lab Oulu is currently training teachers both in the technical aspects and in the pedagogical use of processes and machines of the fab lab. Our instructors believe that in order to promote more educational activities in fab lab and to integrate them into formal education, the activities should have clear learning outcome that matches with the ones in the National Curriculum.

In addition to school activities, building a community around a fab lab is important and Fab Lab Oulu has been doing this in many ways. A local startup, run by university students, organizes after school clubs for children over 11-year-old in fab lab premises. In addition to that, they bring a Mobile Fab Lab, i.e., a small set of fab lab machines packed in a van, to schools all around Finland with the goal of presenting fab lab and digital fabrication to pupils and teachers. During 2018 they reached 2000 students. Fab Lab Oulu also attends different events organized by other institutions (especially events concerning education). Furthermore, in events organized by the university, we advertise Fab Lab Oulu to the general public. Fab Lab has participated in the European wide Researchers' Night, for example, for three years in a row. In 2019 more than 1400 visitors were hosted in just 4 hours. We believe that this is necessary to increase awareness of the fab lab, to show education stakeholders and parents the potential for fab lab for children as well as to create synergies with other organizations. Fab Lab Oulu also aims to attract current pupils to become future students in our university. To that end, collaboration with local schools is important and teachers should consider themselves as part of the community as well (Sánchez Milara et al., 2019). Creating a community takes a lot of time and effort but a fab lab can be only successful if there is a strong community around it.

Finally, concerning existing structures, we think that social media is an important source to advertise fab lab potential and different events. Fab Lab Oulu uploads most meaningful project results to different social media (Facebook, Twitter, Instagram, and Vimeo) and encourages pupils to share their work. We assume that this would make their own work more meaningful to themselves.

The third question regarding conditions of convergence is, **are the activities based on children's own issues and interests?** Actually, the entire Fab Lab concept originated from the interest of people to learn how to build objects that they cannot buy at shops (Gershenfeld, 2012). However, before it is possible to realize what can be done at fab lab and to start working in fabricating something meaningful you need to learn the basic functionalities and processes. When answering this question, time constraint is a central issue: Very short-term activities (~2 hours) in Fab Lab Oulu are guided activities, with the goal that children learn basic principles of a process and instructors decide the object children are fabricating and the process they need to use. The activity should still, of course, lead to a purposeful object with certain level or personalization for the participating children. In that sense, short term activities are not based on children's own issues or interest. In longer activities, design process is part of the learning process and pupils have a lot of freedom to decide on what to work with.

4.2 Conditions of entry

The conditions of entry emphasize broad, inclusive, voluntary and accessible participation of children. In our workshop, interesting observations emerged.

The first questions ask, **Have the participants been fairly selected? Has somebody been excluded? Why?** Short term and one day activities at Fab Lab Oulu premises are usually initiated by teachers who would like their pupils visit our premises. They get to know fab lab educational activities either through word of mouth, through advertising made by city representatives or thanks to any of our other activities (e.g. Mobile Fab Lab or Researchers' Night). Thus, teachers decide which classes and pupils visit the fab lab. In order to warrantee equality of opportunities among all schools in the area (including schools located tens of kilometers away from the fab lab premises and with no good access through public transport) the city government funds bus tickets for all classes who desire to visit the fab lab. In addition, one-day Mobile Fab Lab visits are arranged for those schools far away from Fab Lab Oulu premises. All schools in the area have been informed of the existence of this service. Thanks to these two measures, all local schools have had the chance of experimenting with digital fabrication.

We advertise the long-term activities among all local schools, by social media, by emailing to school administration, and by local city channels. After that, we open a registration process. If there are more applicants than open positions, we select the participants based on a motivation letter and CV/course grades.

Inclusion of students with special needs was raised during the workshop discussions. Among Fab Lab Oulu staff there are no experts to deal with special needs, but all children are welcome to the fab lab to carry out activities, and we have hosted pupils with different kinds of behavior and social disorders (e.g. autism spectrum disorder, ASD) with support from their teachers. Other than a computer room in the second floor the premises are accessible for wheelchair users. With pupils with motor disabilities, it is possible to use laptops downstairs and the staff has arranged videoconferencing system so that people downstairs can follow any class upstairs. All fab lab education involves group work. In that way, even when not all fab lab machines can be used by people with disabilities, children can participate in majority of the tasks. Their team members might perform the tasks that the person with disabilities cannot do.

The next questions regarding conditions of entry ask, **is children's participation voluntary? Why? If not, why?** Nature of the activity affects this in Fab Lab Oulu. If the activity is part of school work pupils' participation is not voluntary; it is part of their formal education and thus mandatory for them. As any mandatory task, some children like it and some do not, although mostly they seem to enjoy working in fab lab. All activities not organized by schools are voluntary for children. Only children interested in the activity register themselves. Sometimes, they are influenced by teachers or parents, but the instructors have never noticed a child that seemed to be forced to attend.

The next question regarding conditions of entry asks, **is the location and schedule for the activities easy to access for children and their families?** Fab Lab Oulu is located next to the University main entrance. The campus is located 6 kilometers away from the city center. University is well connected with the city either by public transport or by car. In addition, several cycling lanes cross the University campus. Most pupils from local schools come to fab lab premises either by biking or by public transport. Schools further away usually rent a bus. Majority of pupils participating in activities outside school hours come by bike or by public transport. We believe that the location is good. The current location inside university premises feels like a good selling point to attract children to get to know university and get some exposure to university life. Children participating in the activity usually share space with university students (either in the fab lab or other common places such as canteen). In addition, a fab lab visit is a good opportunity to get to know some of the research activities carried out at the University. For instance, many of the pupils attend a talk on Virtual Reality given by researchers expert on the topic.

Concerning the opening times, Fab Lab Oulu is always open during school time making school visits possible. In addition, the instructors agree that it is also necessary to have the fab lab open after school. In that way, children can later visit the fab lab on their own to work with their own projects or attend workshops organized in the fab lab.

4.3 Conditions of social support

The conditions of social support aim for supportive and encouraging atmosphere. In order to analyze the findings, we have divided the related questions in two different sets: collaboration in fab lab and behavior of participants.

The questions related to collaboration ask: **Is the environment supportive? Is there team spirit? How can this be encouraged? Do children support and encourage each other? How can this be supported? Are everybody's opinions and thoughts considered valuable?** Collaboration is one of the horizontal competences emphasized in majority of 21st century skills frameworks (e.g. the one proposed by Ananiadou and Claro, 2009). Maker culture has collaboration and sharing of knowledge as one of its foundations (see e.g. Dougherty, 2016). We believe that working in fab lab can be a natural way to learn collaboration and our instructors usually suggest pupils finishing their task earlier to e.g. help other pupils. Particularly in longer term activities, collaborative aspects become more visible as the activities are not very guided and usually some distribution of tasks between group members is needed in order to succeed in the project. We believe that the blurred role of teachers in Fab Lab Oulu (usually acting more like facilitators than traditional teachers) as well as instructors' expert role facilitate collaboration among children as they face that they should solve the problems by themselves without a teacher constantly guiding the steps.

One possible occasion to show the value of everybody's thoughts and opinions is when reflecting on the work done. In Fab Lab Oulu, instructors usually finalize each session of longer activities (one day / long term activities) with a short reflection on the status of the activities and problems faced. During this reflection, all children are encouraged to give their view. The idea is to share possibly useful approaches and show that similar problems occur. It is possible to learn from others how those can be solved. We have noticed, however, that it is very difficult to get all children talk and hence the efficacy of the reflection session might be smaller.

The second group of questions related to conditions of support ask: **Are all participants respected? Do all participants act friendly and politely? How can this be encouraged**? This is not an aspect that Fab Lab Oulu staff has worked explicitly, and they don't have training for how to handle e.g. behavioral problems with children. With school groups, teachers' role is important as they know the children and the type of relationship they have established with each other.

4.4 Conditions for reflection

The conditions for reflection aim for increased transparency in the process: who makes decisions, why these decisions are made, and how the participants evaluate the results. The first questions ask, **do power differences exist between participants? Have the power differences been deliberately negotiated?** In Fab Lab Oulu, power differences are completely different than in a normal school setting as the role of teachers and instructors are blurred. We think that in our short term-activities, the instructors act more like digital fabrication teachers, giving instructions that participants must follow. However, in our long-term activities, instructors act as experts in digital fabrication as well as facilitators, giving only pointers for children when they do not know how to continue. Our instructors argue that teachers' role changes in fab lab environment; they need to act more like counsellors than teachers. In that sense, the power differences are clearly reduced. Between children, due to differences in personality and skills, they spontaneously take different roles: some of them become group leaders, others designers, others work more with the technical aspects. Deliberate negotiations of power are not currently part of the practice in Fab Lab Oulu.

The next questions are related to decision-making: **Who makes decisions? Why? Do all participants understand reasons for decisions?** In short-term activities, almost everything is decided by our instructors. Pupils have certain creative freedom, but the processes are very guided. In long-term projects, children make most decisions. Fab lab instructors just define the goal of the activity (the expected outcomes), present the problems children must solve and sometimes list the processes children may use. After that children are free to work on their own project, choosing the methods that they desire with the support of instructors that would assist children when they need some advice. Hence, the vast majority of decisions are made by pupils themselves.

Regarding reflection on the process and outcome, the following questions are asked: **Are there occasions for all participants for critical reflection on the process and the outcomes? Are there occasions for evaluation for all participants, on both individual and group level?** We consider reflection as important part of learning. Because of that instructors in Fab Lab Oulu reserve time for public reflection where everybody is encouraged to provide their own thoughts after each working session: what tasks pupils have completed, what kind of challenges they faced, where they succeeded and where they failed. Sometimes teachers prepare a survey on the impact of the activity in the pupils and discuss the results later in their classroom. The reflection sessions make sense in long-term activities where children have had time to develop their ideas, to fail, and to find solutions to problems. These sessions do not seem to be easy for the children as they are not generally familiar with this kind of practice, and hence it is sometimes difficult to explain the value of reflection. Some children do not find the activity useful while others are very shy to talk. Hence, reflection sessions can be very difficult to conduct successfully and sometimes almost nothing comes out of it. Exploring different methodologies to make reflection session more successful would be beneficial, for example documenting step-by-step what was done in the activity.

4.5 Conditions for competence

The conditions for competence emphasize increasing children's competence during the activities. The first questions ask, **what kind of responsibility children have / do not have? Why?** In Fab Lab Oulu activities, the main responsibility of children is to attend the activity and to perform the tasks. In long term activities, children's responsibility is to operate the machines correctly after an introduction to the machine use and safety aspects. Instructors always follow the process though. We think this is part of the learning outcomes of the activity

The next questions ask, **who defines the goals for the activity? Are children allowed to take part in defining the goals? Why / why not? Do all participants understand the goals? Does everybody get a chance to contribute? Do all participants listen to each other?** As has been already discussed, in short-term activities, the goal is set by the instructors. In long-term activities the goal is usually to solve a problem. In that case, the goals are set by the instructor and/or teacher. Sometimes, pupils are asked to explore certain processes. In that case, they can define the goals of the activity themselves. When working in groups, children can decide how to achieve these goals, and sometimes they define subtasks with related goals and assign those to one or more members of the group. In these cases, children discuss the feasibility of the idea with instructors. We believe that as fab lab is a new environment for children it would be very challenging for them to define the goals of each activity. Some children come to fab lab to complete their own projects generally outside the school hours. In that case, children define themselves what they want to do and how. Instructors will provide support when needed. To achieve this, children must have adequate skills in some digital fabrication processes. The scope of the activities is planned in such a way that all children can participate if they want to. Some children are more active than others, but generally all of them contribute somehow.

The next questions are related to information: **How much information do you provide in the beginning of the activities? Do children have all information they need? How can they get it?** At the beginning of the activities Fab Lab Oulu instructors provide information on the goal of the activity and its physical outcome and functionality (if any); a short introduction to digital fabrication processes to be used, including the machines to use; examples of conducted projects; how to search for additional information (tutorials, keywords to use); schedule of the activity. During the activities, instructors give tips for information searching or show online tutorials.

The next question regarding conditions for competence ask, **do children's activities have real impact? Does the project result in tangible outcomes? Do children learn something? Does this learning build on top of previous knowledge/competences?** Children's activities really do have an impact. Something tangible is produced in all activities as that is one of the main goals of digital fabrication; this product is something that can be shown to others and can hopefully be a source of pride for children. In some cases, Fab Lab Oulu instructors showcase children's work in the fab lab 'display window' for everybody to see. Children have a possibility to give back something to the rest of the community as well if they end up working in fab lab on their own time and helping then other visitors. In addition, some of the activities organized by teachers in Oulu Fab Lab involved development of business plans and selling out the resulting products. Other schools have used funding obtained from selling products or organizing learning activities to buy new machines for their school makerspaces. Learning activities in fab lab can also be designed so that the goal is to build something that would help others or solve some existing challenge in the community.

At fab lab, children develop a new set of skills; they do not learn only technical and design skills but also some horizontal competences such as creativity, critical thinking, problem solving, computational thinking and collaboration. The longer the activity the more it is possible to learn. Defining the learning outcome should be the first thing instructors should consider when defining an activity. When organizing workshops in fab lab, sometimes this goal is not addressed explicitly in the setup phase, and this can lead to a total failure. Learning in fab lab is built on top of previous knowledge although sometimes children are not aware of that. For instance, when they are doing a 2D design, they need to understand the metric system, the different geometric figures, and what is a segment or a vertex. One big challenge for fab lab instructors is that they usually are not familiar with the background of children. That is why we believe that activities should be built in collaboration with teachers. Learning and competence development should be teacher-led as they have pedagogical competence. We see that they should also be the ones who evaluate children's learning.

The final question addresses an essential issue, **does the work process support children to initiate future projects by themselves?** Getting started with digital fabrication is perhaps the most difficult part. Getting to know the necessary software, machines and processes usually takes some time. When children are familiar with the basic information, know where to find additional information, and know also the possibilities of the different processes it is easier for them to work on their own. We aim to help children to build confidence and feel empowered to try new things. Our instructors always remind children that they are welcome to come to fab lab whenever they want, and that fab lab staff is there to help them. We also explain that it is impossible that they know about all the topics, but the knowledge can be built by doing and by getting inspiration from others - standing on the shoulders of giants.

4.6 Summary of the insights

In Table 2 we summarize the insight gained from our collaborative working, reflecting on the Fab Lab Oulu current practices in relation to the framework on empowerment of children (Chawla & Heft, 2002; Kinnula & Iivari, 2019), in the form of aspects that we propose all fab labs to follow when preparing activities with schoolchildren.

Conditions of Convergence

Is it easy and natural for children to participate?

When organizing activities for schools, teachers should be involved in the activity. They know better the children, their strengths and weaknesses.

Do not replicate same processes as in the school. Give children a chance to work on their own and make their own decisions.

Do not only organize activities for schools. Out of school activities might encourage children to continue to work on their own projects.

Are existing organizations and structures supporting children's participation relied on?

It is important to build a community with local schools.

It is important to educate teachers in digital fabrication. They need to know fab lab potential in order to collaborate more actively in designing of activities.

Educational activities can be outsourced to other organizations. They can reach such groups that are otherwise difficult to reach.

Do not focus on educational events only, it is important that the general public learns to know fab lab potential.

Use social media to promote events and encourage participants to use their own social network to share their work.

Are the activities based on children's own issues and interests?

In short term activities, try to fabricate a personalized object, providing a clear layout.

In long-term activities, give children an appropriate level of freedom to choose what to fabricate.

Conditions of Entry

Have the participants been fairly selected? Has somebody been excluded? Why?

Local government should be involved in advertising and organization of educational activities targeted to schools. They should facilitate transporting of children to the premises. In that way, there is no discrimination due to location of school or other social and economic factors.

When advertising activities it is important to reach as large number of schools as possible. Social networks and direct email messages to principals have worked in Fab Lab Oulu.

Before hosting an activity, participants should be asked if they need some special arrangements. In that way people with disabilities can also participate in the activity. Fab lab space should be as accessible as possible.

Is children's participation voluntary? Why? If not, why?

When teachers include any fab lab activity in teaching, the activity is generally mandatory for pupils. When designing the activity, the instructors should consider that some participants are possibly not going to enjoy the activity and they should be prepared for that. Traditionally, activities run in Fab Lab are targeted to Making enthusiastic and generally motivated people. This change might disturb some instructors.

Is the location and schedule for the activities easy to access for children and their families?

When organizing a school activity in fab lab, collaborate with partners nearby to offer other activities as well (e.g. visiting research centers in a university).

When organizing activities for school-age-children, it is important that fab lab is open during school hours as well as after school.

Conditions for Competence

What kind of responsibility children have / do not have? Why?

Make children's responsibilities visible and link them to learning goals.

Give children the chance to use the machines after explaining them safety issues. It helps them to feel ownership of the activity.

Who defines the goals for the activity? Are children allowed to take part in defining the goals? Why / why not? Do all participants understand the goals? Does everybody get a chance to contribute? Do all participants listen to each other?

Let children define the goal of the project when possible. Be sure that the goals match with the learning outcomes specified in the beginning of the activity.

Prepare activities with enough complexity so everybody has something to do.

How much information do you provide in the beginning of the activities? Do children have all information they need? How can they get it?

Specify children clearly the goal of the activity, expected learning outcomes, schedule and activity structure. In addition, it is recommended to give a short introduction to digital fabrication and the main processes children are using.

Try not to answer children's questions directly; teach them information searching processes instead and give pointers where to find more information. Follow their progress to assist when they are stuck.

Do children's activities have real impact? Does the project result in tangible outcomes? Do children learn something? Does this learning build on top of previous knowledge / competences?

Consider such topics for projects that are meaningful, sustainable and address existing problems in the community.

Aim <u>always</u> for a personal tangible object as an outcome of activities.

Encourage children to publish and advertise documentation of the work in social media / websites.

Have an exhibition space in your fab lab to showcase children's work.

Plan the activities children's learning in mind and build it on top of their previous knowledge. Discuss with teachers children's background and what knowledge they already have.

Does the work process support children to initiate future projects by themselves?

Tell children that first they need to learn and understand the basics and then it is easier to see the potential of digital fabrication.

Help children to see digital fabrication as a possible hobby.

Make sure that fab lab is accessible to children outside of school work.

Conditions of Social Support	Conditions for Reflection
Is the environment supportive? Is there team spirit? How can this be encouraged? Do children support and encourage each other? How can this be supported? Are everybody's opinions and thoughts considered valuable? Activities in Fab Lab promote collaboration among children naturally. Blurring the role of teachers and instructors, converting them into facilitators, seems to foster collaboration among children. A reflective discussion after a session might help to show children that their inputs are valued by the group. However, it is difficult to make all children participate actively in reflection. **Are all participants respected? Do all participants act friendly and politely? How can this be encouraged?** In general, there is cordial and collaborative behavior among the participants. Teachers can help with behavioral problems as they know the children.	**Do power differences exist between participants? Have the power differences been deliberately negotiated?** Power differences in school and fab lab are different; role of teachers and instructors become more blurred than in school environment. **Who makes decisions? Why? Do all participants understand reasons for decisions?** In long term activities pupils usually make decisions; they decide how to tackle the proposed problem. In short term activities the instructors guide the pupils and make most decisions. **Are there occasions for all participants for critical reflection on the process and the outcomes? Are there occasions for evaluation for all participants, on both individual and group level?** Reflection sessions are useful and should be run after each session. However, they are difficult to conduct.

Table 2. Insights from reflection of Fab Lab Oulu practices with the framework of empowerment of children

5. DISCUSSION

In this study, we wanted to understand the potential of Fab Lab in empowering children to make and shape digital technology, and what kind of best practices, limitations, or challenges can be identified.

5.1 Research implications

The contribution of this study comes through a detailed, practice-based contemplation on the potential of fab lab as a site for empowering children to make and shape digital technology. Even if the studies have already brought up fab lab as a site for engaging children in design and making activities (Blikstein & Krannich, 2013; Iivari & Kinnula, 2018; Iivari, Kinnula, & Molin-Juustila, 2018; Iversen et al., 2016; Katterfeldt et al., 2015; Posch & Fitzpatrick, 2012; Posch et al., 2010; Pucci & Mulder, 2015), the particularities of fab labs as such a site have not been scrutinized. Particularly novel and valuable is the inclusion of fab lab personnel in the contemplation of these issues. They have years of practical experience on working with children and teachers in design and making projects in fab lab. Such an experience is now combined with a research-based understanding of the conditions for empowerment of children to make and shape digital technology. Through this, we managed to generate a rich and empirically grounded set of insights on fab lab best practices, limitations, and challenges around empowerment of children. This enables taking the framework proposed by Kinnula and Iivari (2019) a step further. Kinnula and Iivari (2019) critically considered the conditions for the empowerment of children and proposed a set of questions to ask when aiming at empowering children to make and shape digital technology. This study offered a needed, practice-based evaluation and refinement of the questions. The resulting insights should be useful for practitioners working in fab labs as well as in other informal learning settings with children. In addition, the insights should be useful broadly for researchers interested in the empowerment of children to make and shape digital technology through design and making (e.g. Iversen et al., 2017).

5.2 Implications for practice

Based on the insights presented in Table 2 we formulated a set of guidelines for practitioners arranging school visits to fab lab or working with children in fab labs or more broadly in different kinds of non-formal learning settings:

When you are **preparing your fab lab for working with children**:

- Determine what are your goals and motivation for the work as they affect what you do and how you work with children.
- If teachers are involved, organize training also for them. It is important they understand the potential of digital fabrication.
- Organize every now and then events to the general public. It helps to advertise Fab Lab, and that kids are interested in attending to the activity. Use social media to promote the events.
- Sometimes, organizing activities might be outsourced to other partners, for instance, startups.
- Sometimes schools or other organizations working with children face difficulties to gather resources for travelling to fab lab. Try to involve local administration and organizations, in such a way they can put adequate

resources, and avoid discrimination due to location or economic factors.

- Consider your resources, including space to work in, personnel, machine time, physical materials, needed knowledge and education. Be sure that they are adequate enough.

When you are **planning the activities**:

- Remember to ask if there are children that need any special arrangement.
- When possible involve teachers in activity preparation. It is always better if teachers have some training in digital fabrication. It is important that they understand the potential of digital fabrication and how it can be integrated in the curriculum. Discuss with teachers what is the background of the children. Define learning outcomes, methodologies and goals of the activity together
- Learning outcomes and goals should be thought carefully. This should provide the basis to build the activity. Consider that children are going to learn from each other at the same time. Consider also as learning outcomes horizontal competences such as creativity, critical thinking, collaboration or computational thinking.
- Be sure that at the end of activity children build something tangible, better if they can take it home. Try that the object is something purposeful: something that can be used later by themselves or that could help others.
- Use appropriate teaching methods: project-based learning and learning by doing work better for long term activities; tutorial type activity works better if time is shorter
- Activities with schools are usually a mandatory activity for all children. When preparing such activities consider that not all children are going to enjoy it. Try to build a contingency plan for this situation.
- In short-term activities it is better if the goals and methods are defined by instructors. In longer-terms activities, children should try to define the goals and methods by themselves. Instructors could take part in the decisions, guiding children according to what is feasible or not.
- Consider the number members in work groups. Adapt the goals according to that.

Consider the following **during an activity:**

- At the beginning of the activity describe very clearly to children (and teachers): Expected learning outcome; Goal of the activity - what physical object you expect to have after the activity; Short introduction to the digital fabrication process/processes to be used including how to use the machines; Duration and structure of activity, including the reflection sessions; How children can find more information: which online resources are available, which keywords they could use to find information
- Inform children about how to operate the machines and safety instructions. Afterwards, when possible, let children operate the machines. Operating machines safely is an important responsibility for them.
- Advertise other activities that children can do outside school hours (if any)
- Encourage participants to use social media to share their work.
- Understanding roles of instructors and teachers are important. There is an important change to what children are familiar with: Initially an instructor is seen as a teacher, but when children understand the mechanics they are seen as facilitators; Teachers, if present, can assist instructors. They know better the strengths and weakness of the children. From the children’s perspective, teachers have more authority than instructors, so teachers can help to correct some misbehaviors. Anyhow, power difference between teacher and children is reduced in fab lab environment

- Instructor should act as a facilitator, not as a classical teacher. Provide pointers so children can find the answers, do not answer their questions directly. Let children to make mistakes.
- Conduct a group reflection after each session, trying that all children participate. This should make them realize of the things they have learnt and that their ideas could help others. Note that organizing a good reflection session is challenging. Children are not familiar with them, and some of them are very shy to talk. Asking children to document their work might help to conduct the reflection session.
- Teacher, if present, can help to form balanced working groups. Inside a group, we prefer to let children assign roles by themselves. Be flexible, roles might change during activity.

After an activity consider these:

- Try to run a questionnaire both to teachers and children: what worked, what did not work. This will help to improve the activity.
- When possible, make public all content related to the activity, with pictures of the resulting objects and even children's/teacher's opinions. This will help other fab labs who are in the same situation.
- Try to have fab lab open outside school hours. This will help children with special interest to make any kind of project at fab lab on their own time.

6. CONCLUSIONS AND FUTURE DIRECTIONS

In this paper, we have provided rich practical insight and guidelines for working in fab lab with schoolchildren and in collaboration with schools. Behind these guidelines is our firm belief that learning to design and make digital technologies is empowering for children as such, and that with a careful consideration of the working practices it is possible to further support children's empowerment and help them to make and shape their technology-rich world. We hope that these guidelines are helpful for both fab lab personnel – instructors and managers alike – as well as teachers or city administrative staff who plan to work in collaboration with a local fab lab.

This study is limited by its focus on practices of a single fab lab in Finland. Fab Lab Oulu has had extensive collaboration with local schools, however. For future research, we suggest examining further the roles of all different stakeholders somehow related to fab labs and how they can, on their part, help in making the collaboration between schools and fab labs a seamless whole with equal opportunities for all schools and children, regardless where they reside.

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