Supporting Fab Lab facilitators to develop pedagogical practices to improve learning in digital fabrication activities

Kati Pitkänen[†]
Faculty of Education
University of Oulu
Oulu Finland
kati.pitkanen@student.oulu.fi

Megumi Iwata
Faculty of Education
University of Oulu
Oulu Finland
megumi.iwata@student.oulu.fi

Jari Laru
Faculty of Education
University of Oulu
Oulu Finland
jari.laru@oulu.fi

ABSTRACT

Planning and facilitating digital fabrication activities, where students engage in creating tangible artefacts with digital technology, requires knowledge on both technology and pedagogy. Currently, most of the studies see facilitators of digital fabrication activities as technology experts and there are only few studies regarding them as educators. There is not much discussion from the learning sciences point of view, considering what are the requirements to enhance learning in the activities. To fill these research gaps, this paper aims to provide theoretically grounded practical suggestions of how the facilitators may contribute to improve students' learning in digital fabrication activities based on learning science propostions. The aim of this study was to explore, *how Fab Lab facilitators and school teachers can design digital fabrication activities to support students' learning*. We explored the current practices in Fab Lab Oulu from the two perspectives: considering novice students' learning and scaffolding ill-structured problem-solving. We suggest that the facilitators may improve students' learning by taking into account their background and current learning processes, applying instructional scaffolding, and supporting teachers involvement to take active role in the activities.

CCS CONCEPTS

• Applied computing • Social and professional topics → Professional topics → Computing education → K-12 education

KEYWORDS

Digital Fabrication, Fab Lab Facilitators, Teachers, Activity Design, Scaffolding, Ill-structured Problem Solving.

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1 Introduction

Digital fabrication is commonly described as a process of making physical objects utilizing digital tools for designing. Digital fabrication activities can be conducted in the context of a Fab Lab that is a technical prototyping platform, being "comprised off-the-shelf, industrial-grade fabrication and electronics tools, wrapped in open source software" [[9]]. An inventory of machines and equipment recommended by the Fab Foundation includes 3D printers, a laser cutter, a high-resolution milling machine, a large CNC milling machine, a vinyl cutter, an electronics workbench, and a suite of tooling and materials. Fab Labs incorporate flow and experiment-based learning through project-based, interest-driven, student-centered knowledge construction towards liberating and amplifying students [[3],[26]].

Digital fabrication activities, where students engage in realising abstract ideas and creating tangible artefacts with digital technology, include special characteristics on the field of engineering and the field of education [[2],[5]]. We claim that such activities require both technological knolwdge and pedagogical knowledge. In addition to technical coping, it is beneficial to understand and consider the processes of how people learn to utilise the activities' potential for learning. Along with the suggestions to apply digital fabrication in formal education, research of how the activities would be introduced to school environments is necessary [[3]].

In practice, firstly, it is essential to design the activities considering the processes of (novice student') learning, in order to use digital fabrication activities as one pedagogical tool to achieve the goals and skills defined in curriculums, rather than a one-time project arranged by Fab Lab facilitators. Secondly, it is important to involve teachers to take the advantage of their pedagogical professionalism and curriculum expertise. Teachers' experiences and knowledge of the students, students' personal qualities and their learning processes are important, for example, while forming the working groups and taking account ongoing classroom practices [[22]].

Most of the previous studies describe Fab Lab facilitators as technology experts instead of as educators. The studies have focused on researchers', makers' or technology experts' point of views incorporating the idea of *what should teachers learn to lead a makerspace.* There are few studies about the design and implementation of digital fabrication in education from the learning science and teachers' point of view; considering the opposite perspective and respecting the idea of what should technology experts take into consideration in planning and facilitating students' learning processes in digital fabrication.

This study encourages discussion in the field of digital fabrication from learning sciences' point of view. We look into ongoing discussion towards learning by ill-structured problem-solving activities, and discuss novice students' learning, remarking what facilitators may need to take into a consideration to improve students' learning in digital fabrication activities. Our previous study [[28]] found that Fab Lab facilitators and school teachers have different perspectives towards the current structure of digital fabrication activities. Considering these different perspectives as a starting point, we aimed to explore, *how Fab Lab facilitators can design digital fabrication activities to support students' learning.* Focusing on the activity design and the facilitators' ways of conducting the activities, we examined school teachers' considerations and the facilitators' own reflections towards the current practices. Our intention was not to identify either sides' lack of competences, but to elaborate the perspectives and provide theoretical grounding to support the development of the activities. The research questions of this study are as follows:

1. What identifies ill-structured, open-ended digital fabrication activities?
2. What kind of needs for scaffolding exist in ill-structured, open-ended digital fabrication activities?
3. How can Fab Lab facilitators and school teachers design digital fabrication activities which support students' learning?

2 Learning Science Propositions in Digital Fabrication Activities

Cohen, Huprich, Jones, and Smith [[6]] made attempt to fill the gap by exploring educational and teacher students' perceptions of a maker-based learning experience. Hauer and Daniels [[16]] had a learning theory perspective on running open-ended group projects in engineering education. Also, several studies [[8],[17],[33]] have listed differences, possibilities and challenges of digital fabrication in relation to traditional school context from the teachers' new role or school point of view. However, there is a lack of research which considers the fundamental requirements from the learning perspective, when proposing to apply or implementing workshops and courses of digital fabrication in formal education contexts.

2.1 Scaffolding Novice Students' Learning

Not all students who participate in digital fabrication activities have previous knowledge and experience in the field. Moreover, many of them are not used to the applied work methods that require competences such as self-regulation, self-efficacy and persistence [[28]].

It is necessary to understand how novice learners construct knowledge and what challenges they may face in the process. First, compared to an expert, a *novice learner* has limited or non-existent experience of the content [33]. Second, one of the most remarkable differences of learning between novices and experts relates to *human cognitive architecture* (short-term memory, often referred to as a working memory) and long-term memory), which is limited in duration and capacity [[11],[23]]. Thus, novices may have more difficulties in learning, compared to experts who have stored long-term memory which they can apply. Based on human cognitive architecture and previous empirical researches, for a novice student, minimally guided instructions are less effective and less efficient than instructional approaches that emphasise direct guidance on learning processes [[23]]. Direct instructions can help students' deep learning and ability to recall and transfer knowledge to solve new problems [[27]]. Guiding novice students' cognitive processing (e.g., selecting, organizing, and integrating knowledge) not only affect current learning outcomes, but also enhances problem-solving skills itself [[27]]. Thus, it is not straightforward to find the balance between fostering students' imagination and creativity and limiting their freedom to help them proceed [[4]].

Vygotsky [as cited in [30]] stated, "the difference between what a learner can do alone and with appropriate guidance is called the zone of proximal development" (p. 620). Wood, Bruner, and Ross [[35]] defined *scaffolding* to be a process "that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" (p. 90), consisting of the activities provided by an educator to support a novice through the zone of proximal development. Scaffolds can be arranged in the form of *technical scaffold*, such as process worksheet [[23]], mind map, documentation or whiteboard to raise and communicate a problem-solving process [[19]], and through the *human facilitator* for example by question prompts [[12]], visual scaffolds [[1]], providing useful strategies and approaches to a task [Applebee, 1986, as cited in [10]] and demonstrating or modelling solutions to a task [[35]].

By scaffolding, teachers can support students' learning on not only how to conduct a task, but also on why it should be done in a certain way and monitor and recognise students' learning processes to gradually fade their visible support [[18]]. However, Alibali and Nathan [[1]] remarked that scaffolding is not necessary to be faded but instead, may even increase due to students' advancement, in response to their more advanced questions.

2.2 Needs for Scaffolding in Ill-Structured Problem-Solving

In the context of digital fabrication and Fab Labs, ill-structured problem-solving activities are typical. *Ill-structured problem solving* involves working on complex, ill-defined, *open-ended*, and real-world problems, incorporating one or several unspecified aspects, unclear goals, and insufficient information to solve them, which rarely have any single, correct solutions [[15]]. Although ill-structured or open-ended problems are the ones people encounter more frequently in everyday practices and industry, the well-structured problems are more common ones encountered in traditional school contexts [[15],[16],[21]].

The key factors in effective *instructional scaffolding* include appropriateness of the instructional task build upon student's previous knowledge and skills and adding a new challenge to learn, and a structured learning environment including providing students with useful strategies and approaches to the task [Applebee, 1986, as cited in [10]]. Alibali and Nathan [[1]] concluded that *greater scaffolding is needed at least in three situations*: 1) when new instructional material is introduced, 2) for material that is more complex or more abstract, and 3) scaffolding may increase in response to students' questions. They suggested that by providing appropriate gestural grounding, educators can scaffold students' comprehension of instructional language and foster their learning of lesson content.

3 Research Methods and Case Description

To learn the context and examine initial practices of digital fabrication activities arranged in the context of Fab Lab, we adopted characteristics of ethnographic case study. In ethnography, researchers immerse in to the cultural scene studied and observe and interact with participants for a certain period to understand and record detail aspects of the phenomenon [[14]]. A case study is an investigation about the case(s), focusing on what can be learned from the specific, unique, single or multiple cases [[34]].

3.1 Context and Subjects of the Study

We investigated activity design, instruction and facilitation in digital fabrication activities arranged for students in Fab Lab Oulu, in Northern Finland. The Fab Lab, located at the University of Oulu, was established in 2015. Since that, there have been continuing interests to understand the digital fabrication activities in the Fab Lab from the varying perspectives [e.g. [13],[28],[23],[30]]. For example, through Fablab4School -project (http://fablab4school.fi/), Fab Lab Oulu has arranged different type of digital fabrication activities for school groups [[23]]. The activities have typically included: 1) 2D- and 3D -designing and manufacturing, 2) prototyping with electronics, 3) programming incorporating the basic programming of embedded systems with a high-level programming language, or 4) utilizing the tools and machines at the Fab Lab to fabricate prototypes [[30]].

We focused on the three cases of schools (A–C) participating in digital fabrication activities in Fab Lab Oulu in October and November 2016 (see Table 1). The school participants, in total 41 students (aged 12–15 years old) and five teachers, were from three secondary schools in the city of Oulu. The activities were facilitated by two technology experts, who work in the Fab Lab. One of them has background in electrical engineering and another in ubiquitous computing and human-computer interaction. In this study, we call them as Fab Lab facilitators. The students worked on projects as teams with different design briefs and required conditions provided by the facilitators and/or the teachers (see Table 1).

Table 1. The three schools participated in digital fabrication activities in the autumn 2016

Activity Design	Case I: School A	Case II: School B	Case III: School C
Period	5 days	3 days	5 days
Design Brief	Open-ended topic given by the facilitators: students were completely free to ideate their project	Open-ended theme given by the teachers: Finland 100 years; students were free to ideate their project	Design brief given by the teachers as part of ongoing project at school: Playhouse; students were free to design a playhouse for their school
Required conditions	Use Arduino Uno as a microcontroller and Use at least one actuator Fabricate mechanics using laser cutter or 3D printer Make functional artefacts in 5 days	Use Arduino Uno as a microcontroller Fabricate mechanics using laser cutter	The playhouse needs to serve the whole school community, students in 1st - 9th grade

Projects	Useless box Rail for a camera Electronic controlled lock Jukebox game Music car	Finland 100 years calendar Finland 100 years history wheel Finland's flag day clock	Two prototypes of playhouses

3.2 Data Collection and Data Analysis

First, in order to understand the context and the current activities, we conducted participants observations. Additionally, we carried out informal interviews of 13 students, the five teachers, and the two facilitators during and in the end of the activities.

Second, we investigated the perspectives of the two expertise groups: Fab Lab facilitators and school teachers. We carried out two semi-structured focus group (FG) interviews of the school teachers (FG I) and the Fab Lab facilitators (FG II). In February 2017, we conducted FG I for school teachers, who participated in the activities with their students. The facilitators participated into FG I as observers. In March 2017, we held FG II for the facilitators to investigate their opinions, including their reflections based on observation of FG I.

Third, in order to learn and develop our understanding of the principles of tools, processes and the context, we familiarized ourselves with Fab Labs and digital fabrication since the autumn 2016. Two of us conducted internships in Fab Lab Oulu (www.oulu.fi/fablab/) in Finland for three months (Iwata, autumn 2017), and in FabLab@SCHOOLdk partnership (http://fablabatschool.dk) and FabLab Silkeborg (campusbindslevsplads.dk/index.php/fablab/) in Denmark for five months (Pitkänen, 2017–2018). We observed and participated to organize different digital fabrication events, as well as discussed with diverse participants, such as students, school teachers, school leaders, Fab Lab leaders and Fab Lab facilitators. Additionally, two of us participated in Fab Academy (http://fabacademy.org/).

We analysed the observations data of the three school visits including field notes and transcribed informal interviews of the facilitators, the teachers and some students, and transcribed and analysed the data of the two FG interviews. We focused on finding participants' descriptions and perspectives of the current digital fabrication activities arranged in Fab Lab Oulu. To examine the design and implementation of the activities, we used theory-driven analysis strategy applying the definitions of ill-structured, open-ended problem solving described by Ge and Land [12]. We employed data-driven analysis strategy focusing on the different perspectives of the facilitators and the teachers regarding the structure of the activities, as well as emerged needs for scaffolding and considerations to develop the activities. Our analysis process followed the five key stages for qualitative data-analysis including: 1) familiarization with the data, 2) identifying a thematic framework, 3) coding, 4) charting, and 5) mapping and interpreting the data [[29]]. Since the sample size of both FG interviews was small, we limit to specify individual participants and instead, we group the three secondary school teachers together as *the teachers*, and the two Fab Lab facilitators together as *the facilitators*. We use group of people as unit of analysis [[25]].

4 Results

4.1 What Identifies Ill-Structured, Open-Ended Digital Fabrication Activities?

Digital fabrication activities arranged in the context of Fab Lab Oulu had characteristics of ill-structured, open-ended problem-solving activities that incorporate hands-on experience. Instead of designing and providing fixed topics, the facilitators set required conditions regarding the tools and electronic components to use (School A and B, see Table 1) which after they gave students freedom to come up their own projects. The activities did not follow any premade structure or schedule, instead the students were free to organize their working. The facilitators promoted students' self-efficacy and self-regulation on learning, as one facilitator described: "We are not teaching them, students have to learn more actively by themselves and more as a group".

To guide the students' working, the facilitators presented some of the previous projects completed at the Fab Lab, provided instructions of basic operations of the machines, software and processes, and supported students who had problems. The facilitators did not give straight answers but pushed the students persistently think by themselves:

> ….When they were making certain prototypes, they somehow made mistakes, and after they realized something had gone wrong, they began to search for solutions. Eventually, they learned how to fix the problems on their own. This is what we call "Black Box Thinking", you make a mistake, you check the cause, and correct yourself.

4.2 What kind of Needs for Scaffolding Exist in Ill-Structured, Open-Ended Digital Fabrication Activities?

We found needs for scaffoldings among different perspectives between teachers and facilitators towards the activity design and facilitation, and the level of instruction. The facilitators wanted to provide opportunities for students to have freedom and creativity in their self-driven project-management and problem-solving. The activities included experiments, and repeating trials and errors, which encouraged students to be responsible on their own learning. The importance of scaffolding was revealed during the activities. Students had challenges in their project- and time-management, causing stress of the limited time left. The teachers mentioned that they would have *defined goals, prepared the activities more thoroughly and structured the activities to have breaks and time for thinking and creativity*.

4.2.1 Needs for defining learning goals and providing instructions. The teachers agreed on that to improve learning, it would be beneficial to make goals more transparent to students and advice students both about the overall process and methods applied in the process, such as collaborative problem-solving. One teacher reflected that brief introduction to the content, for example principles of 2D designing or programming with a microcontroller, would have increased students’ understanding of the time required for design and fabrication.

One facilitator noted that although some students had previous experience and content knowledge to proceed the project with less guidance (e.g. providing only keywords to search information), especially the younger students needed more guidance. The facilitators realised that the students lacked understanding of what they need for solving their problem, in order to consider where they can search this information and evaluate what is relevant information. They found that the students lacked technical terminology, which is essential for using specific keywords for searching information. Furthermore, they noticed that the information for technical problems, which is often written in English, caused an additional challenge for younger students or those who were less competent in the foreign language.

The teachers would have put more effort on *scaffolding students’ learning* by limiting the freedom and giving them more specific instructions. For example, the students from School A (see Table 1), who had full freedom on choosing the topic, had challenges to get started. It was their first time to participate in the activity in the Fab Lab, and they had no idea what can be done in that context and in a given period (five school days). Yet the groups eventually came up with the product ideas, and designed and fabricated them, it was observed that only some of the students were able to proceed with the given minimum instructions. The rest of the students were mainly able to follow and conduct some simple tasks delegated by advanced group members. Additionally, one teacher remarked that students needed scaffolding in self-evaluation on their learning, to recognize by themselves what they have learned.

4.2.2 Needs for instructional designing and structuring the activities. The lack of structure in the activities made both the teachers and the facilitators point out needs on scaffolding learning. One facilitator reflected that students spent too much time on ideation processes reducing the time to complete the projects: “Maybe there was not enough time for thinking and maybe thinking of what options are, but you just had to select something and start doing”. The facilitator considered that short time of the activities caused the rush: “I think one week is a bit too short for all the things our students need to learn, and I believe if we were given more time, our students would have been able to achieve more things.” *Considering the processes of learning*, the facilitator recognised the weaknesses on their “minimal guidance” approach:

> ….I feel like that we should guide them more…. giving them more guidance in choosing appropriate tasks they want to learn, because sometimes the tasks they choose might be too demanding for them to learn in a limited period time.

One teacher considered that providing a clear structure of design process could have helped the students on their project management. However, even though the teachers in general did not fully subscribe the facilitators’ “minimal guidance” approach, one teacher considered that it might make some sense “to let children go on.” Also, the facilitators used some scaffolding techniques, which the teachers found supporting students’ learning. For example, one facilitator made logical thinking visible for students by the demonstration of logic ports on a microcontroller, that was carried out by asking students to act as part of the logic port and consider their logical reactions in different situations. The facilitators got reinforcement also of the mid-term wrap-up sessions they held for students, which the teachers found supporting students’ reflection on their project phases and learning.

4.3 How can Fab Lab Facilitators and School Teachers Design Digital Fabrication Activities Which Support Students’ Learning?

During the activities in the Fab Lab, the roles of the teachers were mainly observing the activities and maintaining general schedule of students. The teachers, who were not familiar with digital fabrication, described that they had almost no clue what can be done in the Fab Lab. Likewise, both facilitators described the biggest challenge in conducting the activities to be that teachers were not familiar with Fab Lab nor digital fabrication processes, which impeded them to participate in designing and facilitating the activities: “basically we need to guide the whole process.” However, the same issue went also the other way around, since the facilitators did not know students nor their existing knowledge to be able to consider it in activity design and implementation: “These kids are bit too young, they did not have mathematical background and they didn’t remember what is pi,” indicating the *lack of collaboration between Fab Lab facilitators and school teachers*.

To avoid digital fabrication activities to be considered as an extra project at schools but instead, make teachers keen to apply the processes into their teaching practice, the facilitators saw it fundamental to train teachers. They considered that in order to facilitate the activities in co-operation, teachers should first join the activities and learn digital fabrication. To make teachers rethink their ways of teaching, for example link subjects and learn programming to solve some real life problems using digital fabrication, one facilitator expressed willingness to organize workshops and give teachers first-hand experiences similar to students: “Let them make design process, design some kind of device that can be fabricated in Fab Lab, to see what…. children will face in Fab Lab” and – not only as a workshop to introduce the machines but rather – provide teachers with ideas how to integrate the activities in education. Likewise, one teacher considered that facilitators could make teachers more familiar with the do-it-yourself philosophy, working on projects and combining different skills to make something concrete:

> ….If you sort of start with teachers, you multiply effect, because teachers are not there breaking the process…. [without teachers] you don't really get it as a part of the school culture, and then it's just becomes the nice place with those nice technology.

The facilitators thought that they should put more emphasis on collaboration with teachers to increase effectiveness of the activities. In the future, the facilitators would like to provide the facilities, technical support and fresh ideas to teachers, while teachers, who know students and their capabilities, could initiate and prepare the projects in advance at schools, define learning outcomes, and facilitate the activities.

5 Discussion

In order to develop digital fabrication activities to support students' learning, we provide suggestions to integrate instructional scaffolding in the activities considering novices' learning and the nature of ill-structured problem-solving activities. The suggestions are based on the identified four essential elements of designing digital fabrication activities, which are illustrated in the figure 1, as well as Fab Lab facilitators' and school teachers' general expertise in designing such activities for formal education.

The first two elements relate to *develop pedagogical practices in the activities* recommending to:

1. Consider processes of learning as a base for activity design
2. Provide instructional scaffolding to improve learning.

The following two elements suggest design the activities in collaboration to enhance applying digital fabrication in formal education, recommending to:

3. Familiarise teachers with Fab Labs and digital fabrication activities
4. Increase collaboration between Fab Lab facilitators and school teachers.

5.1 Developing Pedagogical Practices for Scaffolding

Nor providing only a setting for open-ended problem solving—neither the pure subject, that is often approached in a well-structured manner—are not enough to achieve learning [16]. Based on the first two essential elements, we propose pedagogical practices that Fab Lab facilitators can apply to scaffold students' learning.

Although our previous study showed that fluent and flexible time frame enhanced students' project management skills [[28]], this kind of activity design also faced one of the biggest perception differences between the facilitators and the teachers. The teachers explained that working for a long time without breaks and rushing in the end because running out of time to complete the projects may negatively influence on students' performance and creativity [[28]].

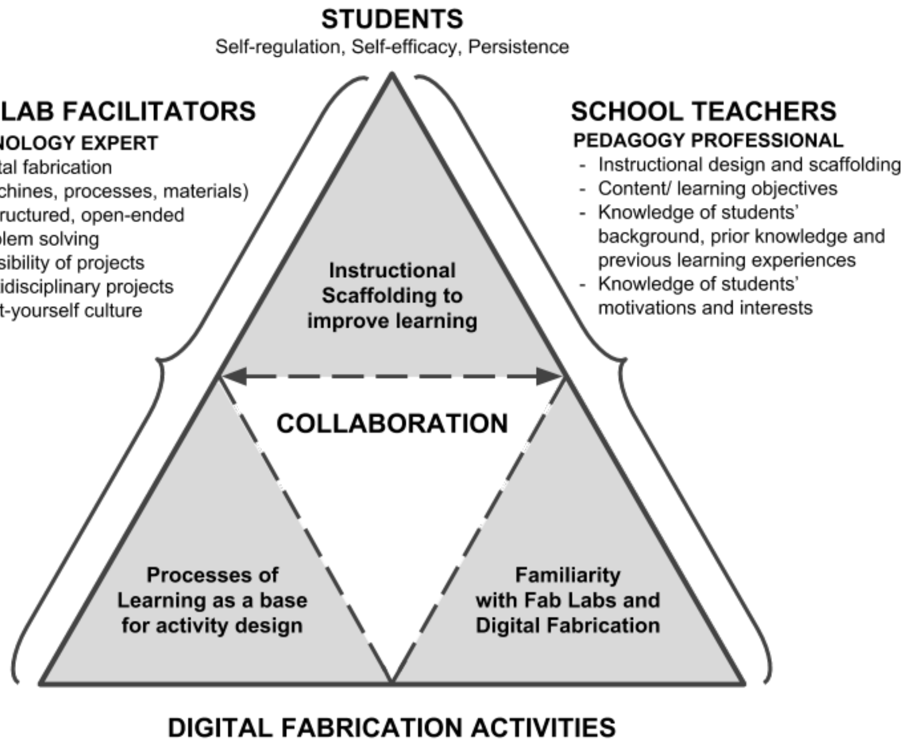

Figure 1. The Essential Elements of Designing Digital Fabrication Activities to Support Students’ Learning

Further, the facilitators considered students spending too much time on ideation process reducing the time to complete the projects. As technology and engineering experts, the facilitators have an ability to evaluate complexity and feasibility of the projects that students are proposing, in order to ensure learning possibilities and benefit the outcomes. Students themselves, as well as many school teachers lack this ability since they are novices on digital fabrication.

Furthermore, we found that the ill-structured, open-ended projects included *too much content for students who had limited skills and time period*. According to Applebee [as cited in [10]] and Daniels, and Hauer [[7]], educators need to reserve adequate time and consider appropriate learning content for students. Designing the activities considering students’ prior knowledge, learning experiences and skills in digital fabrication relates to feasibility: what contents are the students in question able to learn in a given time without rush, having enough time for critical thinking, decision making and reflection.

The teachers and the facilitators claimed different perspectives towards facilitation: while the facilitators intentionally designed the activities as self-directed without strict structures, the teachers’ answers revealed that insufficient scaffolding hampered some of the students to contribute their group’s problem-solving processes on one’s own initiative. As Alibali and Nathan [[1]] stated, new instructional material, especially complex and abstract contents, requires greater scaffolding. Fab Lab facilitators need to consider, test, observe, and adapt the way and level of guidance and scaffolding based on interactions with the students. As Daniels and Hauer [[7]] remarked, scaffolding needs to meet the level of a student, where too much scaffolding leads to non-challenging setting and frustration of a student, whereas too little scaffolding leaves a student without actual help.

Fab Lab facilitators can scaffold students learning, first of all, by making goals and process clear. In the current activity design, freedom in design brief and framing the task caused challenges to get started, direct and proceed the project. Providing student s with design briefs and expediently frame their projects would benefit engaging students for design challenges [[20]] and enable them to gradually navigate through their own open-ended problem-solving processes [[32]]. The facilitators can make goals and processes visible to student s, and support their creativity, critical thinking and reflective working through trials, errors and iterations. Especially when facilitating novice student s, it is important to consider *adequate instructions of the processes*.

Second, Fab Lab facilitators can scaffold students to search and select relevant information. For example, when the facilitators provided students with keywords to use for search, they scaffolded the students to focus in correct direction but made them maintain the control of their problem-solving process. The facilitators can make key aspects of their expertise visible through questions that scaffold students' thinking and learning, model an investigation model to emulate and the kinds of questions that students need to be asking themselves, and coach in sense making, searching and selecting relevant information, articulating and arguing their decisions, and reflecting on their learning.

5.2 Supporting Teachers' Active Involvement

In addition to developing instructional scaffolding practices, facilitators may improve students' learning in the activities by supporting teachers to take active role in the activities. According to the latter two essential elements, ensuring teachers' familiarity of digital fabrication is necessary to utilize their pedagogical professionalism in the activities. Teachers knowledge of students, such as students' background and current learning processes, are beneficial to plan and implement the activities [[22]].

The facilitators mentioned that in the future, they would like to provide mainly the facilities and technical help, while teachers could define learning goals and be in response on facilitating the activities. To reach this situation, *the facilitators cannot externalize themselves from the activities*, rather they could investigate and consider students' background and utilise teachers' pedagogical and curriculum professionalism. The facilitators can act as technology experts, but collaboration is needed to take the advantage of teachers' experiences and knowledge of the students, students' personal qualities and learning processes. Preparing and informing teachers about the aimed working methods and structure, dialoguing and discussing learning objectives, and defining the goals together beforehand, could benefit the collaboration as a starting point.

6 Conclusion

We explored, *how Fab Lab facilitators and school teachers can design digital fabrication activities to support students' learning* based on two learning science propositions: novice students' learning and scaffolding ill-structured problem-solving activities. We examined facilitators' and teachers' perspectives towards the current practices of digital fabrication activities in Fab Lab Oulu. To utilise the full potential of digital fabrication activities for schools, we claim that it is necessary to develop pedagogical practices in the activities. Finally, we emphasise that in order to design the activities that can improve and foster students' learning, it is crucial to increase collaboration between Fab Lab facilitators and school teachers and discuss different perspectives to see what we can learn from each other.

As limitations of the study, we are aware that the sample size of the study was small (three teachers in the first focus group and two facilitators in the second focus group). Therefore, instead of specifying participants, we limited to not specify individual participants, which may affect the trustworthiness and transferability of the study. For future studies, it is important to investigate, how designing activities in collaboration affects in applying digital fabrication in schools. Furthermore, it would be valuable to extend the activity design to cover all the participants, including students' participation.

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