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# Makerspaces for Pedagogical Innovation Processes: How Finnish Comprehensive Schools Create Space for Makers

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## Abstract

Finland has its own version of a "makerspace": craft class. Originally, there was one craft class for boys and one for girls. Later, there were classes for different materials, especially for wood and textiles, which are deep-rooted concepts in the Finnish crafts mindset. To reclaim craft class for pupils, or "makers", we must determine teachers' and pupils' mindsets concerning collaboration, differing interests and sharing. Craft is a compulsory learning-by-doing subject for pupils in grades one through seven, with activities based on craft expression, design and technology (CDT). This research is part of a national endeavour to develop innovative CDT as a basic education subject. The paper explores two pilot case studies in which technical and textile work teachers taught together in a shared learning environment, rather than in traditionally separate learning environments. The aim was to develop criteria for a new kind of learning environment that would promote learning to develop innovations and pupil's innovation competencies. The first study used a mixed methods approach, including systematic observation, inquiry and pair interviews of five co-teaching teams in primary school, to test the new teaching culture. The second study used an experience sampling method in the form of a mobile application to reveal various parts of pupils' design and making processes in a school setting. The key finding is that collaborative teams can support teachers' and pupils' innovative learning activities when the work is supported by shared spaces, practices and new tools. The paper concludes by relating preconditions for implementing makerspaces in the context of formal comprehensive education to learning outcomes, traditional workshops, learner differences and pedagogical innovation processes.

## Keywords

makerspace, basic education, school reform, co-teaching, self-assessment, pedagogical innovation process

## Introduction

Earlier studies give us a broad perspective of good learning environments. Well-being in schools is based on school conditions, social relationships and means for self-fulfilment and health (Konu & Rimpelä, 2002). Learning environments should be safe and reflect connections to the surrounding society (Piispanen, 2008). Good learning environments also depend on teachers' active collaboration in the design process (Nuikkinen, 2009). Successful teacher communities require supportive leadership, trust and respect for professional development and effective group dynamics and compositions (Vangrieken, Meredith, Packer, & Kyndt, 2017). Finally, learning environments should support the use of modern teaching and learning processes (Kuuskorpi, 2014, 2012). All of the above are critical considerations when creating a space or environment to facilitate learning.

Spaces for hands-on learning and learning by making in formal and informal education—so-called "makerspaces"—have gained global prominence since the advancement of digital modelling and fabrication. 3D printing, laser cutting and other computer numerical controlled (CNC) devices have been used as means of concretising innovative ideas, even with young learners (e.g. Halverson & Sheridan, 2014). However, making is not only about modern technology; it is also the primitive human obsession to use tools to survive in various circumstances. The history of mankind is a history of tooling and solving a variety of problems and challenges. Today, people's individual innovation competence allows them to acknowledge new problems and construct highly usable solutions as part of teams. Individual innovation competence is seen as a combination of personal characteristics, future orientation, creative thinking skills, social skills, project management skills, content knowledge and concretisation and implementation planning skills (Hero, 2019; Hero, Lindfors, & Taatila, 2017).

In many countries, traditional workshops for craft have either never existed or been removed from schools for various reasons (e.g. modernization, financial savings, a lack of appreciation or safety concerns). As a result, there is an insufficient culture of design and technology as a curricular subject. Finland has a unique tradition of makerspaces in comprehensive schools (7- to 16-year-old pupils). The Nordic tradition of teaching craft and technology as a subject in comprehensive education for all pupils (Johansson, 2018; Porko-Hudd, Pöllänen, & Lindfors, 2018) has guaranteed the existence of workshops in formal education as places of design and making since the 19th century. Originally, these makerspaces were segregated by gender, as the curriculum from 1866 to 1970 reflected contemporary society's agrarian labour division of men and women (see e.g. Marjanen & Metsärinne, 2019). Today, society calls for innovative solutions to serious problems in personal and work life. The National Core Curriculum for Basic Education 2014, launched by the Finnish National Board of Education (FNBE), defines learning as being based on observation and exploration of the built environment, mandating efforts to offer pupils contemporary ways to design and apply technological knowledge of their multi-material world in practice (FNBE, 2016). To participate as active members of society, pupils should have opportunities to learn how to deal with and survive new and complicated challenges, such as climate change. Therefore, instead of the earlier labour division-based workshops there is now a need for learning environments that can facilitate creative and innovative problem solving. The question is: What kind of learning environments, or makerspaces, will teach pupils to learn and develop their individual innovation competence?

Teachers, schools and local administrators play central roles in educational change when innovating education. The teacher's role goes beyond simply being involved in the implementation (Organisation for Economic Co-operation and Development [OECD], 2017): Teachers institutionalise the original initiation of educational change over time (Fullan, 2016). However, with studies focusing on the learning environment of workshops and makerspace development still very rare, it is important that the unique tools in future learning spaces, such as shared design practices and digital fabrication tools among other materials and techniques (Allan, Vettese, & Thompson, 2018) be researched and explored to ensure the initiation of educational change starts out from a solid foundation. The study in this paper aims to fill this gap by recognising facts and preconditions for the development of makerspaces as learning environments for formal comprehensive education.

## Theoretical views on spaces of making

### *Learning outcomes and workshops*

The Finnish National Board of Education (Laitinen, Hilmola, & Juntunen, 2011) assessed learning outcomes in the 9th (final) grade of comprehensive education. A substantial number of the pupils failed in the key objective areas of CDT, and learning outcomes were weakest in product design skills (Hilmola, 2011, pp. 14–16). According to the teachers, pupils designed products often or very often (74%), while nearly half (42%) of the pupils answered that they rarely designed products, though two-thirds of pupils had positive attitudes toward CDT as a subject. According to a more recent study (Hilmola & Autio, 2017), attitudes differ depending on which kinds of workshops (textiles or technical work) pupils study in. The study did not reveal what appealed to the pupils when working in various workshops: material technologies, processes, products, or ways of teaching. However, it is clear that there are differing perceptions of designing and making between pupils and teachers and that the learning environment has an impact on pupil attitudes.

Peer and self-assessment is an integral part of learning in CDT education or learning through making. When asked about peer assessment as a learning approach, only 10% of teachers and pupils believed that peer assessment was used often or very often (Hilmola, 2011, pp. 168, 175). According to Saarnilahti, Lindfors and Iiskala (2019), pupils used self-assessment in a narrow manner, and some did not see its meaning in their own work. On this basis, it seems that instruction is experienced differently by pupils and teachers. To see makers (in this case pupils) as identities and parts of communities of practice (Halverson & Sheridan, 2014), it is important to ensure that pupils play an active role in defining problems and challenges as part of the innovation process. If teachers decide too many issues on behalf of pupils, there will be no ongoing holistic processes. On this basis, learning environments should nurture pupils' design activities and self- and peer-assessment skills, in addition to enhancing positive experiences through places for co-working and co-design. The surrounding material world lays a foundation for a sustainable way of living, and the educational task is to support pupils' well-being and life management skills (FNBE, 2016).

While investigating the learning outcomes of CDT, Lindfors and Hilmola (2016) identified three different groups of pupils: positive achievers, positive underachievers and negative underachievers. Positive underachievers fail in their tasks, but still have positive attitudes toward learning. Negative underachievers fail in their tasks and have negative attitudes (Hilmola & Lindfors, 2017). From pupils' motivational point of view, there is a need to understand pupils' actions, likes and dislikes in more detail to support their competence development in makerspaces. Joint practice development is key to self-improvement (Hargreaves, 2014), and self-regulation is an important topic when defining learning tasks related to pupils' own technological and practical experiences (Metsärinne, Kallio, & Virta, 2015). In addition to social and physical considerations, information and communication technologies are important aspects of contemporary learning environments. Pupils' activities can be studied and supported in real time using mobile applications (Ketamo, 2009, 2011) based on theories of flow (Csikszentmihalyi, 1990) and the zone of proximal development (Vygotskij & Cole, 1978).

#### ***A makerspace as a formal learning environment in CDT education***

Makerspaces are typically informal sites for creative production in art, science and engineering. In the context of arts education, the focus is on metarepresentational competence (Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe & Owens, 2014). According to Tan (2018), science education in engineering makerspace depends on three practices: playful components, highly authentic scientific practices and attention to tacit knowledge in learning. Creating something out of nothing and exploring one’s own interests is central to so-called maker culture. According to Halverson and Sheridan (2014), the three components of the maker movement are a set of activities, makerspaces as communities of practice and makers as identities. Connecting design thinking to the theoretical notion of knowledge creation relates to makers’ initial level of agency in determining the kinds of making in which they are engaged (Hughes, Morrison, Kajamaa, & Kumpulainen, 2019). According to Lefebvre (1991), a space is a social product: a complex social construction that affects spatial practices and perceptions. Research considers the processes of production, rather than the physical space itself. Space serves as a tool and offers places to develop shared practices. The maker movement is about making by hand—in the digital age—a set of tools and skills needed to fulfil basic intentions (Dufva, 2017).

A learning environment for learning-by-doing/making/developing supports an understanding of the operating principles of technology and consists of suitable and safe facilities, tools, machines, equipment and materials. Information and communication technologies (ICT) and projects that cross subject boundaries in cooperation with experts and communities outside school offer many new possibilities (FNBE, 2016). In the Finnish context, traditional craft workshops are well suited for learning with several themes. Technical workshops typically include a basic workplace (one side of a workman’s bench) and various workstations and workshops, usually for computer aided design (CAD), robotics, electronics, woodwork, machine tools, metalwork, plastic work, finishing, heat treatment and storage. Textile workshops are more like studios, equipped with basic workplaces and workstations for sewing, seaming, knitting, weaving, printing and sewable electronics.

In CDT, the learning environment is also considered a working environment because of the tools and machines used as a part of the pedagogical working processes. This adds to the conversation concerning safety issues in the form of criteria for safe and secure CDT makerspaces. In this way, safety culture is a relevant part of spaces for making. Safe and appropriate movements between basic workplaces and workstations/work areas/separate workshops impose certain conditions on building technology and managing noise, dust, machining waste, chemical emissions and heat treatment. In the formal school context, productive actions should follow the current curriculum and prepare for the future.

## *Support for pupils’ different interests and processes*

Pupils’ abilities, skills and learning processes vary; thus, in managing a holistic design process, there is a clear need for timely support (Lindfors & Hilmola, 2016). Today, the Finnish core curriculum (FNBE, 2016) includes more innovative design processes than material technologies. In formal education, the Finnish makerspace focuses not only on the facilities of digital fabrication, programming and electronics, but also on the combined role of craft, design and technology in supporting pupils’ personal growth and technological literacy. Instead of implementing either textile or technical work techniques in separate workshops, schools use a wide range of material technologies to invent and manufacture solutions for problems that pupils see as important and that educational authorities believe to enhance their innovation competencies.

One solution to support various kinds of pupils is co-teaching. Co-teaching is an instructional practice for teaching a heterogeneous group of pupils in the same space, and it involves active teacher participation in assessment, planning and instruction (Cook & Friend, 1995; Murawski & Lochner, 2011), as well as effective utilisation of the resources of the group and the interactions among the pupils. Co-teachers must manage different learners and ensure that all pupils have access to the content outlined by the curriculum. A shared makerspace can be seen as a microcosm of society, setting the tone for learning and community. In co-teaching, professional responsibility is shared and widens management of the whole learning environment. Professional co-teaching enables collective actions and dialogue spanning a zone of proximal development for teachers (Roth, Robin, & Zimmermann, 2002) and timely support for pupils in developing their innovation competencies. In CDT education, co-teaching allows teachers to learn from one another (e.g. unfamiliar material technologies and instructional approaches) and gives pupils more support in their design processes.

### *Supporting pedagogical innovation processes in a learning environment*

Places for making, play a key role in bridging the humanities and the sciences, which is a complex problem (de Melo-Martín, 2010; Snow, 1964). Recently, the co-operation between these two sciences has increased, and innovative campus complexes have been developed to bring together different experts and views to facilitate innovations. However, higher education is far too late for pupils to begin learning innovation competencies. In comprehensive education, the pedagogical innovation process is a creative and reflective problem-solving, design, manufacturing and testing process for developing new solutions for various contexts. The process involves a user needs analysis, a problem definition (based on a learning task and user needs), ideation, critical testing of options based on ideas, usability development, prototyping, planning, making, fabrication and usability evaluations conducted through self-reflection and process and solution assessment, either individually or in a group (Lindfors, 2007, 2012; Lindfors & Hilmola, 2016). This innovative process develops contextual problem-solving skills and the critical optimisation of solutions in the material world (Lindfors, 2010). The process itself can also serve as a contextual learning environment (Hero et al., 2017), such that a pupil can invent a solution to a challenge at hand.

Traditionally, textile work is considered to be more human and aesthetically oriented, while technical work is, obviously, more technical (i.e. based more on natural sciences; Kojonkoski-Rännäli, 2001, 2006). In co-teaching, these two approaches form a perfect pair to actuate design thinking and technological literacy, as long as the work begins with the user's interest and supports pupils' different needs. However, solving tensions between instruction and construction when developing makerspaces is a common problem worldwide (Rosa, Ferretti, Guimarães Pereira, Panella, & Wanner, 2017; Tan, 2018). The quantity and range of the maker movement is defined by communities engaged in do-it-yourself activities. In the school context, learning is too often imagined to be orchestrated by instructors, rather than by hands-on makers, pupils or their own interests and experiences (Dewey, 1997). If pupils only passively respond to activities and events planned on their behalf, learning-by-doing and innovation competence development do not reach their full potential.

It is also important to consider who is in charge of a maker community and its organisation. Finnish teachers balance broad pedagogical freedom and responsibility. Local school curricula are planned and constructed by teachers, principals and municipal authorities according to the national basic education core curriculum, regulating pedagogical activities with various local interpretations (Simola, 2017; Toom & Husu, 2012). Teachers play a key role when deploying the maker movement in the context of formal comprehensive education. The recent studies (Hero, 2017, 2019; Hero & Lindfors, 2019) discussed developing innovation competence as a multidisciplinary activity system within the institutional higher education context. The findings suggest that conceptions of a learning experience in a multidisciplinary innovation project relate to: (1) solvable conflicts and unusual situations, (2) becoming aware of and claiming collaborative agency and (3) internalising the phases of the innovation process. The relevant factors for learning to develop innovation were categorised under six topics for guiding curriculum development and the pedagogical design of problem-based projects: competence factors, factors related to assessment, pedagogical processes, organising the activity, teachers' roles and opportunities for tutoring and using the concept in education.

## The study context

The FNBE funded the Käsitäksää ("Do you get it?") project to pilot Finland's first elementary education makerspace that would allow co-teaching. The project unified traditional workshops into a coherent space for making. It also added digital modelling and fabrication machines. Pupils' basic workplaces and workstations for different material technologies were combined into a unified learning environment—a makerspace—instead of being divided into the traditional categories of textiles and technical work. The first author was in charge of the project coordination and the implementation of new ideas.

The study is based on two peer-reviewed pilot studies conducted in Finnish comprehensive education (Jaatinen & Lindfors, 2016; Jaatinen, Ketamo, & Lindfors, 2017). These two co-teaching case studies were interventions designed to solicit teachers' and pupils' perspectives and, thus, understand the preconditions for a makerspace. According to the norm of the Finnish comprehensive education core curriculum, pupils should be able to develop their innovation competence through CDT processes (FNBE, 2016). For example, CDT education can be carried out according to the following models: 1) shared craft education, 2) from technology to design, 3) from idea to product and 4) innovation processes (Lindfors, Marjanen, & Jaatinen, 2016; Lindfors & Hilmola, 2016). On this basis, a makerspace must enable, encourage and enhance various ways of teaching and learning CDT. For this reason, the main question of this study is: What are the preconditions for makerspaces enhancing pupils' pedagogical innovation processes in the context of formal comprehensive education?

The study context was a typical Finnish suburban primary school for grades one through six. The teachers involved in the study were primary school teachers with master's degrees, and three of the teachers also had CDT subject teacher degrees. Co-teaching and pupils' actions were observed in natural school study groups across three parallel classes of the same grade. Previously, a class of pupils was divided into two groups, which were taught one by one but switched between a textile teacher and a technical work teacher in the middle of the school year. The Käsitäksää project anticipated the implementation of the National Core Curriculum for Basic Education in 2014 (FNBE, 2016) by shifting the teaching system from individual teachers to co-teaching in the autumn of 2014. In the study context, several aspects of the learning environment (Manninen, Burman, Koivunen, Kuittinen, Luukannel, Passi & Särkkä, 2007, p. 15) were modified to support pedagogical innovation processes (Figure 1). This helped achieve the objectives of CDT teaching (FNBE, 2016) where the focus is on multidisciplinary and innovative holistic design processes.

First, the space for learning was organised to enable co-teaching (1st study: Jaatinen & Lindfors, 2016), and later, the interior was designed as a lounge based on ideas envisioned in teachers' and pupils' participatory workshops (2nd study: Jaatinen et al., 2017). Second, pupils' workplaces and different workstations and workshops were organised according to different phases of the flow in the holistic process, whereas previously a basic workplace was defined according to its material processing. Further, what was previously the supervisor's booth was transformed into the pupils' secret corner or ideation place. Third, the practice was developed to be more design-oriented, focusing on transversal competence and co-teaching. Fourth, the community was widened spatially and virtually to support natural connections to other subjects. Finally, following Wilson's (1996, p. 3) ideas of a constructivist learning environment, changes were made to the resources (e.g. the QR code instrument used in the second study).

***Figure 1. Modified CDT learning environment***

## Methodology

The overarching aim of this research and development project was to develop a learning environment for pupils' pedagogical innovation processes in CDT education (Figure 2). To consider different perspectives on development, two studies were conducted in the context of Finnish comprehensive education. The research design sought to briefly summarise the two peer-reviewed pilot studies (Jaatinen & Lindfors, 2016; Jaatinen et al., 2017) and consider findings in relation to preconditions of makerspaces for formal learning environments in CDT education.

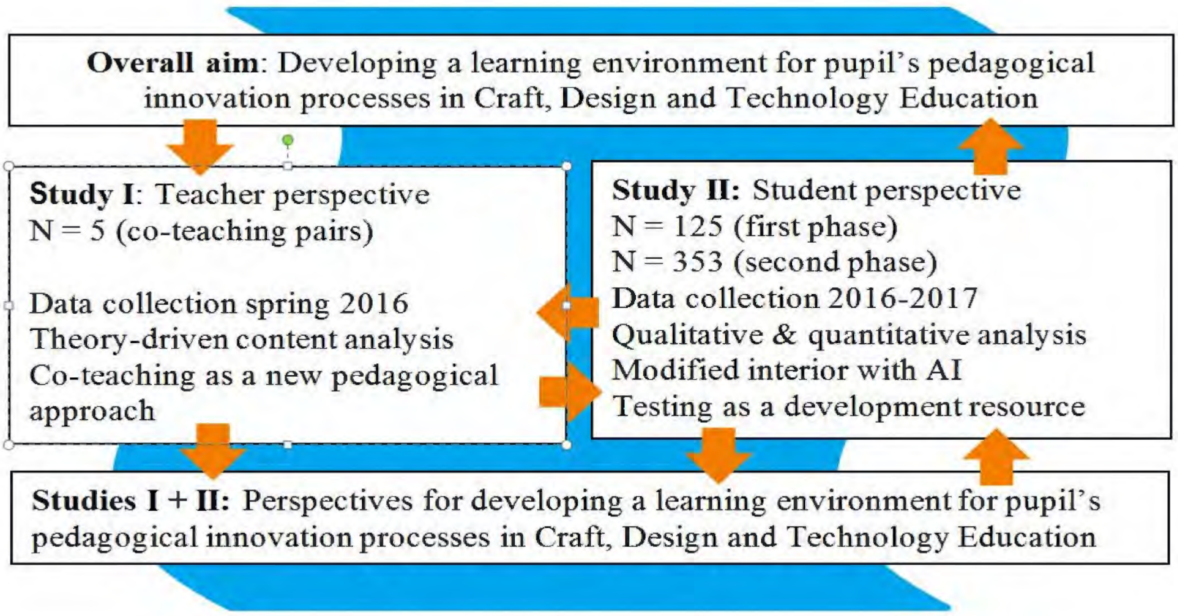



***Figure 2. Research design***

### *Study I: Co-teaching data and analysis*

Co-teaching was used as a new pedagogical approach to find ways to enhance pupils' pedagogical innovation processes. The participants were five co-teaching pairs in primary school grades 3 through 6. Materials were collected based on triangulation with systematic observations (22 hrs, 2 to 6 hrs/team), individual inquiries and pair interviews of co-teachers (Figure 2). The study was conducted in the second year after the co-teaching started. The research design was created and adjusted based on Murawski and Lochner's (2011, 2014) work on observing co-teaching: what to ask for, look for and listen for. The framework was adapted to the Finnish educational context and content based on the work of Jaatinen and Lindfors (2016). The procedure was to observe the co-teaching, collect answers to inquiries and conduct interviews based on questions drawn from the inquiry. The research question was as follows: What is CDT education subject teaching when the approach is based on co-teaching? The data were analysed using theory-driven content analysis.

### *Study II: Experience sampling method and analysis of pupils' actions*

In the second study ESM - an experience sampling method (Csikszentmihalyi, 2014; Hektner, Schmidt, & Csikszentmihalyi, 2007) with a gamified learning analytics instrument was used to examine a pilot implementation of a mobile application designed for use in the makerspace (Figure 2). There was a need for a method to reveal pupils' activities supporting and not supporting pedagogical innovation processes in the co-teaching setting. The mobile application was used as a new pedagogical approach that made it possible for teachers to challenge pupils' competence levels with increasingly difficult tasks.

Participation in the research was carried out in two stages. Teachers participated by collectively defining activities, and pupils participated by self-reporting their responses to activities. QR codes for the self-assessment application BOOK-AI were developed in the fifth and sixth grade teachers' workshop, and preliminary measurements were carried out in grades five through six (ages 10 through 12, n = 125) during a four-week period in 2016. The teachers' current teaching activities served as a backbone for the thematic mapping of the curriculum (Figures 3c, 3d & 5). The first four-week period was used to familiarise the pupils with the new ESM instrument and to detail measuring points for the holistic process. The list of pupils' learning activities was updated by all teachers involved in the CDT teaching. The updated list was tested in 2017, and materials were collected from all pupils in the project school (n = 353). The research question was: How are pupils' activities and progressions seen on a curriculum level when using information collected by a self-assessment application in activities defined by teachers? The analysis was conducted by introducing semantic maps of individual pupils' actions and progress and different kinds of group examples. This semantic network, built according to the keywords of the activities defined by the teachers and assessed by the pupils, is presented later in the document.

### *Studies I + II: Finding preconditions for a makerspace in CDT education*

In the second phase of this paper, the results of studies I and II were considered in relation to the identified preconditions for a makerspace for a formal learning environment in CDT education. A review was conducted of theoretical views on spaces of making: learning outcomes, current workshops, ways of supporting various learners and pedagogical innovation processes. The research question was: What are the preconditions for makerspaces enhancing pupils' pedagogical innovation processes in the context of formal comprehensive education?

## Findings

***Study I:*** Jaatinen & Lindfors (2016) analysed co-teaching teams (two teachers, a teaching assistant and 18 to 21 pupils) in a learning environment that had been redesigned to promote pupils' pedagogical innovation processes. Based on theory-driven content analysis, the results of the study revealed that co-teaching was positively adopted as a new teaching approach. The results are presented by describing 11 core CDT co-teaching competencies (Table 1) and ways of mastering both emerging and developing co-teaching and proficient co-teaching. Co-teaching requires co-planning, co-instructing and co-assessing (Murawski & Lochner, 2011).

*Emerging and developing co-teaching*

The teachers involved in the study felt that co-teaching and multi-material craft were positive things from the pupils' point of view, even though these increased the requirements for teachers' skills. In light of the results (Table 1), it seems that the lack of planning time is a challenge in the emergence and development of co-teaching. Typically, in emerging and developing co-teaching, the learner and learning are not yet in focus, despite a shared learning environment. Tasks include selecting techniques for everyone (instead of organising peer interaction) and supporting holistic processes. Instructional practice suffers from a lack of own design know-how.

> *The lessons should be agreed and planned together in order, so that both teachers have a shared vision of how to proceed and which one presents and teaches certain issues, how the division of labour works, etc. Instructing a pupil's design is sometimes demanding depending on the pupils' differences… I need help with it. (Co-teaching pair 5.)*

Professional responsibility is not considered from a new co-teaching point of view. In emerging and developing co-teaching, teachers do not yet see the connection between learning tasks and holistic craft processes and cannot motivate challenging pupils. The prioritisation of design time into pedagogical innovation processes seems to depend on the teachers themselves.

> *The team of third grade teachers meets weekly. The team of fourth grade teachers meets at different times, leaving less time for co-design with teachers. (Co-teaching pair 1. & 2.)*

Table 1. Researching (structured observation, inquiry and pair interviews with inquiry themes) and developing the core competences of CDT co-teaching. Created and adjusted based on the work of Murawski and Lochner (2011, 2014). Content based on the work of Jaatinen and Lindfors (2016).

| *Emerging and developing co-teaching* | *Proficient co-teaching* |
|---|---|
| ***I Teachers' commitment to a learner & learning*** | |
| **1. Learner differences** | |
| The same work instructions are given to all pupils, although they are at different phases of their process. Teachers do not recognise a need for individual support. | Pupils receive guidance according to their needs, and processes differ according to the development levels of their competencies. |
| **2. CDT workshop environment** | |
| Teachers do not share a common approach when a pupil's process is not proceeding as desired. Teachers do not discuss pupils' need for support. | Teachers treat each other with caring and respectful behaviours. Teaching supports and anticipates pupils' processes. |
| ***II Teachers' commitment to a task at hand*** | |
| **3. Content knowledge** | |
| There is a lack of consistent ideas concerning the whole lesson, and the guidance of pupils' design process is uncertain. | Teaching is based on formative assessment, and learning skills are consistently taught. |
| **4. Compliance issues** | |
| Interactive school support is absent, and the tasks required from all pupils have not been agreed. | Peer interaction is supported, and teaching is pupil-centred and implemented in co-operation. |
| **5. Co-teaching construct** | |
| Only a few co-teaching models are in use, and shared responsibility is not clear. | There are several co-teaching models in use, and the common guidelines form a coherent whole. |
| ***III Teachers' instructional practice in a pilot makerspace*** | |
| **6. Assessment** | |
| A pupil does not understand the meaning of evaluation, and there are no documents of the process. | Documentation is part of the evaluation process, and pupils' assessment is made in collaboration. |
| **7. Planning** | |
| There are few methods to guide design, and it is hindered by the teacher's own lack of design expertise. | Versatile co-planning methods are used to support pupils' holistic processes. |
| **8. Instruction** | |
| Pupils' self-regulation is taken for granted, and pupil grouping is not done appropriately. | Collaborative learning is based on motivational tasks, and peer collaboration is encouraged. |
| ***IV Teachers' professional responsibility in co-teaching*** | |
| **9. Communication, collaboration & problem-solving** | |
| There is no co-planning and no flexibility in technical or textile work teachers' roles. | Teachers use we-speech, and learning tasks are pupil-centred. |
| **10. Families & community** | |
| There is no cooperation with stakeholders; Only one teacher maintains e. g. contact with families. | Pupils' processes are visualised in a web for parents, and information is given in parents' meetings on pupils' progress. |
| **11. Professional practices & ethics** | |
| Teaching is dominated by material and technology centricity and is not based on transversal competence or pupils' holistic processes. | The beginning, educational entity and ending of a lesson are organised together to enhance pupils' smooth holistic processes. |

## *Proficient co-teaching*

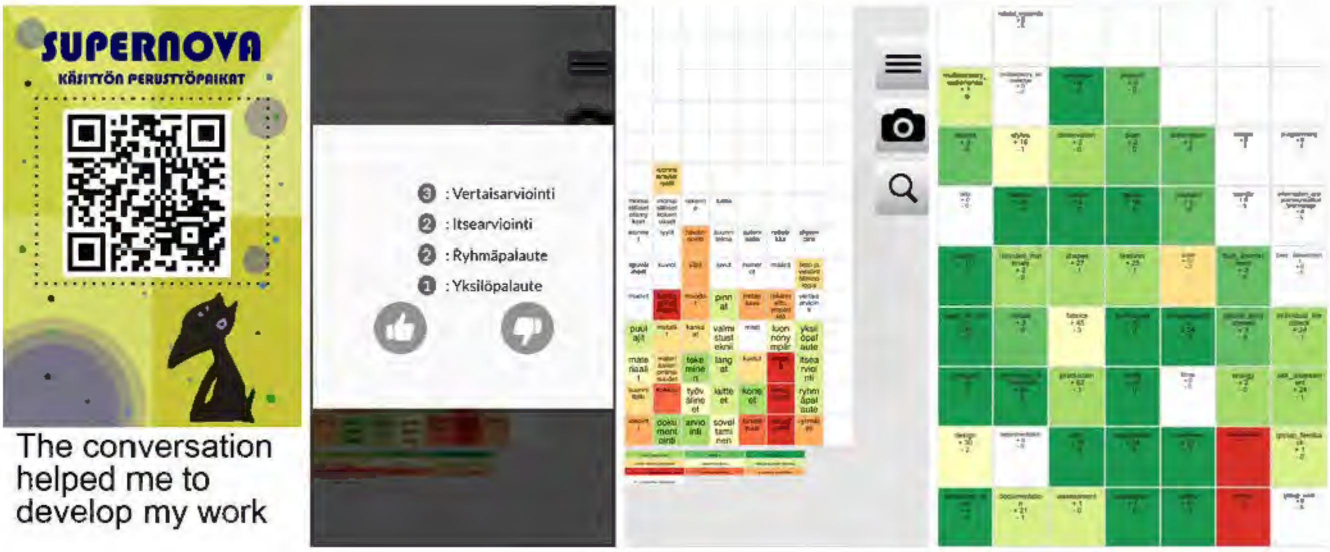
According to the results, interactive and collaborative planning, instruction and assessment for a pedagogical innovation process are key elements of proficient co-teaching. In proficient co-teaching, learner and learning are understood as learner-centred and common aspects of a shared learning environment. Tasks involve managing peer interaction and support for various and holistic processes. Instructional practice is manifold, and professional responsibility is a pride.

> *In early autumn, I was sceptical. Then I got interested in it, and I am in the more sceptical mode again. Multidisciplinarity provides opportunities, but it requires a lot from both teachers and pupils. (Co-teaching pair 3.)*

*Conclusions from study I*

The results suggest that higher CDT development targets (Hilmola, 2011; Lindfors & Hilmola, 2016) can be achieved through proficient co-teaching, including developing holistic process management and meaningful learning tasks for pupils. Pupils' activities should be developed to support more collaborative learning.

***Study II:*** Jaatinen et al., (2017) investigated pupils' processes in CDT education by combining school architecture and a web-based learning environment (Figure 4). The aims of the study were to: 1) make pupils' CDT processes visible in everyday CDT workshop practices through information collected by a mobile application and 2) identify the curriculum topics covered during everyday learning activities. Individual tasks were connected to the larger conceptual framework. Figure 3a provides an example of a scanned QR code ("The conversation helped me to develop my work"). The learning objects are described by detailed rank-ordered keywords (tags, concepts) that define the themes of the content, as well as a difficulty estimator that describes the tags' estimated differences in terms of expectations of difficulty (Figure 3b). A pupil's level is shown in the data through a time series in ontology map (Figure 3c). The ontology map is essentially a personal profile that is coloured by users during use. The ontology map covers all concrete action-related concepts in local and national curricula. Initially, the blocks are coloured white, meaning that a concept has not yet been assessed. The blocks begin to turn orange at the first "thumbs up"; later, they turn to yellow to show good progress and green to show that a pupil has mastered a curriculum concept. A thumbs down turns a block's colour to red. The difficulty level is not meant to be strict and general throughout the network, and it must be accepted that there is relatively high uncertainty about estimated difficulty. However, at a conceptual level, the semantic network is very strict, and this difficulty in estimation is meant to strengthen this part of the network. Figure 3d presents group-level data for grade 6.




(a) (b) (c) (d)

Figure 3. a) A QR evaluation spot on a basic workplace; b) an action example (peer- and self-assessment, group and individual feedback); c) a pupil interface in Finnish, including main concepts in the local and national curriculum; and d) one example of group-level data visualisation using a 6th-grade group with many participants during a test (n = 21).

*Workshops settings—towards a makerspace*

The scanning of the architectural plan focused on the different actions of the key contents (Figure 4). At the start and end, educational entities and key content areas are discussed together. Basic workplaces offer a variety of actions, which were documented with own spatial arrangements in the studio. Different kinds of workshops for dirt, dust, heat and safety controls were equipped with work phase-related QR-evaluation spots. As this was a pilot study, it is impossible to draw far-reaching conclusions regarding what happened in each spot, and many user-related variables were unexamined. However, visualisations helped to reveal the relevance of different activities.

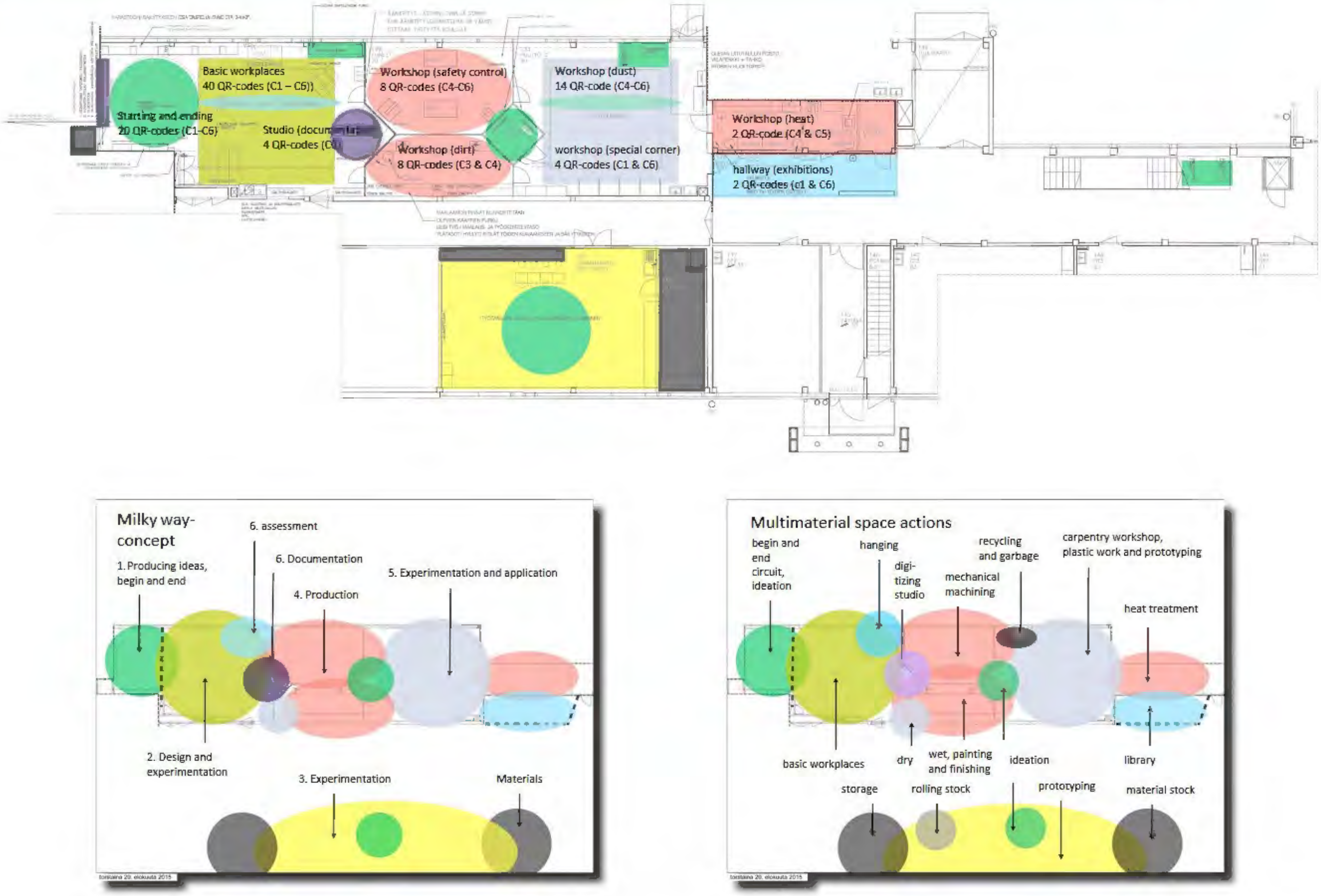



***Figure 4: QR-evaluation spots in the pilot makerspace and main use of workshops during the 2nd test phase (Jaatinen et al., 2017).***

## *Describing the learning activities*

All concrete action-related concepts in local and national curricula are shown on the left in Figure 5 and organised according to occurrence by volume in the system's data mining. These concepts include (observe) objects, (use) scales, (experiment with) materials, (produce) products, (familiarise with) safety and (conduct) peer assessment. Activities are not emphasised on the regulation level. Data collected with ESM tools show the frequencies of the 54 curriculum keywords in the system over the course of the research period. Each activity was defined by several keywords. These form a set of words connected to one another via the activities, such that the keywords for each activity are all interconnected because they share the same activity-related meaning or purpose. The curriculum keyword is a fundamental concept. The keywords are connected via one or more activities. The semantic network is presented on the right in Figure 5 and the network was built according to the keywords of the activities defined for the second test phase. Most of the first defined actions related directly to the production phase. Design was linked to the actions (and, thus, evaluated), but it was not closely related to the production phase. However, the process did not focus on peer assessment, as it should in a maker community.

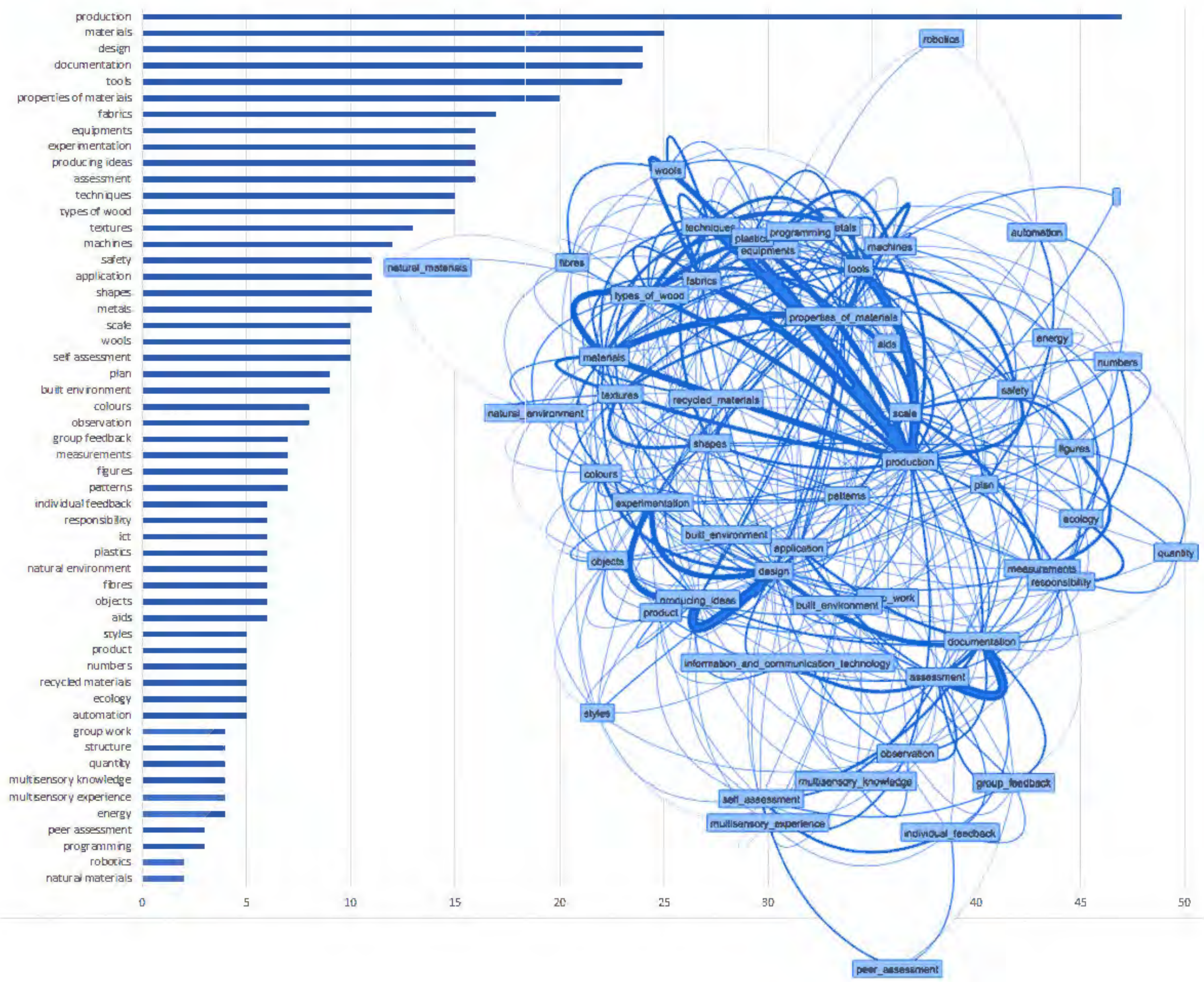



***Figure 5. Left: the frequencies of the 54 curriculum keywords in the system. Right: a semantic network, built according to the keywords of the activities defined by teachers and assessed by pupils.***

## *Conclusions from study II*

The pupils considered the self-assessment to be easy as a technical process; however, there were several factors in the learning setting that made the process challenging, and it was relatively difficult for teachers to describe the workshop activities and process topics in terms of the curriculum. Following the preliminary test, the teachers described activities in more detail and developed new activities that better supported the ideas of the curriculum and the pedagogical innovation process.

### *Preconditions for a makerspace in CDT education*

The second phase of this study considered the results of studies I and II in relation to the learning outcomes, the current workshops, the ways of supporting various learners and the pedagogical innovation process (Table 2). The theoretical views on spaces of making were reviewed as follows:

The learning outcomes illustrated weak product design skills (Hilmola, 2011) and teachers' and pupils' differing views concerning them. In the pilot makerspace, proficient co-teaching supported pupils' different interests. A learning environment with various material technologies gave pupils the opportunity to sense basic workplaces, workstations and workshops as makerspaces with multifaceted opportunities. According to an earlier study on positive and negative achievers and underachievers (Hilmola & Lindfors, 2017; Lindfors & Hilmola, 2016), timely support during pupils' processes is important for enhancing pupils' skills and positive attitudes. In studies I and II, the question no longer concerned designing something to be manufactured by textile or technical work techniques (although teachers struggled with how to face the deep-rooted tradition of division). Instead, there was a problem that needed to be recognised and solved with suitable material technologies, as is typical for makerspace and making culture thinking.

A makerspace that integrates the current workshops of textiles and technical work with digital modelling and fabrication could offer a place to develop shared practices (Study I). The digital application (ESM) added a new dimension to community support, but was also necessary to support assessment and pupils' self-regulation. Advanced use of the ESM application connected the concepts of making to a wider context and opened a discussion from the pupils' own perspective. However, making, manufacturing and material technologies gain more weight in practise than design and problem-solving, not to mention self- and peer-reflection and assessment (Study II). Thus, a makerspace must have places for pupils to share work (e.g. ideation, self and peer assessment, idea testing and prototyping). This also seems to be an aspect of instructional practices (e.g. how teachers nurture pupils' interests and motivation). On this basis, makerspaces can be used in creative ways to shift the focus from material technologies to problem-based design processes that utilise different technologies with shared practices as means and tools to create solutions. Teachers have responsibility for safety; thus, a school makerspace must advance safety in the form of both physical facilities and social construction. An important precondition for a makerspace is a space that facilitates a creative atmosphere as a construction of a safe whole. Pupils work in their basic workplaces, move among workstations and work areas and develop their competencies while designing and engineering their solutions. Since physical safety is regulated by norms, co-teaching and pupils' shared work must be adapted using architectural and constructional solutions.

To support various learners, an optimal makerspace should guide pupils and teachers to find solutions and achieve positive experiences. This means that pupils must have easy access to supplies and materials and use them as libraries for design. Abandoning traditional teaching and giving more support to pupils and learning requires certain preconditions. To fulfil pupils' needs and follow the aims of the curriculum, the core competence model for co-teaching (Jaatinen & Lindfors, 2016) is presented as a solution for pupils' needs. From a makerspace criteria point of view, there is a need for spaces that advance co-teaching and move the focus from teaching to enhancing pupils' holistic processes and exploiting various material technologies and workstations in their processes.

Makerspaces and pedagogical innovation processes cross subject boundaries. The results indicate that the co-teaching teams enhanced pupils' learning activities, as the teachers' work was supported by shared spaces, practices and new tools. Proficient co-teaching promoted pupils' different interests in ways that enhanced the pupils' innovation competencies in pedagogical innovation processes through co-teaching rooted in pupils' needs (Study I, Table 1). The learning environment, which was designed to include a basic workplace, various material technology workstations and wider workshops (e.g. digital fabrication, wood work, sewing, engineering and weaving), was considered a holistic makerspace with well-defined areas of working and paths for moving from one workstation to basic workplaces or other workstations. This approach facilitated pupils' multifaceted opportunities to design and fabricate solutions to important problems and motivating them with proficient co-teaching.

***Table 2. What are the characteristics of the learning environment that support innovation learning?***

| Study I (co-teaching and community) | Study II (pupils' identities and peer collaboration) | Studies I + II (instruction—construction) |
|---|---|---|
| **1. Learning outcomes:** Pupils' motivation and freedom—teachers' timely support for pupils and sense of professional control | | |
| Proficient co-teaching supports pupils' different interests and mindsets, allowed and necessary in pedagogical innovation processes. A learning environment with various material technologies gives pupils an opportunity to see basic workplaces, workstations and workshops as makerspaces with multifaceted opportunities. | Pupil- and class-specific skill profiles illustrate various processes. Observations collected directly from pupils in different work phases serve as a "backup" for teachers. To be a usable tool, the piloted teacher application requires a greater focus on user orientation. | The pupils' freedom is supported by environmental psychological considerations, and the teacher's sense of classroom management. Social versus individual equity is considered. |
| **2. Craft workshops as a makerspace** (formal learning environments in CDT education): Redefined basic workplaces—workstations and workshops | | |
| Co-teaching allows different kinds of orientations and helps pupils be seen as makers: from human- and aesthetically oriented learning towards multidisciplinary problem-oriented learning. Proficient co-teaching also requires co-operation. | The development of one's own micro-competencies brings a playful, engaging and motivational dimension to learning and is one tool for calibrating motivation. | Basic workplaces are transformed into workstations and workshops. Craft workshops are good preconditions for developing makerspace thinking. Safety culture deals with values, attitudes, knowledge and skills and depends on pupils' own experience and teachers' supervision. |
| **3. Various kinds of pupils:** Spatial support for flow—stimulus, inspiration, and materials in a creative process | | |
| Pupils' different uses of various material technologies challenges basic questions concerning the organisation of teaching and the division of teacher labour. Proficient co-teaching is one solution. The shared professional responsibility arises from the responsibility of ordering small things towards a greater vision of the use of a makerspace. | In a meaningful project, the pupil learns the basic skills just in time. The same basic concepts can be learned in many different ways and workstations (the relationship between concepts in the curriculum map and the keywords, without the mediating classroom activities) | The learning environment equals the design process. Spatial support is provided different learners to support a flow-channel useful for rethinking storage as places to share, stimuli, inspiration libraries and material banks in creative processes. |
| **4. Pedagogical innovation process:** Crossing subject boundaries—local autonomy makes participatory concepts possible | | |
| Curricula point out transversal competencies. The wide-ranging nature of primary school class teachers' profession provides an opportunity to emphasise the teachers' involvement in makerspace development. | Advanced use of the ESM application connects the concepts of making to a wider context and opens the discussion from the pupils' own perspective. | Teachers operate between broad pedagogical freedom and responsibility for school reform. This pilot study is one example. |

While the teachers defined and improved the curriculum concepts and learning contents for the mobile application (study II), they developed their own understanding of the contents of the pedagogical innovation process. From the pupils' perspective, a key issue was not achieving equality across different material technologies, but securing intensified support for self-regulation and individual needs in various processes. On this basis, a makerspace should be a space and a mental state for cultivating design and innovation, instead of mere production. The co-teaching and pupils' different uses of various material technologies challenged basic questions concerning the organisation of teaching and the division of teacher labour. Shared professional responsibility arose from the responsibility of ordering small things towards a greater vision of the use of a makerspace (study I).

The results suggest eight preconditions of formal CDT makerspace design and construction (Table 2):

1. A makerspace should be a place and a space as a mental, physical and social construction that enhances positive experiences, spatial practices and perceptions. (Table 2, spec. 1.)
2. A makerspace should guide teachers and pupils in a future oriented way in their work as co-operators. (Table 2, spec. 1.)
3. A makerspace should be a safe place that encourages various kinds of solutions based on learning tasks. Pupils should be able to use the CDT workspace in a meaningful way by moving between their workplaces and the workshops both independently and according to the teacher's guidance. (Table 2, spec. 2.)
4. A makerspace should be a learning and working environment equipped with various workstations and material technologies that enhance practical problem-solving. (Table 2, spec. 2.)
5. A makerspace should be a place for co-working and co-design that nurtures ideation and design activities, as well as pupils' self- and peer-assessment. A place where it is possible to recognise one's skills. (Table 2, spec. 3.)
6. A place where it is possible to recognise pupils' different personal characteristics and provide timely support to enhance their innovation competence through several kinds of design problems and material technologies. (Table 2, spec. 3.)
7. A makerspace should facilitate that design and technology education exist in cooperation across subject boundaries. (Table 2, spec. 4.)
8. A makerspace should be a shared place for co-teaching and enhancing pupils' innovation competence. A makerspace should facilitate professional co-teaching that recognises pupils' various needs and enhances their attitudes, abilities and skills in pedagogical innovation processes. (Table 2, spec. 4.)

## Discussion

The previous studies dealt with co-teaching mainly in the context of special education (see e.g. Murawski & Lochner 2011). The study I considered co-teaching as a new tool to use in creation of the makerspace that integrated the traditional workshops with digital technologies. The triangulation data (study I) made it possible to understand emerging, advanced and proficient co-teaching in the context of CDT education. It revealed the importance of teacher labour division and support and guidance for pupils. On this basis it would be possible to create a questionnaire to enable the use of quantitative data on co-teaching in CDT education to enlarge a dataset in future studies. Despite the case study nature of the results, the co-teaching approach seems to be a promising way to enhance pupils' innovation competences in formal makerspace context.

The digital application (ESM, study II) offered a new tool for following pupils' learning processes. It offered the required resource on its side and revealed how pupils assessed their work. It made very evident (Figure 5), that there is lack of design and ideation to be connected to pupils' making processes. It also seemed to help teachers in understanding the phases in pupils' processes – even if it was difficult at first for teachers to verbalise the various phases of pupils' processes. On the basis of this pilot experiment and data, ESM seems to support pupils and teachers in assessment and pupils' in their self-regulation. ESM (see e.g. Hektner, Schmidt & Csikszentmihalyi, 2007) opened the discussion from the pupil's own perspective in a new way. The advanced use of the ESM-application (Figure 3d) connected the concepts of pupils' processes more deeply and detailed. It seems that ESM could be used in future studies as a research method to obtain lager datasets, but also as a tool in teachers' and pupils' ordinary work in makerspaces. Talking about the makers, pupils could have also been involved in developing the ESM application as it would have been a more user-oriented approach.

A makerspace for formal education (see e.g. Halverson, & Sheridan, 2014) can be developed in different schools on various bases, depending on the shared view of teachers, pupils, school administrators and designers. As a starting point for practical pedagogical solutions to enhance pupils' holistic processes and innovation competence, a makerspace should follow certain basic pedagogical tenets. For example, involving teachers with broad freedom and autonomy is crucial. When developing makerspaces, we had to develop an entire school organisation and multidisciplinary activity system (see Simola, 2017; Hero, 2019). Curricula are renewed every ten years, so the exploration of better methods is always topical.

The selected research methods supported development well. The piloted Studies I and II as well as integration of the results from makerspace point of view can be viewed as a first round of design research. There are a lot of new research possibilities to identify links and relevance between CDT learning activities from a pupil perspective. As Andreas Schleicher, OECD (2017, p. 3) Director for Education and Skills, stated, "If there has been one lesson learnt about innovating education, it is that teachers, schools and local administrators should not just be involved in the implementation of educational change but they should have a central role in its design". On the basis of the study at hand, we would add that in makerspace creation also pupils should have a central role.

## Conclusion

The tendency for makerspace development is both global and local concerning informal and formal settings. Pupils should learn problem solving at schools by developing solutions to problems they define based on meaningful learning tasks. Design and making in formal learning require more empirical research to develop the theory, knowledge and skills necessary to design new kinds of learning environments: makerspaces that support creative problem-solving for problems that do not yet exist. Research seldom asks what kinds of learning environments would best facilitate this outcome.

According to the curriculum for primary and secondary education, persistent and innovative working processes and positive experiences that strengthen self-esteem and bring joy are crucial for CDT

(FNBE, 2016, p. 290). The results imply that the pilot makerspace with professional co-teaching could be one way to transform CDT learning from the tradition of textile and technical work to a teaching and learning approach that facilitates pupils' innovation competence.

Studies of grades seven through nine and different local premises might offer other suggestions for how Finnish comprehensive school can create space for makers. However, the results of this study are relevant, as education policy challenges touch everyone, whether the emphasis is on balancing material technologies, science and technology or some other cultural tension. In a more user-oriented approach, pupils should also be involved in developing the application, since a study with a piloted application is like a first round of design research. There are many possibilities for new research to identify the relevance of and links among activities from a pupil's perspective.

Makerspaces in formal education should enhance pupils' possibilities to design, manufacture, fabricate, test and assess innovative solutions to meaningful problems and challenges. They should also support holistic processes of learning to develop highly usable solutions, including small-scale innovations as learning experiences on a personal level. Teachers consider a good CDT learning environment to consist of appropriate collaboration and division of teacher labour, as well as an environment and tools that support pedagogical innovation processes and pupils' self- and peer-assessment. The future-oriented CDT makerspace can be seen primarily as a "state of mind" that involves a re-evaluation of both teachers' and pupils' current practices. On this basis, the makerspace should be a space and a mental state for cultivating design and innovation, instead of mere production. An important precondition for a makerspace is a space that can facilitate a creative atmosphere and pupils' scaled innovations to construct a safe whole.

## Limitations

This case study and development project was carried out in grades one through six in one school in a single Finnish town. Due to the nature of the data, the results are not widely generalisable, though the number of pupils (n = 578) is statistically reasonable to allow for broader conclusions. However, the study gives an example of how to develop CDT learning environments as makerspaces by considering teachers' and pupils' perspectives.

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