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STEAM in Oulu: Scaffolding the development of a Community of Practice for local educators around STEAM and digital fabrication

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ABSTRACT

There is an increased interest to integrate STEAM methodologies and digital fabrication processes into formal education. However, teachers have repeatedly reported a set of impediments that hampers them to succeed. This integration requires a set of changes in the school organization, resourcing and a proper teacher training. A Community of Practice formed by different stakeholders of a local educational community might provide the necessary grounds to lead to this transition. In this paper, we report our experience of creating and scaffolding a local Community of Practice for a period of ten months. We present the different activities we carried out during this period, emphasizing a digital fabrication training that we conducted, at our university Fab Lab premises, for teachers and school principals separately. We also explore the influence of this training on scaffolding of the development of the Community of Practice. We expect the training structure, discussion and insights presented in this paper would inspire other researchers and practitioners trying to bring digital fabrication to formal education.

1. Introduction

STEAM is a broad concept that aims to bring together education in Science, Technology, Engineering, Arts and Math in an integrative way, bringing together the technological design methodologies typical of engineering and technology fields with the enquiry learning approach used in Maths and Science [1] and the divergent thinking style coming from Arts [2]. STEAM practices support switching from traditional lecture-based teaching to inquiry and project-based strategies that promote also other social skills such as collaborative learning. Pupils are educated as future citizens that approach problem solving through innovation, creativity, critical thinking, effective communication, collaboration and, of course, new knowledge [3]. During the last few years, there has been an increased interest in integrating activities promoting STEAM in formal education context [4]. Apart from scientific and arts, other subjects such as History, Music and Geography could benefit from the STEAM mindset [5].

Between 2014 and 2017, Finland initiated a reform to its National Core Curriculum for Basic Education. The new curriculum emphasizes developing pupils' transversal competences (e.g. ICT competences, multiliteracies, cultural competence) as part of every subject to respond to the needs and the requirements in a changing society [6]. The new curriculum encourages schools to seek new ways of learning and teaching. New Curriculum goals and methodologies fitted very well with those in STEAM, and a rise in the usage of STEAM pedagogies in Finnish schools was expected.

We share with other authors (e.g. [7,8]) the belief that personal digital fabrication (DF from now on) can be a catalyst for the successful integration of STEAM education in schools. DF is a set of manufacturing processes where machines controlled by computers can be used to fabricate a rich set of different artifacts. These processes enable individuals "[...] *to design and produce tangible objects on demand, wherever and whenever they need them*" [9]. The proliferation of Fab Labs, small-scale workshops offering the access to DF processes and machines to the general public, has contributed to the democratization of these technologies, bringing them even to schools. In recent years, Europe has witnessed and increased research interest in DF, making and STEAM education, with different projects exploring a wide set of aspects such as change of mindset in schools (eCraft2Learn Project [10]), physical tools for teacher support (H2020 PELARS) [11] and the introduction of computational thinking in non-formal and informal learning environments (H2020 COMnPLAY-Science) [12].

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Multiple authors have observed the potential of utilizing DF for educational purposes [13–19], for instance, it provides adequate means for the implementation of interdisciplinary projects, facilitating multiple cycles of design and enabling the contextualization of learning in STEAM [16,20]. Despite the reported advantages of STEAM and DF in education, they are not yet widely integrated in formal learning context. In a recent literature review, Margot and Kettle summarized in-service teachers' perceived challenges for integrating STEAM in their classes [21], including inadequate in-service teacher education, the need for a clearly defined STEAM curriculum, lack of time for collaborative planning, inadequate facilities, inefficient management and organization and lack of support from learning officials and local administration. All of this shows that it is necessary to change the mindset and work culture in schools, which involves the efforts of different stakeholders. We think that, while teachers should guide this transition, other actors such as school principals, education officials, researchers and Fab Lab instructors also have their word and can contribute to the change in mindset. Otherwise, without a common agreement on values and practices between stakeholders, STEAM based activities may become ephemeral educational tasks that are run every now and then at schools, but not as an educational philosophy to be developed further and integrated into the curriculum [22–24].

In the Oulu area, a 205.000 habitant region located in northern Finland, there has been a growing interest in STEAM education in the last few years, likely accelerated by the changes in the National Core Curriculum for Basic Education. The opening of Fab Lab Oulu in 2015 and collaboration with local schools added interest in DF, nurturing the opportunity to introduce STEAM and DF to local schools. In order to guide this transition, we promoted a Community of Practice (CoP) [25], that is, a group of people informally bound by shared practice related to a set of problems. Here, mutual interactions and relations build up a shared body of knowledge and a sense of identity [26]. Teachers would need some help to scaffold the development of this CoP, hence we encouraged local stakeholders (teachers, school principals, education administration representatives, researchers and Fab Lab instructors) to work together in the development of the community.

In this paper, we report a set of activities (training, hackathons and dissemination events) conducted from August 2018 till May 2019 in order to facilitate the development of the CoP. These activities aim to understand the potential and impact of utilizing DF for STEAM in formal education, prepare teachers to utilize DF processes in their classes, and disseminate teachers' insights and challenges.

Although in this paper we discuss different aspects of the CoP, the focus is on describing the structure, characteristics and insights of different training events that we organized to support the CoP.

This paper has three main contributions: (1) Identification of the main stakeholders (and their roles) needed to succeed when creating a CoP around STEAM and DF in education, (2) a description of the main activities we run to support the development of the CoP, with special focus on two case studies: teachers' training and principals' workshop, and (3) analysis of principals and teacher perception on DF after the training and foresee how it can influence the CoP.

2. Theoretical framework and related work

2.1. STEAM training for educators

As the interest in STEAM in school [27,28] and out-of-the school [29] contexts are increasing, previous studies have contributed to understanding teacher needs and supporting their professional development. Quigley and Herro [3] organized a yearlong STEAM training for math and science middle school teachers aiming to build background STEAM literacies, with a focus on problem-based learning, transdisciplinary teaching, technology integration and their relevance to pupils. During the professional development sessions, participants formed teams that collaboratively solved problems based on local issues. Afterwards, participants implemented their own practices, with continued yearlong support (e.g. peer support). Main difficulties observed were related to transdisciplinary teaching, arts integration and collaborative learning. Previous studies [30,31] have highlighted the importance of collaboration among teachers across the boundaries of subjects and increasing teachers' awareness towards collaboration through STEAM teacher training.

The development of appropriate pedagogical approaches is another aspect that has been studied in STEAM training for teachers. Bush and Cook [32] reported a study about a community of educators to develop in-service elementary teachers' pedagogical content knowledge in STEAM subjects. The training was structured as iterative cycles of whole-group professional development sessions and individual teacher's practices at schools, where teachers design and implement STEAM lessons as problem-based learning. Henriksen and colleagues [33] studied the role of design thinking when building STEAM lessons. In order to create project-based and real-world oriented STEAM-based learning experiences, teachers need to be creative designers by changing classroom practices and rethink the curriculum rather than implement existing teaching methods. The authors noted that the phases of a design thinking model, that is, empathize, define, ideate, prototype and test, can be used as a tool for teachers to implement STEAM lessons.

2.2. Digital fabrication training for educators

In order to utilize DF tools in teaching and learning, teachers' professional development is essential. Teacher training in this context has focused on integration of technologies into teaching and learning. Smith [34] used the technological pedagogical content knowledge (TPACK) framework to integrate technologies into teaching practices. The results identify TPACK elements that are associated with DF activities, such as encouraging technical resourcefulness as technological knowledge, utilizing constructionism approach as pedagogical knowledge, and developing multiple modes of literacy as content knowledge. The study highlighted the fact that the TPACK framework can be used to integrate digital technologies into teachers' existing knowledge of content (subject matters) and pedagogy.

The eCraft2Learn project [10] aims to develop 21st century skills in the context of DF and making. The authors note that the workshops for training teachers were useful for them to develop understanding towards technologies and tools in DF. However, teachers were not certain of their understanding of the pedagogical ideas behind DF activities when those were presented in the workshops. It was only through the actual implementation of the activities with the pupils after the workshops that the teachers gradually developed a clear understanding of the pedagogical ideas. This indicates the importance of iterative cycles of theoretical sessions and practicing at schools. The authors also discuss the challenges for the teachers, such as limited time and changing the role from traditional teaching to coaching. The participating teachers also expressed the fear of failing to support pupils because they felt they were under-prepared.

Smith and colleagues [35] present a study of in-service teachers' professional development in DF. They noted that teachers faced challenges due to the contradictory nature of practices in DF compared to the practices at schools to which they were accustomed, such as implementing activities as explorative open-ended rather than goal-oriented, understanding technology as a process rather than a product, and letting pupils do rather than controlling them. Aiming to address the main challenges identified, researchers [36] developed a master's course on design processes and DF for in-service teachers and education professionals. Their results suggest that educators can acquire the required skills with training based on a framework that combines workshops to present design and DF literature, in-school-practice to apply what is discussed in the workshops and peer-to-peer learning based on co-development and common reflection sessions. Andersen and Pitkänen [24] studied, to what extent this recommended framework prepares educators to apply DF in schools. They found that the programs were practical rather than theoretical, recognizing the difficulty to implement theory-based lectures and peer-to-peer reflection in them.

2.3. Workplace community for educators? Theoretical ideas of community of practice

Another approach for teachers' training in the context of DF is building a community to support and encourage teachers. Andersen and Pitkänen [24] explored how professional development practices in DF should be designed in order to empower educators. The authors highlight the importance of organizational structure which involves different stakeholders and gatekeepers with critical roles, such as teachers, principals, Fab Lab instructors, project coordinators and local politicians. Further, increasing collaboration among teachers and Fab Lab instructors has been suggested to activate and strengthen teachers' participation in designing DF activities for K-12 education [37].

In the context of this paper, we explore the idea of the community from the perspective of Community of Practice (CoP), a concept first defined by Lave and Wenger [38] and then further developed by Wenger [25]. A CoP can be described as "a set of relations among persons, activity, and world over time and in relation with other tangential and overlapping communities of practice" ([25] p. 98). Wenger identifies four components that must be integrated in any social theory of learning (e.g. CoP) in order to characterize social participation as a process of learning: meaning (abilities and changes of abilities to experience the world), practice (shared historical and social resources and frameworks that sustain mutual engagement), community (social configuration of the common enterprise, and how the individual competences affect it) and identity (how learning changes who they are) [25]. Based on this, Wenger identifies three different dimensions in a CoP: *joint enterprise*, which is based on the set of goals or requirements for the practice negotiated and defined by members of the community; *mutual engagement* involving the actions and interaction of members in the community share; and *shared repertoire,* which refers to facilities for the practice, such as signs, tools and definitions. Thus, a CoP constitutes an informal, social structure initiated by members that reflect their collective learning [39].

The concept of CoP is grounded in an anthropological perspective, which underlies how we learn through everyday social practices in self-organizing teams of informal learners. CoP can be effectively used for workplace learning. According to Brown and Duguid [40], workplace learning can be best understood in terms of communities being formed and personal identities being changed. The central goal of CoP is becoming a practitioner, not learning about practice. In a CoP, members who share a common interest for the field in which they work come together to help each other out, solve problems, and create knowledge collaboratively [26]. Moreover, a member can belong to different communities and there can be collaboration among overlapped communities. For instance, a teacher is a member of the school community, at the same time, s/he can also be a member of a community which aims to develop skills in a specific field. Such overlap participation of the members may bring changes in a CoP.

CoP can be used as a theoretical lens in STEAM training for teachers. In [32], researchers analyzed two cases of in-service teachers' training in STEAM education through theories of CoP. The authors identified successful conditions of CoP in STEAM teacher training which are: (1) sharing common values for the aim of the practices, (2) developing a mood where teachers are able to express their opinions freely, (3) adjusting the balance of power among participants and preparing a sound decision-making process, and (4) collaboration among teachers across the boundaries of their major subjects. The authors remark that teachers' professional development should shift to community based, focusing on developing expert communities rather than individual experts.

The work presented in this manuscript has been strongly influenced by the FabLab@SCHOOLdk partnership [24,41,42], one of the most inspiring examples of CoP around DF. One of the manuscript authors has been working in the project in recent years. The partnership has done consistent, research-based work for developing a community of different stakeholders to provide primary and secondary school pupils with technology comprehension and 21st century skills. To that end, the community organizes various types of professional development training and activities for education professionals in DF and design thinking. The UMI-Sci-Ed project from Norway [43] aims to build a CoP composed by diverse stakeholders as well. Their starting point is the analysis of existing local communities of computing education. Makerskola is a national project in Sweden [44] aiming to develop an understanding of how the makerspaces distributed in different schools around the country work and to generate channels of communication among them.

3. Establishing "STEAM in Oulu" community

In contrast with most attempts of building educational CoP or shared collaboration networks [32,33], we consider that teachers are not the only stakeholders. Other actors with decision-making power and administrative authority on education should also engage to build such a community. First, utilizing STEAM and DF in formal learning environments definitively entails a change in the teaching culture, especially in those schools with more traditional instruction methodologies [45]. For instance, previous literature [3,46,47] suggests that student-centered methodologies with multi/transdisciplinary approaches require collaboration among teachers of different subjects. Second, equipment utilized for DF becomes a limited resource and requires an adequate policy for resource allocation. Finally, many times teachers lack adequate skills to handle the equipment, or do not have knowledge and inspiration to utilize these processes in their classes. In Finland, school principals have enough autonomy to define the learning culture they envision in their schools, as well as the financial capacity and decision power to reallocate resources in order to ensure the necessary assets to implement that vision.

On the other hand, although we aim to include as many local schools as possible, we opted to start gradually with a group of pioneer schools [35]. Teachers and principals from those schools would help in the future to develop the network by providing resources and education to new members. A local education administration official contacted all local schools that had expressed interest in STEAM and DF in the past. Six of them joined the community. Those schools got some funding from the "Finnish National Agency for Education" to partially finance the teacher training and the acquisition of machines and material.

Table 1
Stakeholders participating in the creation of CoP.

Stakeholder group	Number	Role
In-service teachers	12 (2/school)	—Receive education in DF and associated pedagogies —Educate other teachers —Provide feedback concerning needs opportunities, and challenges to other members of the CoP
Principals	6	—Take part in the initial decisions —Allocate resources for teachers to participate in the CoP —Facilitate the necessary tools and equipment to the school —Support teachers
Officials from local education administration	2–3	—Help to coordinate the work of different schools —Organize joined activities —Apply for funding —Help to disseminate the work done at the CoP
University researchers	3[a]	—Formalize the work done inside this project within a learning framework so it can be replicated in other cities or countries —Partially responsible for designing and conducting education for teachers and principals (especially in the pedagogical and learning methodologies aspect) —Dissemination of the work in scientific conferences —Collection of data for research analysis —Present the potential and challenges of applying STEAM and DF in schools to school principals and other members of the local education administration
Fab Lab instructors	1[a]	—Educate teachers in DF tools and processes (including pedagogy and learning methodologies) —Support teachers to organize the activities —Counsel to teachers/principals on equipment and software tools for DF

[a] 1 of the researchers was also a Fab Lab instructor.

A coordination team in charge of leading the community during its initial steps was in charge of taking initial decisions, organizing main activities of the year, and disseminating results, trying to bring more stakeholders to the community.

Summing up, to start the CoP, we counted up stakeholders presented in Table 1. It includes their role inside the organization and the number of them who initially started.

The stakeholders are:

(1) *In-service teachers* from the six comprehensive schools who initially joined the community. The principals of each school chose the teachers among their staff. Instead of selecting only technology skilled teachers, they were recommended to choose teachers from different backgrounds to avoid silos, that is, include only teachers with technology or ICT background. It was preferred to include teachers not technology-skilled but excited about learning new things and willing to inspire their colleagues.
(2) *Principals* from the six participating schools who decide on general education strategies and allocate resources for education. Principals need to understand the opportunities, challenges and needs of their teachers to assign adequate resources and to show their support [48].
(3) *Officials from the local education administration*. This includes teachers not working full time as docents but taking some administrative or organizational tasks.
(4) *University researchers and teachers* in the fields of Learning and Education Technology, Human Computer Interaction and Computer Engineering.
(5) *Fab Lab instructor*. Experts in the field of DF, with some pedagogical background.

The coordination team is formed by members of different groups; initially it was composed of two researchers and two educational officials. The team established several communication channels supporting collaboration among community members: including a Facebook group, a WhatsApp group, a Microsoft Teams and a website.[1] The name of the community was decided by all members who participated in one of the initial hackathons: "*STEAM In Oulu*".

3.1. Activities for supporting the development of the CoP

Between August 2018 and May 2019, we executed the following actions to scaffold the development of the CoP: Firstly, we educated principals and teachers in DF. Secondly, we organized several participatory activities to build a common understanding on the philosophy of the community and to facilitate collaboration among different stakeholders. Finally, teachers dedicated part of their time to individual professional development, applying and testing their new skills and organizing learning activities in their schools based on the training and promoting DF among fellows. Fig. 1 shows the schedule of these main events.

3.1.1. Goals and structure of the training for principals

The goal of this activity was to present the opportunities and challenges of DF and education and to agree on a common vision for the community of practice. This prior understanding of community goals would serve principals to plan resources and choose the most adequate teachers to participate in the community. We set up five practical questions that guided our activities during the training:

1. What skills can pupils learn utilizing DF processes?
2. What added value does digital design and fabrication bring to learning?
3. How can Fab Lab processes be applied and integrated into the school? How do these processes integrate in the National Core Curriculum for Basic Education?
4. What would be the impact of DF in the future of education?
5. How to convince reluctant teachers of the potential of Fab Lab processes for developing pupils' multidisciplinary skills?

Principals' training was scheduled in three different workshops, of four hours each. The workshops were held every two weeks at Fab Lab Oulu premises. The principals from the six

[1] http://www.steaminoulu.fi/.

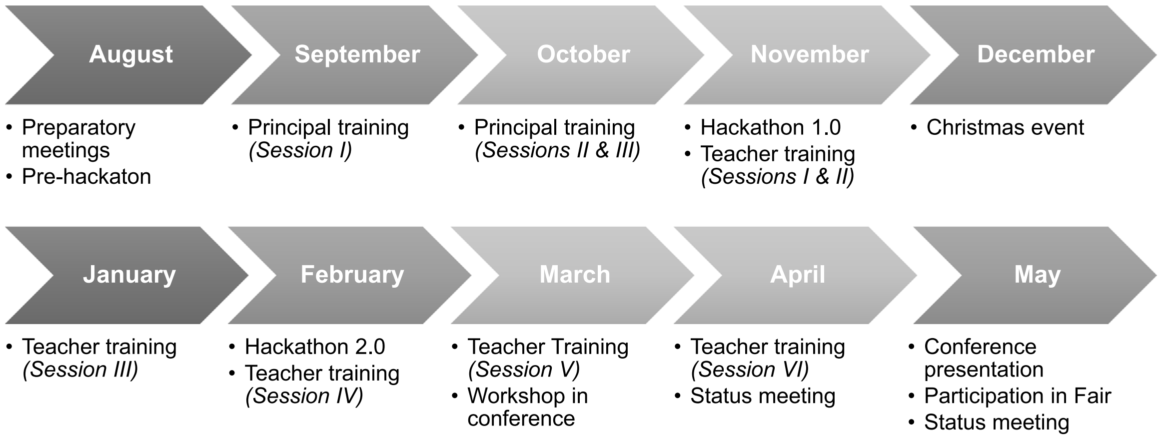

Fig. 1. Main events schedule.

Table 2
Activities carried out during the principals' training.

Training session	Practical activity	Theoretical presentation	Topics for discussion and reflection
Session 1	Use of learning design process model [36] Design a sticker that visualizes your vision of collaboration and leadership for the community Fabricate the sticker using a vinyl cutter	DF and Fab Lab concepts Pedagogical methodologies: e.g. learning design process circle [36]	Collaboration opportunities among schools DF and transversal competences from the National Core Curriculum for Basic Education
Session 2	Use of a 3D CAD design tool Fabricate a 3D object utilizing a 3D printer or a laser cutter	Similar communities: FabLab@SCHOOLdk case Education programs associated to DF Examples of school projects done at Fab Lab	Current pedagogical values and visions for each school Support needed by teachers DF processes integrated in formal education
Session 3	Tools for electronics design Basic electronics	Teacher training plan and schedule	Schools' vision in 5 years for each school Administrative and financial challenges DF and transversal competences from the National Core Curriculum for Basic Education

schools participated in all the workshops sessions. Each session included activities mixing hands-on exercises, in which principals learnt some elemental principles of DF, with other actions promoting discussion and reflection on how to integrate DF activities in their own school. The practical tasks guided the principals to design and fabricate a LED desk lamp, step by step, utilizing the Fab Lab machines giving them the chance to experience the nature of DF. At the same time, the different tasks were designed to raise awareness and promote discussion about the needs and challenges that teachers might have when creating activities for STEAM, as well as reflecting on school views and values.

The instructor team was formed by two experts, one in the field of technology and DF and the other in the field of education (although both have good knowledge in the other's area of expertise). In addition, one official of the local education administration provided support in some phases of the activities and participated in the discussion. Table 2 summarizes the different activities carried out during the three workshops.

3.1.2. Hackathon-like activities and teachers' professional development

We organized three different hackathon-like activities in which we brought together representatives from the different stakeholders (including teachers' colleagues not receiving the training). During the hackathons, participants collaborated in different semi-guided activities with the goal of sharing their knowledge and vision of DF and associated pedagogies. One of the goals of these hackathons was to establish a framework or a set of guidelines to scaffold STEAM education utilizing different processes, including DF. The framework was named "STEAM Opinpolku" (STEAM Learning Path in English).

We held a first hackathon (October 2018) with three goals: to get to know each other, to identify schools' resources and responsibilities, and to ideate and sketch a first draft of the STEAM Opinpolku. Participants also discussed the strengths of each school, and how to develop STEAM Opinpolku further.

During the second hackathon (November 2018) participants took part in three different activities in small groups. First, they built a "STEAM robot teacher" out of recyclable material to reflect on the skills necessary for a good STEAM teacher. The participants continued developing the STEAM Opinpolku connecting it better to the curriculum and acquisition of transversal skills.

In the third hackathon (February 2019), participants were introduced the first graphical illustration of the STEAM Opinpolku framework based on their previous input. Later, the participants presented their idea of a collaborative STEAM project to be submitted to a local event.

Some of the teachers got their teaching duties reduced during the training period to develop their DF skills, prepare activities for and with pupils, educate their colleagues in schools, and

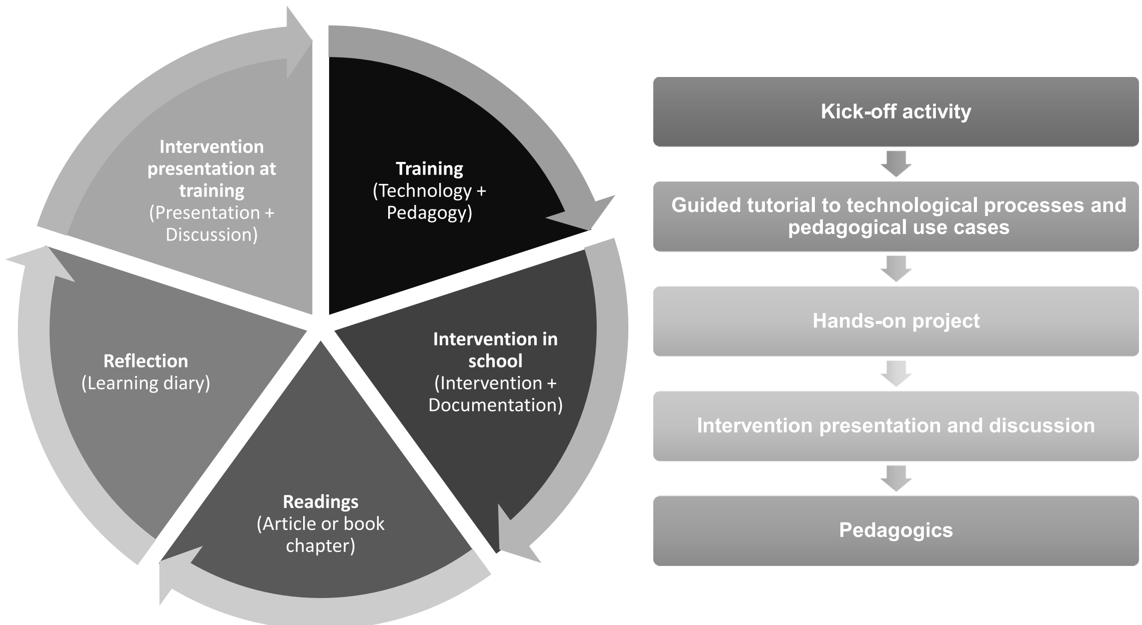

Fig. 2. Training circular process (left) and structure of the training sessions (right).

prepare the curriculum for the following years integrating some DF activities in it.

3.1.3. Goals and structure of training for teachers

Teachers' training aimed to teach different DF processes and to provide teachers with the mindset of a STEAM teacher, introducing them to the maker culture. When designing training activities, we carefully considered the findings of the previous study [24] and aimed to find the balance between practical and theoretical, and technological and pedagogical contents. Further, we focused on assigning clearly, for example, which readings were considered as obligatory for all, and which were additional to gain deeper knowledge of the topic. Additionally, we designed theory-based lectures and included intentional, structured peer-to-peer reflections in the training. The teachers were provided with the pedagogical theories behind DF, computational thinking, and a design process model to scaffold complex learning projects. The training was designed so that teachers gain confidence in the different tools, processes and methodologies, so that they could apply them in their teaching practice. Throughout the training, the teachers' own reflection [49], as well as the discussion and feedback from colleagues were emphasized.

The training was structured in six workshop sessions, of eight hours each, held every month at Fab Lab. The whole training was implemented as a circular process (Fig. 2, left). During each workshop session, participants learnt about one concrete DF process and discussed different pedagogies. After each workshop, the teachers had to perform three different tasks: (1) design and execute an intervention in their school and document it utilizing a predefined structure, (2) write a learning diary reflecting on their learnings and challenges they faced during the training and intervention, and (3) read one or two related articles or book chapters as part of the provided training bibliography. In the following workshop session, teachers presented their intervention to the rest of the participants and received feedback and suggestions both from the instructors and the colleagues.

The structure of each session is presented in Fig. 2 (right) while the specific content of each one of the six sessions is summarized in Table 3. Each session started with a kick-off activity, usually a short and fun activity with the goal of breaking the tensions and activating teachers. Afterwards, some pedagogical use cases were presented followed by a guided tutorial of a specific process, software or tool. Finally, teachers were asked to apply the acquired knowledge in their own design and fabrication project. Usually, the project specification requires the fabrication of one artifact that can be utilized later. During the design of the artifact, the teachers usually needed to discuss some aspects linked to education, such as pedagogical values or teaching organization and methodologies. A Design Process Model developed at Aarhus University in collaboration with FabLab@SCHOOLdk [36] was utilized to support this task. The model applies design thinking in order to help teachers and pupils to scaffold explorative design processes. The structured process model includes six main steps: (1) Design Brief, (2) Field Studies, (3) Ideation, (4) Fabrication, (5) Argumentation and (6) Reflection [50].

The last part of the workshop session is reserved for a discussion of the interventions executed at schools and some activities oriented to present and rise discussion on certain pedagogical aspects.

During the whole duration of the training, teachers could ask for online support from the instructors or from their own colleagues while preparing activities for their pupils, for instance, utilizing a WhatsApp channel. This tool turns out to be an excellent communication channel for teachers to present their progress and activities to the rest of colleagues.

3.1.4. Supporting knowledge sharing within the community and disseminating results

Knowledge sharing outside the community and dissemination of results to the national and international community all around the world was also an important part of the CoP. We built a website to advertise the community, report results and disseminate teachers' activities. In March, we presented the community with initial results in a workshop that was held at the biggest national education technology conference in Finland. Later, in May, we presented for the first time the "STEAM In Oulu" community as a poster in an international scientific conference. Also, schools in the community presented some of the work made by the pupils in a local scientific/technology fair in which companies were also participating.

We utilized different social network channels to share knowledge within community members. We created a private Facebook

Table 3
Content of different sessions.

Training session	Kick-off	Processes	Project topic	Pedagogical/theoretical content	Intervention
Session 1	Get to know the colleagues and introduce each other	2D design Vinyl Cutting	Interview and design a logo for your colleague's t-shirt illustrating a challenge at school that he/she has overcome successfully	Fab Lab ecosystem Existing educational communities Constructionism Resource bank and bibliography	Carry out an activity where pupils first build something utilizing paper and scissors and then digitize it to fabricate something useful with the vinyl cutter.
Session 2	Quiz game on educational methodologies	3D design Laser cutting	Build a custom box for some of the teachers' tool	Opportunities and challenges of DF in education	Co-design an activity with another teacher in which pupils utilize 2D/3D design and cutting. Run the activity in different classes.
Session 3	Design stamp using CAD software	3D parametric design 3D printing	Design and fabricate, in pairs, an innovative tool holder	Teachers' role-playing game. How do different actors see maker education at schools?	Build some artifact that supports your teaching in any form.
Session 4	Using different interactive electronics boards (Makey makey and Touch Board)	Soft electronics	Hack a toy or build an artifact that allows pupils to provide feedback or express emotions	Planning and running DF activities in school	Co-design with your pupils an educational activity involving electronics. Conduct the activity with another group of pupils.
Session 5	Algorithm implementation: Prepare a coffee	Embedded programming (Micro:bit)	Measure a natural signal with one device that activates somehow another device	Computational thinking	Design and conduct an educational activity for computational thinking targeted to adults (e.g. colleagues).
Session 6	Describe your Makerspace	Process integration	Design a learning activity which includes different DF processes	Makerspace infra and management Project based learning Integrative education Assessment	Implement the activity designed during the session

group and a WhatsApp channel for all members of the community in which education events were advertised and relevant results were shared. Microsoft Teams was used to share documentation, such as meeting notes and project proposals.

4. Research methods and data collection

In this manuscript, we analyze the impact of the activities presented in the previous chapter on the actors of the CoP. We also investigate their initial perceptions, perspectives and insights. We focus on teachers and principals in this analysis since they were initially in the majority (see Table 1). To that end, we conducted two longitudinal case studies [51]: one covering the whole teacher training (see, Section 3.1.3) and the other covering the principals' training (see, Section 3.1.1). During these two case studies, we collected different kinds of ethnographic [52], focus group and survey data.

4.1. Case study 1: Principals' training

Participants. Six local school principals (3 male and 3 female).

Context. Three workshop sessions of four hours each, described in more detail in Section 3.1.1. The sessions took place at Fab Lab Oulu premises. During the workshop, two researchers that collected data acted also as instructors.

Process. We investigated principals' perspectives towards hands-on practices and topics covered (see Section 3.1.1 and Table 2) in the training by holding discussions during and at the end of each training session. Throughout the training, participants were asked to write down their thoughts of the successes, challenges, possibilities and questions they faced and found during the training. These notes were collected to the shared wall of ideas, which formed a base for the reflective discussions. The reflections of the first and the second session were analyzed, categorized, summarized and presented to the principals in the third session as a base for discussing their feelings of success and empowerment and remaining challenges and questions, as well as their vision of the CoP after the training sessions.

Data collection. As part of the training, we organized several focus groups promoting reflective discussion. The topics were documented in the form of a diary [53] written by one of the instructors. The diary entries were written during and after the reflective discussions in the three training sessions and were stored in an online document. One entry contained from two to six notes of each principal, the personal average being three in one entry. In addition, the instructors shared different notes and reflections after each session that were incorporated also into the diary.

Analysis. The content of the diary was later discussed with the other author participating also as instructor in the training sessions and in that way validating the data. We analyzed the diary by coding the main ideas in four categories: successes, challenges, possibilities, and questions when implementing DF activities in their own school. The systematic analysis of the diary and notes followed the guideline introduced by Krueger and Casey [54], relying on the theoretical propositions to focus on the specific aspects of the data [51]. Further, we applied theory-driven analysis [55] to enquire how the principals found in the training session influenced their view of the CoP and if it influenced their mindset building towards resourcing properly a maker space in their school.

4.2. Case study 2: Teachers' training

Participants. 12 primary school teachers of 6 different schools (5 females, 7 males), most of them novices in DF. Subjects and children age are presented in Table 4.

Context. Six digital workshop sessions of eight hours each, described in more detail in Section 3.1.3. All sessions took place at Fab Lab Oulu premises.

Process. In this study, we wanted to contribute to the development of CoP through teacher training. Such actions are presented in Section 3.1.3. After the last training session, we conducted a survey to gather data about the impact of the training in teachers both from their own personal development and the CoP perspectives. The survey was delivered as an online questionnaire format one week after that last workshop session, and the teachers had one month to complete it. Answering the questions was voluntary and the data was collected anonymously.

Data collection. The survey consisted mainly of open-ended questions asking about the impact of the training, e.g. *Which has been your main gain in this training? What worked, what did not? How are you planning to integrate the learned concepts in school? Has there been any change in your mindset concerning pedagogy?* In addition, we included several rating-scale questions to evaluate how the training has impacted their own teaching practices, as well as the other colleague teachers around them. Eight out of twelve teachers answered the survey.

Analysis. In this case study, we wanted to learn about the effect of the training in the teachers practices and how they could affect the mutual engagement and joint enterprise dimensions of the CoP. To that end, the survey was analyzed mainly using qualitative analysis methods, categorizing data in three different topics [56]: challenges appeared during the training, the impact of the training in teaching practices and the impact of the training in relation to the CoP.

5. Results

In this section, we describe and present the results from (1) the diary of principals' reflections and (2) the survey filled in by the teachers.

5.1. Principals' reflections of the training sessions

Questions. At the beginning of the training, principals raised several questions regarding how to change the operating culture and start implementing STEAM activities or maker culture in their school or how to prioritize purchasing the machines. Also, some of the principals were clearly unsure about using their own time for the training. After the three training sessions, one of the principals admitted her initial concerns over the utility of the training. However, he recognized that the hands-on experiences increased awareness of the learning process and challenges the teachers might face during their training, as she reflected on: "*I understand this now, although I was a little skeptical at first – because it takes a lot of time – but why is it useful to do this way? When you do this yourself, you understand these challenges experienced in this process*".

In the last training session, there were still few open questions, such as how to allocate time resources for teachers' collaboration to foster these activities at secondary school, where schedule was tighter than in primary school. However, the questions shifted to more practical and community building aspects: for example, how could they find interesting contents for teachers of music and sports, in order to attract them also, while they are presenting STEAM ideology at school.

Challenges. During the three training sessions, most of the principals developed their considerations regarding the machinery. One of the principals noted: "*(earlier) I have had a technology-focused perspective on STEAM*". The principals found that machinery is not a key to start STEAM activities at school, but they can be started from a very low level and even without machines at all. They realized that it is more important to start from the school's vision and values, engage a wide range of people, and consider what are the needs of users regarding the machinery. However, principals presented as one significant challenge, that some teachers do not recognize the need for developing their practices to adapt them to the increasingly changing world we are all living in. As one principal commented on: "*It is not about the principal's idea, but the school must develop so that children can be guaranteed a better future or, as a nation, they will be left behind*". Together with encouraging different types of teachers and pupils to engage into STEAM activities, they considered time constraints and structural challenges as main challenges.

Possibilities. The principals identified many possibilities in the STEAM and DF vision that was presented during the training. It is not only about processes, but also about methodologies they utilized. For instance, they found the emphasis in reflection very useful for pupils. This can be seen in one principal's comment: "*it's not just conducting teacher-centered activities, receive an assignment and just finish it and that's it, without considering what is the purpose and the design process they are following to finish the task*". Furthermore, another principal found the presented activities are suitable for the pupils of a wide age range: "*you may begin with the tiny ones, start using paper, cardboard, fabrics, and cut things [by scissors], and then with the bigger ones, continue to more advanced processes, even to very high level activities*". The principals discussed that such activities give pupils whole new possibilities to participate and found new, creative ways of learning and get excited about learning.

Success. The principals recognized the training as a successful activity, recognizing the value of the training to develop a common understanding and define a common starting point for each school to work for the community, determine the actions required from them as leaders, establish the resources and responsibilities that they need to consider, and clarify the necessities and the benefits of the collaboration. This is summarized in the voice of one principal: "*We are here for changing the operating culture*". They claimed to be more empathetic with teachers and expressed their willingness to listen to teachers concerns more carefully.

5.2. Teachers' considerations after the training

We structured the analysis of the survey under the following three topics: (1) Challenges appeared during the training; (2) Impact of the training in teaching practices, and (3) Impact of the training in relation to the CoP.

Challenges appeared during the training. During the training, teachers remarked on the huge amount of content that they had to deal with along the training. Some of them claimed that the time that it was assigned to them to attend the training and prepare the activities (intervention, write documentation, read articles …) was not enough, so they had to use their own free time to continue learning. This is reflected in the survey as a negative aspect of the training by teacher 7: *"I found the work required after training was a little bit overloaded (learning diary, text readings, document intervention…) [...]. I took time from me and my*

Table 4
Subject and age of teachers participating in the training. Pupils' age in parentheses.

School 1	School 2	School 3	School 4	School 5	School 6
Class teacher (10–12)	Handicraft teacher (12–16)	Class teacher (9–10)	Physics and Chemistry (12–16)	Class teacher (8–9)	Language teacher (12–16)
Class teacher (12–13)	Class teacher (11–12)	Class teacher (12–13)	Arts (12–19)	Religion/History/Social sciences (15–16)	Math/Physics, Chemistry/ICT (age not disclosed)

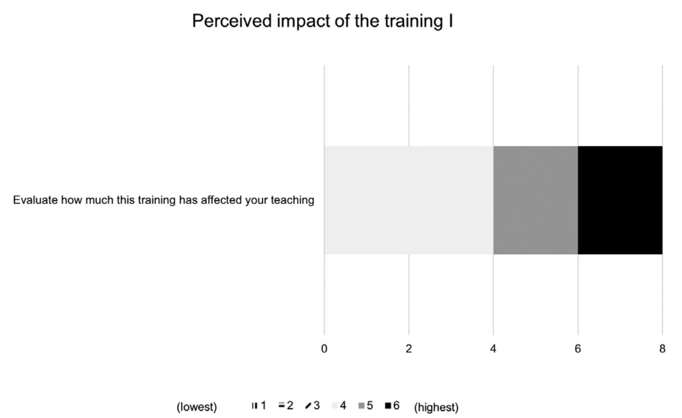

Fig. 3. Perceived Impact of the training (N = 8) in own teaching. 1 means no impact at all; 6 is a considerable impact.

family. The work done with pupils was good and did not require that much effort''. Teacher 2 agreed: ''*Interventions project came too quick, and at least a subject teacher does not have enough resources to prepare them*''. The form to document the intervention was also too complex according to some of the teachers and required too much time to prepare.

Impact of the training in teaching practices. In Fig. 3 (bottom), we present the perceived impact that the training has had in the teachers. All teachers considered that the training has had a significant impact on their teaching practices (4 or more in a scale of 1–6).

Some teachers expressed explicitly in the survey that the training has had an impact on their view of teaching: for instance, teacher 2 claims that ''*It was a lot in a short time* [...] *on the other hand, it looks like the ball has started rolling in my head*'', confirming the usefulness of the activities in order to change the mindset.

Teacher 2 found useful the methodologies and material provided in the course: ''*There were many different processes and ways of working. A lot of different good examples were presented*''.; In addition, based on the answers, teachers found that they got reinforced by the design process, realized the importance of hands-on learning and letting kids make mistakes and considered the different roles of a teacher as a learning facilitator. Teachers also mention the ''*courage to use information technology and related technologies in teachers*'' (teacher 2) as one of the most important outcomes of the training.

All teachers participating in the survey confirmed that they were already planning how to integrate DF into their classes, and some of them already provided some examples of projects they had in mind. They run from very specific projects, such as applying a vinyl cutter for teaching architecture or using LEDs for fabricating clothes, to more general structural and methodological ideas, such as providing pupils with collaborative projects, developing new learning modules to develop their transversal competences, and sharing new ideas and learnings with colleagues at school.

Impact of the training in relation to the CoP. In Fig. 4 (top), we present the teacher's perception of the impact of their own training in other colleagues. Five teachers (N = 8) considered that the impact has also been remarkable in their colleagues (4 or more in a scale 1–6). None of the participants gave any explanation on how this impact is really materialized, however.

Other important aspects we analyzed are different alternatives to develop teacher training in the future. As shown in Fig. 4 (bottom), most of the teachers fit comfortably training other teachers (grade of 4 or more in a scale of 6). Only one teacher provides a lower grade. Another dimension we explored is the optimal place to receive training for DF processes. Results are presented in Fig. 5. The figure shows that a combination of training at Fab Lab and school is preferred for most of the teachers in most of the processes. Three of the teachers consider that micro:bit programming and 3D design should still be trained only in Fab Lab. Training outside their own school was seen as one of the most positive aspects of the training by some of the teachers. For instance, teacher 2 mentions ''*Was great to leave school premises and learn again at the university*''.

Another element that we considered important in the training was not only the acquisition of knowledge, but also the creation of community. In that sense, teacher 5 remarks as one of the best parts of the training ''*having a cup of coffee and a small talk, while sharing experience with the rest of colleagues*''., teacher 6 when says: ''*reflection with other teachers was very important*'' or teacher 4 when she remarks ''*exchange ideas with colleagues*'' one of the best outcome of the training.

Some teachers mentioned the challenges they face to change school culture. For instance, Teacher 1 reflected: *''In school everyday life, rigidity (schedules, spaces) and challenging large groups of pupils make it difficult to implement many ideas — it is also difficult to achieve a change in the operating culture with a couple of teachers*''.

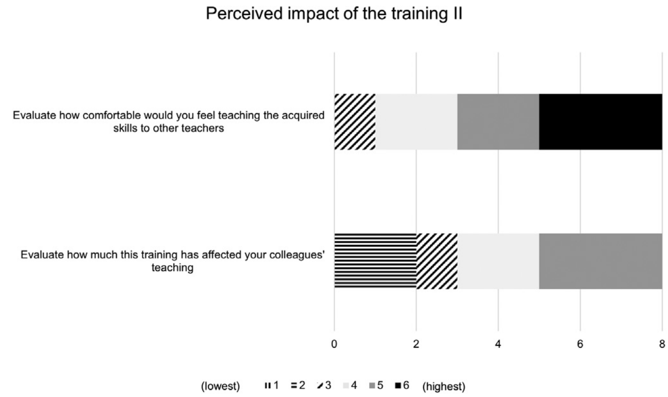

Fig. 4. Perceived Impact of the training for the community(N = 8). 1 means no impact at all; 6 is a considerable impact.

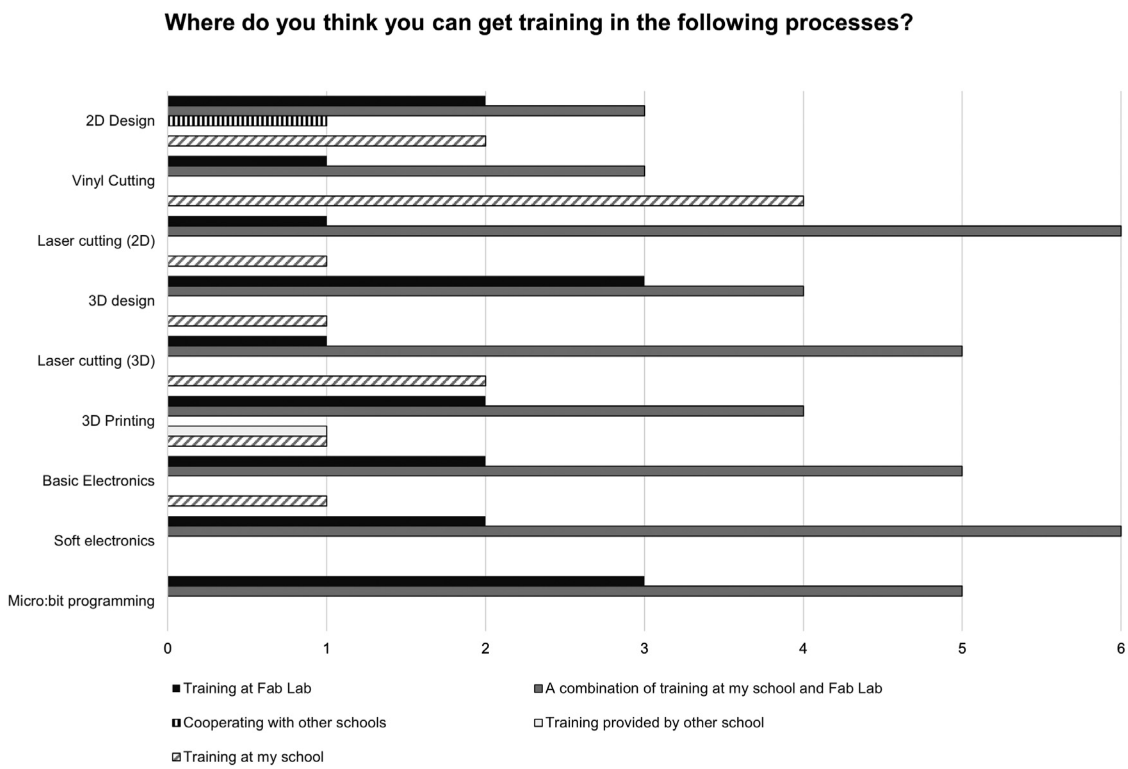

Fig. 5. Preferred training place for different processes (N = 8).

6. Discussion

In this discussion, we will consider some key aspects of scaffolding the development of a CoP in the city of Oulu, based on our insights, diaries and teachers' surveys. First, we will justify the need of the CoP and identify it as such, second, we will summarize the learning and implications of our experience, and finally, we will discuss the limitations of our research.

6.1. A CoP in the context of STEAM in Oulu

Why build a local CoP? Transversal competences were an important addition in the last reform of the National Core Curriculum for Basic Education [6]. The acquisition of those competences inside traditional subjects has been a discussion topic among the education community for several years. Many defend the utilization of STEAM and DF as possible enablers to acquire those competences [44,57,58]. However, STEAM methodologies and DF processes are not yet fully integrated into our local school community. Such integration requires an adaptation of school environments (such as new spaces, tools and machinery), a modification in school management to favor inquiry research and project-based learning and an education of teachers in the new processes.

In our initial discussion with principals, they presented "*a technology-focused perspective on STEAM*", that is, a common belief that the work starts by buying the machinery. From our point of view, buying machines without a defined strong pedagogical purpose affects the vision the school community has over the technology, being for many a useless and expensive waste of resources, especially among non-technology-skilled teachers and pupils. At the end of the training session with principals, they agreed that it was more important to start with their school's vision and values, engage a wide range of people, and consider what are the needs of users regarding the machinery. By supporting this CoP, we promote this approach (that we have defined as the pedagogy-first approach in Fig. 6). We addressed the importance of starting by considering curriculum and learning goals, justifying pedagogical added value, identifying user needs and only then considering, what are the machines that serve the needs. Introduction of STEAM and DF is not only a matter of using machinery or technology but there are important pedagogical concepts to develop as well, such as integrative learning approach, interdisciplinarity and project-based learning [1].

Our initial informal discussion with teachers and principals revealed a real need to support this transition. Teachers do not usually have the technological knowledge, time and equipment, and they need support to adapt these methodologies to the new curriculum. These claims summarize very well two goals of this CoP: induce a change in the school culture and educate teachers with appropriate pedagogies, learning methodologies and DF processes. It is important to note that changing the school culture is not only in the hands of the teachers, but other actors have an important role to play as well. This challenge has been identified by teachers in the surveys: without a change of culture, and given the rigidity of schools (schedules, space), it is difficult to implement new ideas. This challenge has to be coped with the whole education community: principals and education officials have decision power and can allocate resources, researchers can contribute in the pedagogical and methodological aspects while Fab Lab instructors can contribute with their technical expertise and practical experience running activities in Fab Lab.

Who can be considered a member of the CoP? There is no common agreement on the boundary between a CoP and other social structures such as project teams or community of interest [59]. For instance, Fisher [60] argues that a CoP is an "homogeneous community" formed by members of a single discipline. Following strictly Fisher's idea, principals and education officials would not be part of the community. On the other hand, Wenger [61] presents two new roles: leaders and the facilitator. The leaders are respected people within the organization, who recruit members and provide resources for group activities. The facilitators, on the other hand, are responsible for the group's day-to-day activities. In our CoP, we could associate the role of the principals to the one of leaders while the education officials, since they are involved in the coordination team, might be considered as facilitators. We consider both roles crucial for the community, especially in a supporting role. After all, without them, the knowledge generated in the community could not be put into practice.

Some might argue that researchers and fab lab instructors are not part of the CoP since they do not belong to the same discipline (primary education). However, teachers, researchers and instructors are experts or apprentices [38] in the field STEAM, DF and education, and share knowledge with each other, hence they are considered members of the CoP. For instance, fab lab instructors and university researchers have been training teachers and principals in the presented activities. At the same time, instructors organize constantly informal learning activities with pupils at university Fab Lab, from which they can get valuable pedagogical insights that can later be shared with teachers.

Finally, we argue that teachers from different disciplines belong to the same CoP. Actually, multidisciplinary collaboration has been identified as crucial for success of STEAM education [3,21,31]. While other research studies emphasize the role of math, science or technology teachers [30], we do believe the CoP must be conformed by teachers from a broader set of disciplines and education levels. As shown in our results, the teachers participating in our training remark the interdisciplinarity and collaboration as one of the most important gains from teacher training.

Components and dimensions of our CoP. Wenger identified four components (meaning, practice, identity and community) in any social community [25]. All of them are interrelated in a Community of Practice. Wegner established three important dimensions in a CoP: *joint enterprise, mutual engagement and shared-repertoire* [39]. The different stakeholders of our CoP share a common vision in which STEAM and DF can bring significant positive benefits to primary and secondary school education, especially after the recent change in the Finnish national core curriculum for education. The integration of STEAM methodologies and digital fabrication processes into formal education, and improving the skills of teachers and kids are the leading efforts of the CoP, and shape our *joint enterprise*. This common vision was heavily discussed and shaped during the different events we organized, especially during principals' and teachers' training and during the initial pre-hackathon. As principals emphasize in their reflections, the whole school system must develop to guarantee a better future to our children.

On the other hand, enabling *mutual engagement* was one of the key driving forces in all the activities we organized. During the teachers' and principals' training, we emphasized group activities, discussion and reflection. All assignments, in which participants had to use DF processes, included also empathizing, discussing and reflecting with colleagues. Teacher training was intentionally eight hours long, so teachers had to interact with each other, not only during class, but also during breaks and lunch time. The fact that teachers could have "*a cup of coffee and small talk*" or the chance to "*exchange ideas with colleagues*" outside their school environment and during the training sessions was considered one of the most positive aspects of the training. In order to promote mutual engagement, co-design was included in some of the interventions, so teachers had to collaborate with each other in a real educational setting. We had periodically activities such as hackathons (where multiple stakeholders came together with the goal of defining strategies and discussing future of the community), teachers workshop (where they instruct or support other teachers), coordination meeting (with representatives from a different stakeholder group) and even an informal meeting like a small Christmas party at local Fab Lab. All these activities contribute to mutual engagement and the community building and the organization of other spontaneous activities by some of the participants. In addition, we utilized our own website, Facebook group and different WhatsApp-groups to share interesting content, achievements, successes and challenges. The informal character of WhatsApp turned out to be a really good tool for social interaction.

Finally, all members build together a *shared repertoire*, including common vocabulary, activities and methodologies. For instance, the "*STEAM opintopolku*" (STEAM Path) built and refined during the different hackathons provides a process model (including different guidelines) that could be used by any of the teachers. In addition, all the teachers had to document their intervention and pedagogical activities and make them available to other members of the community through the community website.[1] The different makerspaces of the schools also become an important actor. They all shared a common set of machines (generally, those in a Fab Lab [9]), but at the same time, each school gave it their own identity. For instance, each school named it in a different way.

6.2. Main learnings and implications

Need of a coordination team to kick-off the community. In addition to work done by the school community, as Andersen and Pitkänen [24] defend, we believe that, to establish a common, equal ground for the community, the efforts and actions done by the impartial coordinator team are necessary in order to form a

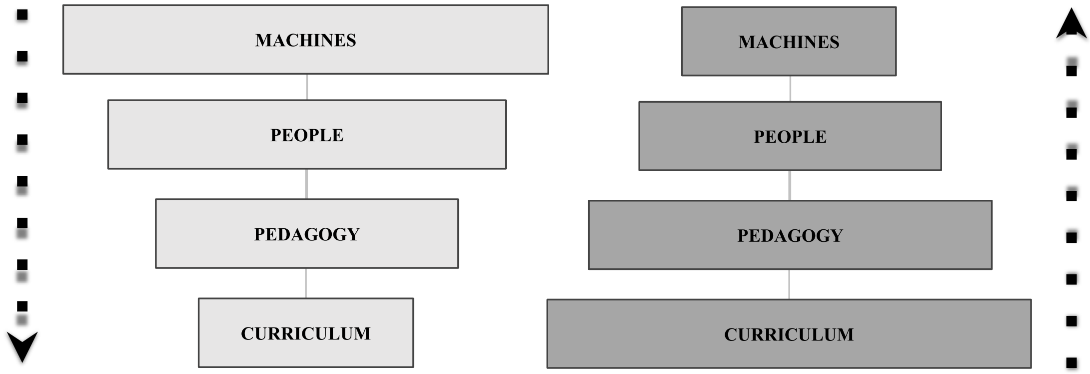

Fig. 6. Two approaches to bring DF and STEAM to schools: Technology-first (left) vs. Pedagogy-first (right).

solid ground and ensure continuity and growth of the community. This team advised the schools allocating financial and time resources, as well as dividing responsibilities, arranged collaborative activities to get to know each other and to increase the sense of belonging, coordinated, informed the necessary stakeholders in and around the community and disseminated the results.

Training school principals as a success factor for the CoP: Principals have an essential role in the proposed CoP. Principals are fundamental [62] for creating school environments where teachers are receptive to new instructional strategies. They are responsible for fostering collaboration, defining the learning strategy of the school and allocate resources for teachers. However, in order to perform these tasks efficiently, they should understand well the opportunities and, more importantly, the challenges of bringing new processes to formal education. Hence, during the workshop, principals used the same tools and faced similar problems as teachers would do later.

This manuscript results present how, after the principals' training session, there was a common agreement that the experience was necessary to open their eyes and increase awareness of the learning process and challenges the teachers might face during their practice. They expressed their willingness to be more receptive to teachers' complaints, especially those concerned with resource and time allocation. In the end, all shared their ideas and vision and formed a common understanding on how the CoP should be developed, which should be the collaboration among schools and even which could be the steps at medium and long term.

Principals agreed on the necessity of allocating for teachers sufficient resources for collaboration, community building and developing the ideas they learn in the training. However, teachers repeatedly communicated not having enough time to engage enough colleagues in the wagon and hence having a significant modification of the operating culture. One of them even complained that he must dedicate "*too much time from me and my family*" in order to prepare the interventions. We believe principals should reserve teachers enough time not only for their own development or preparing teaching content but also assign resources to contribute to the growing of the community. We would like to raise these concerns with teachers in future discussion with them.

Scaffolding of the development of CoP through the teacher training. In our opinion, teacher training was one of the most important events organized during the year. The train serves at least four different purposes: educate teachers, prepare teachers to discuss with other teachers (ensuring continuity in the community), define common goals (join enterprise) and engage teachers in the community (mutual engagement). Our training method was applied from the suggestions made by Andersen and Pitkänen [24] for developing a field of practice by 1+1+1-model. The teachers spent one work day receiving training and inspiration at training sessions (in total, six days), they were asked to design and conduct an intervention after each training day, and they were encouraged and provided with different channels to communicate and reflect on their considerations and ideas with the peers, as well as instructors, throughout the training period.

We did not only provide teachers with adequate technological knowledge in DF, but as presented in the training results, we also helped them, as shown in the Results section, to lose the fear of trying new things and to have the courage to use the learnt technologies. All the teachers performed at least one intervention, even when they did not feel they completely mastered the process. At the same time, the training serves to have bigger empathy with their pupils. They face similar problems during training as pupils found later when utilizing those methodologies. Furthermore, we also utilize STEAM methodologies for instruction, including design thinking and project-based learning. Some of the teachers replicated the same activities we organized for them in their own teaching. We believe that it is important to *train STEAM using STEAM* methodologies.

In addition, the training lets teachers know each other better and share their perspectives, supporting the mutual engagement. Teachers presented the work they have done with the pupils and their impressions on how each process can be integrated into formal education. Generally, communication was fluent, and teachers gave each other valuable feedback. This contributes to the creation of a shared repertoire. In some of the interventions, it was required that they collaborate with other teachers either during the design of the task or in the execution. These interventions aimed to increase the bonds in the community. Results demonstrated that teachers perceived that the training had an impact both in their own teaching practices and in the practices of colleagues. After the training, all teachers had ideas on how to put their learning in practice during the following course.

Finally, we intend to prepare teachers to train other teachers, spreading the knowledge they received. This is necessary to create the experts/apprentices relations typical of the CoP. In one of the interventions, they had to prepare an activity for other teachers, so they could scaffold learning activities for teachers. In the questionnaire, most of the teachers reported that they feel comfortable teaching the acquired skills to other teachers. Furthermore, they considered that training must be provided within a collaboration between Fab Lab and schools. Some subjects can be taught in local schools, but some consider that other topics such as embedded programming or 3D design are better to be taught at Fab Lab.

Balancing technology and pedagogy to initiate mindset building to support the CoP. We valued the possibility to provide the teachers with the feeling of complexity, trials and errors, and experiencing hands-on activities, which are part of the DF processes [63]. However, for each training day, we aimed teachers build some tangible object, both to provide the teachers with the feeling of first-time success and to have something to present and discuss with the colleagues. There were some teachers, who would have appreciated focusing more on practicing technologies, and not that much emphasis on pedagogies. Overall, we were pleased with teachers' reflections in the post-questionnaires regarding their feelings of general empowerment. It seemed that lectures containing learning science theories and rationales behind maker culture, helped teachers to adapt their new role as a STEAM teacher. Additionally, the teachers described significant benefits of collaborative assignments and facilitated reflections after the daily hands-on practices and interventions at school.

6.3. Limitations of the study

In this manuscript, we report the activities carried out in a period of ten months with the goal of supporting the development of a CoP being in its initial phase. Creating a strong CoP might take several years, so the time analyzed is short for having stronger and more consistent results. Nevertheless, we still believe that the preliminary data we provide, as well as the detailed description of the activities might help other practitioners on developing a CoP in their own environment.

This study is limited by the reduced number of participants that were participating in CoP and data collection. With such a sample, it is not possible to derive findings that can be statistically significant and extend across larger populations. For this manuscript, we analyzed the data reported by six principals and eight teachers in different training sessions. The number of participants is small for a quantitative study based on surveys. Instead, we collected open-ended qualitative data.

In addition to that, participants were sampled by using convenience sampling. However, this approach is quite often used in pilot-like studies like this. Concerning the convenience sampling, principals and teachers studied were somehow interested in STEAM education. When we enlarge the group, including people with different attitudes towards STEAM, DF reflections and feedback from subjects would possibly vary. However, we believe it is important to choose "pioneers" for starting the CoP, that is, teachers and principals who have a certain interest in STEAM and DF. They will demonstrate the validity of the methodologies to other colleagues and guide them in the process.

Last limitation of the study was methodological, namely, used data collection techniques. In order to analyze the reported activities, we utilized a diary in the principals' training and an online survey (teacher training). Other qualitative data collection techniques such as focus group discussion, interviews, video analysis of the sessions, survey to principals could have provided a more profound understanding of teachers' attitude towards the CoP. We are planning to keep tracking the development of the CoP, and we will organize more focus group discussion and interviews with teachers and principals (e.g. twice per year).

To sum up, this is an early exploration and the main focus of the paper is on the design and scaffolding of the activities, as well as their support to the CoP, so data collection was not the highest priority in this space yet. In the future research designs, we will put special emphasis on sampling, data collection and analysis

7. Conclusion and future work

In spite of the reported advantages of utilizing STEAM and DF for learning, they have not been integrated into formal education yet. This integration requires a change of mindset and culture in some of the schools to adapt the methodologies and structures. We believe that this transition must be led by teachers, but they would need the support from other stakeholders, including school principals (able to define learning philosophy of schools and allocate resources), researchers and DF experts (able to support and train teachers) and local education officials (able to apply for funding and promote education events). In this paper, we have presented the structure and training activities that we have organized during a period of ten months in order to scaffold the development of a community of practice that drives the integration of STEAM and DF in schools. We describe in detail how we have structured the teacher training, promoting knowledge sharing and preparing teachers for educating other colleagues. In addition, we justify the importance of including principals as stakeholders and provide DF training for them.

We aim to track and report the evolution of the CoP in the following months and years.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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