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Supporting the development of students' technological understanding in craft and technology education via the learning-by-doing approach

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Abstract

Many studies have shown how practical learning and the hands-on activities help students to conceptualize technological knowledge and develop their intellectual processes. Researchers have also pointed out that a variety of cognitive skills and higher-order thinking skills can be nurtured through their application to a practical context. Learning by doing and creating things using the hands have always been key elements in Finnish craft and technology education.The overall purpose of this study was to explore and produce knowledge about the pedagogical approach of learning by-doing and making in the context of craft and technology education in Finland. The study focused on the learning processes when students were acting (doing and making) in craft lessons, but the aim was also to develop a pedagogical tool for teachers to better observe and guide the development of their students' technological understanding. First, a qualitative theory-oriented content analysis was performed to examine the extent of the learning-by-doing approach in craft and technology education in the National Core Curriculum for Basic Education (Määräykset ja ohjeet 2014:96, Juvenes Print – Suomen Yliopistopaino Oy, Tampere, 2014) document. In the analysis, Roberts (Beyond learning by doing: theoretical currents in experiential education, Routledge, New York, 2012) descriptions of four philosophical tenets for pragmatism were utilised. To gain broader knowledge regarding the pedagogical approach of learning by-doing in craft and technology educational practices a questionnaire for students who were studying craft and technology education was created. The questions were formulated on the basis of Roberts' (2012) four philosophical tenets so that each tenet was representative to provide knowledge on the phenomenon.This data were analyzed using the frequentist descriptive method by identifying students' descriptions of each category. The findings of this study support the argument that technology education has the potential to develop students' skills in many ways by providing pupils with opportunities to work in a practical way, accessing the domain of technological knowledge and working technologically. It was also evidenced that social interaction and learning from peers is a highly present component in craft and technology education lessons.

Keywords Learning-by-doing approach · Hands-on learning · Pragmatism · Craft · Technology education

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Introduction

Already 30 years ago, a critical concern was raised that activities at schools too often create a separation between knowing and doing by treating knowledge as "an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used" (Brown et al. 1989, p. 32). This might still be the case, as Programme for International Student Assessment (PISA) studies show that students may have a good knowledge of school subjects and disciplines but appear to have problems in the practical application of their knowledge. This disconnect indicates that there is a need for a greater emphasis on soft skills, i.e. problem solving, creativity, collaboration and critical thinking, which have become more relevant in today's society.

Technology education has been developed to help students with technology by providing them the tools and skills they need to understand and utilize it. Technology education makes a unique contribution to the development of all young people by providing them a wide range of knowledge and skills, i.e. technological literacy, to participate in the rapidly changing technologies (Banks and Barlex 2014). In order to be a technologically literate person, one must have a proper image what technology is and how it interacts with humans and society (de Vries 2018). There is no doubt that skills such as problem solving, creativity, collaboration and critical thinking are crucial for children's future, including the demands of working life. Thus, technology education is relevant because it has the potential to develop students' skills in many ways by raising their awareness of the various dimensions of technology and can also enhance the creativity and innovativeness of young people (Niiranen 2016). Evidently, technology education is a complex domain with several interrelationships between discourses surrounding technology and the social, economic, political, cultural, religious and philosophical perspectives (Dakers 2018, p. 6). In fact, the precise identity or definition of technology education is still unclear, and there are many varying orientations towards teaching it in schools worldwide (de Vries 2018; Williams 2009).

Positioning technology education

Practical learning and the hands-on nature of technology educational activities helps students to conceptualize technological knowledge and develop the intellectual processes (Gibson 2019; Ritz and Fan 2015). Researchers have pointed out that a variety of cognitive skills and higher-order thinking skills can be developed and nurtured through their application to a practical context (Strimel 2019; Williams 2009, p. 248). Also, the core argument of the learning theory of constructionism is that people learn best when they are making (constructing) something because of the powerful interaction between thinking and action during making (Barlex and Steeg 2018). Thus, the domain of technology education provides an important proving ground for theories of cognition, as concepts in technology are often taught through laboratory-based and other hands-on methodologies (see Hayes and Kraemer 2017). Learning can be seen as a gradual process whereby understanding is built upon already existing knowledge. According to this view, learning is most powerful when the construction environment is rich and there is ample opportunity to view the success of one's construction efforts (Barlex and Steeg 2018, p. 343). The process-like way of designing and making things hands-on promotes understanding by balancing the need to think reflectively and projectively about the task with the need to take action (Stables 1997). However, as Watkins et al. (2007) point out only 'doing things' is not enough for an effective learning. In order to learn effectively, learners need to connect their actions and experiences, to make sense of what they are experiencing through reflective thinking (Kuen-Yi and Williams 2017; Watkins et al. 2007).

Over the past 10 years, the pedagogical approach known as "Maker Education" has gained momentum in schools around the world. It is commonly used when referring to the practices and processes that underline students' own ideas and the power of learning by doing as open-ended learning processes. Maker Education embraces the constructionist frame of progressive education, particularly Deweyan constructivism, which frames learning by constructing knowledge through acting or making (Rosenfeld Halverson and Sheridan 2014). When defining Maker Education, one could also relate it with the concept of active learning. According to active learning the attention is guided towards the learner's experience and what they do with that experience, including their own decisions about it (Watkins et al. 2007).

In order to understand technology education in Finnish basic education, it is necessary to consider it within the subject of craft, particularly the domain of technical craft activities. As Jaatinen and Lindfors (2019) describe, Finland has its own version of a 'makerspace' in craft classes. In Finland, technology education is not an independent subject in basic education; rather, technological topics are decentralized and taught through various subjects (National Core Curriculum for Basic Education 2014, hereinafter NCCBE 2014). However, craft education, particularly technical craft, supports technology education. Craft is a practical subject that involves many hands-on activities during which students actively practice experimentation, investigation, invention, problem solving and designing skills. In craft education workshops, students work with various materials and techniques when creating their projects. Finland's former NCCBE (2004) introduced seven cross-curricular themes in Finnish education, one of which was "Human beings and technology", which addresses technology education. Much of the technological content of the theme was studied during technical craft lessons and shared some technology related specific aims (Järvinen and Rasinen 2015). In a study of technology education implementation in Finnish basic education, 90 percent of students in ninth grade (N = 1181) regarded manual skills and technology as interrelated (Järvinen and Rasinen 2015). Finland's current NCCBE 2014 describes seven transversal competence areas, one of which is "Taking care of oneself and managing daily life". This competence area addresses students' need to receive basic information about technology, its advancement and its impact on various areas of life and the students' environment. Students are guided to examine the versatility of technology, and to understand its operating principles. Students are also guided in the responsible use of technology and are invited to consider ethical questions related to it.

As making and practical approaches to learning are emphasized in Finnish craft and technology education, the purpose of this study was to explore the pedagogical approach of learning by doing and making things with one's own hands in the context of craft and technology education. This study focused on adding to our understanding of the learning processes where students were 'doing and making' and aimed also to develop a pedagogical tool for teachers to better observe and guide the development of their students' technological understanding.

Learning by doing in craft and technology education

Craft and technology education provides students with a systematic approach to solving problems and a context in which students can test their own knowledge and apply it to practical problems. Commonly, technology education, engineering design or design and technology education emphasize learning by doing or in other words learning while designing. This is most evident in Scandinavian countries where the emphasis in craft and technology education is on learning through 'doing and making'. Gibson (2019) defines craft as a dynamic process, interchange between individuals and their social environment in which a practitioner demonstrates mastery of materials and techniques in the production of an object. Thus, during activities, designers are involved with continual reflection; brainstorming and prototyping; learning by iteration from feedback and failure; and by noticing and troubleshooting in dialogue with ideas, materials and people (see Adams et al. 2003; Crismond and Adams 2012). The idea behind hands-on learning and learning-by-doing pedagogy is based on a constructionist view of learning, i.e. on how the learner actively constructs learning from experiences. These kinds of pedagogical approaches enhance students' understanding and engagement (Kelley and Knowles 2016). Watkins et al. (2007) suggest that engaging pupils behaviorally involves them actively utilizing, testing and creating things. But beyond this, active learning requires learners to make decisions and think 'in an active manner', thereby encompassing a cognitive element (Drew and Mackie 2011). In the following section, the learning-by-doing approach and pragmatism in relation to technology education are discussed.

John Dewey (1859–1952) was unquestionably the most significant figure in the field of experiential education. He was also a leading proponent of pragmatism, an example of which is learning by doing. Roberts (2012, p. 49) divides the concept of pragmatism into four philosophical stances that are understood to loosely define it. The first concerns *examining things based on practical consequences*. In other words, one chooses a course of action according to the likelihood of its success or with an awareness of the consequences of one's actions (Roberts 2012, p. 50). In the context of craft and technology education, learning by doing is accentuated by activities involving problem solving, design and scientific inquiry. The design process in technology education, may often be characterized as a goal-directed and iterative activity whereby the designer learns about the problem by proposing solutions and synthesizing ideas (see Purzer et al. 2015). Barak and Albert (2017) introduce a similar idea, namely systematic inventive thinking, in engineering and technology education. This is a method of finding solutions to problems by making systematic alterations or manipulations to a system's components and attributes.

The second stance of pragmatism is that pragmatists understand that thinking cannot be removed from the world, since *knowledge acquisition is inherently interactive (*Roberts 2012, p. 51). In other words, the interactions between thinking and action and how they revise one another are seen as key factors in learning (Roberts 2012, p. 51). Thus, learning process is highly contingent upon interactions with the environment and the people who are related to it. The role of context is of central importance in craft and technology education where interactions with tools, concrete objects and materials offer a potentially supportive environment for collaborative actions (see Hennessy and Murphy 1999). Hennessy and Murphy (1999) also add that thinking and problem-solving strategies are intimately connected with the social and physical context and adapted to the perceived characteristics of a situation. A study by Fain et al. (2016) indicated that problem-based learning can facilitate knowledge transfer, encourage and support collaborative work and improve students' thinking and designing skills. It is important to note that pupils' learning in craft and technology education is often fostered through supporting collaborative actions between pupils.

The third tenet of the pragmatist ethos *the importance of context* (Roberts 2012, p. 52) relates also to the learning environment. As described previously, in order to consider practical consequences interactively, one must be situated somewhere. It has been argued that situativity is a dominant perspective in technology and engineering disciplines by emphasising the role of the environments that require extensive content knowledge and analytical skills to engage in learning (Hennessy and Murphy 1999; Johri and Olds 2011; Pleasants and Olson 2019). In terms of technology education, problem solving, project-based learning and creating things with the use of one's hands are evidently suitable methods for learning, and each of these pedagogical approaches is inherently contextual (see also Kilbrink et al. 2014). When learning is grounded within a specific context, it is often authentic and relevant and therefore representative of an experience that may be found in practice (Kelley and Knowles 2016).

The fourth stance of the pragmatist ethos is *fallibilism* (Roberts 2012, p. 52), which means that errors are seen as part of the learning process and are an inherent part of technology education. This idea relates to an interesting characteristic of technology education, the high degree of tacit knowledge inherent to it. Tacit knowledge and skills, i.e. understanding how various materials behave and knowing how to manipulate them, can be gained only through concrete experience. This means that often some errors are made during the process of making. The concept of tacit knowledge also adheres to the concept of embodied cognition as both emphasize the body's role in forming cognitive representations. By action, one's cognitive systems are affected, even constrained and these sensorimotor processes, including perception and action, strengthen learning when included in a structured lesson, given their close and unique relationship to the cognitive system (Weisberg and Newcombe 2017). As Gibson (2019, p. 27) describes, tacit learning happens most often 'on the job'. Thus, sometimes hands-on activities are seen as a "black box" in learning and what students have actually learnt might be hidden (Kuen-Yi and Williams 2017).

Research design

The overall purpose of the study was to explore and produce knowledge about the pedagogical approach of learning by doing and making in the context of craft and technology education in Finland. This study focused on the learning processes when students were acting (making and doing) during their craft and technology education lessons. Also, the aim was to develop a tool for teachers to better observe and guide the development of their students' technological understanding. To do so, the topic was approached via two research questions:

(1) How are students encouraged into learning by doing by Finland's NCCBE 2014 in the Craft subject?
(2) How would teachers observe and analyse the development of students' technological understanding in craft and technology education?

First, an analysis exploring the learning-by-doing approach in Finland's NCCBE 2014, the craft section was carried out. The craft section was analysed using a qualitative theory-oriented content analysis. This analysis method was determined to be an effective method for describing the meanings of qualitative material in a systematic way due to the use of pre-determined analytical criteria. As Schreier (2012) argues if there are certain criteria or a theory for interpretation, meanings can be more standardised. In the analysis, Roberts' (2012) descriptions of four philosophical tenets for pragmatism was employed. When conducting this qualitative content analysis, the primary aim was to investigate and discover themes based on their occurrence by choosing the meaningful textual sentences as the analysis units. After coding, the analysis units were grouped and categorised according to the higher order headings of Roberts' (2012) philosophical tenets for pragmatism. In order to ensure the correct interpretation, the original textual descriptions and their reductions were repeatedly reviewed. This ensured that they corresponded to the reductions, subclasses and upper classes formed from them.

To gain broader knowledge regarding the pedagogical approach of learning by doing in craft and technology educational practices and to answer the second research question, a questionnaire for students who were studying craft and technology education was created. Due to the fact that craft education in Finland is strongly a practically oriented subject that involves many hands-on activities, and learning is often hidden, the questionnaire was developed as a pedagogical tool for teachers to better observe and analyse how their students' technological understanding develops. The questionnaire had eight open-ended questions for students to choose from and students were encouraged to choose multiple options and report all they could recall. The questions were formulated on the basis of Roberts' (2012) four philosophical tenets so that each tenet was representative to provide knowledge on the phenomenon (see Table 1).

First, potential primary school teachers who were teaching craft and technology education during the study period were asked to participate in the study. The rationale behind choosing only a few teachers from bigger schools was to get access to as many students as possible, but so that the same teacher would have lessons for many groups of pupils. After the teachers agreed to participate in the study, permission to conduct the research was requested also from the schools and parents. Then, craft lessons in which students were actively working with their projects were chosen for the study. Teachers were also asked to describe shortly the objectives for learning in the lesson(s) and provide some general info about how they would organise the lesson(s). Five groups, 45 students in total, from the fifth and sixth grades (ages 11–13) of three schools answered the questionnaire at the end of their technical craft lesson(s). All the lessons were in the spring term of 2018. The projects that students were working on included the use of basic hand tools, such as hand saws, chisels, mechanical drills, hammers, screw drivers, soldering machines, and tools for cutting and bending metal wires. Many techniques were also used, such as making nail/screw or doweled/Lamello joints, soldering, painting, varnishing and waxing. Some students used machines, such as drilling and sanding machines, while working. This data were analyzed using the frequentist descriptive method by identifying students' descriptions of each category.

One limitation of this study was that collecting material from pupils only as written reflections was a risky choice due to pupils aged 11 to 13 are at a heterogeneous level with their writing skills. Also, in order to keep the questionnaire as short as possible and easy to answer at the end of the craft lesson, the number of questions in the different categories was not balanced. Thus, an important topic of the follow-up study would be to include observations of pupils working by collecting video data and combine that data with students' reflections.

Table 1 Four stances of learning by doing by Roberts (2012) and the questions (Q1–Q8) for the students modified for craft and technology education

Examining things based on practical consequences
One chooses the right course of action based on the likelihood of success, or with an awareness of the consequences of one's actions. In craft and technology education, learning by doing is accentuated by activities involving problem solving, design and scientific inquiry.
Q1 I solved a problem: *What kind of problem?*
Q2 I chose one technique from many options: *Which one and why?*
Q8 I ended up doing something contrary to my plan: *What did I change?*
Knowledge acquisition is inherently interactive
The interactions between thinking and action and how they revise one another are seen as key factors in learning. Thus, a learning process is highly contingent upon interactions with the environment (craft and technology education classrooms) and the people who are related to it.
Q3 I asked for help from others: What did I need help with?
Q4 I helped someone to make something: How did I help?
Q6 I designed or developed my work together with others: What did we design?
Importance of context
In order to consider practical consequences interactively, one must be situated somewhere. Situativity is a dominant perspective in technology and engineering disciplines. Problem solving, project-based learning and creating things with the use of one's hands are inherently contextual.
Q7 I learnt a new technique: Which one?
Fallibilism
Errors are seen part of the learning process, is also an inherent part of technology education. High degree of tacit knowledge and skills, i.e. understanding how various materials behave and knowing how to manipulate them. These skills can be gained only through concrete experience.
Q5 I made a mistake when doing something: What mistake did you make?

How learning-by-doing approach appears in the craft curriculum

Based on the theory-oriented content analysis of the NNCBE 2014, it can be concluded in general that learning by doing was an inherent component of craft education. The findings from the analysis of the objectives and key content areas of crafts in grades 1–6 (ages 7–12) were divided into four sub-categories based on how learning by doing was related to them:

(1) *Ability to manage a complete crafts process*: pupils are guided to design and produce their own craft product independently using a diverse range of techniques, tools, machines and equipment.
(2) *Use of multiple materials:* pupils are guided to invent and experiment with crafts and to work with various materials in a suitable way, promoting pupils' manual and motor skills.
(3) *Development of skills:* pupils are guided to design and produce and to practice their spatial awareness, sense of touch, creativity, experimentation, persistence and capacity to work responsibly.
(4) *Learning by doing supported by working methods and environments:* pupils are guided towards learning by doing, experiential learning, and the use of drama and stories, as well as multidisciplinarity.

In relation to Roberts' (2012) learning-by-doing theory, the category of *examining things based on practical consequences* was highly present in the NCCBE 2014 Craft section. Examples of textual descriptions are:

- Making crafts is an exploratory, inventive and experimental activity
- Guiding pupils in choosing between different techniques, tools, machines and equipment and in using them in their work
- Observing and analysing objects as well as built and natural environments to produce new ideas
- Examining the structures and the use of energy in materials
- Studying the properties of materials and the operating principles of the most common machines and tools needed in craft
- On the basis of the experimentation, developing the product or piece further
- Selecting and using tools and equipment that are suitable for the work
- Selecting and combining crafts materials and techniques and working with them

In the craft section of the NCCBE 2014, there were also some descriptions related to the *knowledge acquisition is inherently interactive* component of Roberts' (2012) learning-by-doing theory. Examples of textual descriptions are:

- Designing and producing a crafts product or piece independently or together with others
- Shared activities are emphasized in the teaching and learning of crafts
- Pupils' surroundings, the local cultural heritage and the cultural diversity of the community
- Guiding the pupil to assess, appreciate and examine interactively his or her own crafts process and the processes of others as a whole
- PUPILS' own solutions as well as constructing and applying knowledge creatively both independently and together with others is supported

Students' reflections about their working in craft and technology education lessons

According to the previous analysis of NCCBE 2014 Crafts section, it was evident that students are encouraged to learn-by-doing in many respects during the craft lessons. When designing and producing their own products in the workshop, they are encouraged to creatively and independently use various materials, tools, machines and techniques for different purposes. In the following section, students' responses to the questionnaire ('What did I do in today's craft lesson') are identified and discussed in more detail.

Three of the questions (1, 2 and 8) reflected one of Roberts' (2012) philosophical tenet of pragmatism, namely *examining things based on practical consequences (*see Fig. 1*)*. Almost half (20/45) of the students responded to question (1) 'I solved a problem: What kind of problem?'. The problems were mostly related to a specific phase of creating the project. To solve the problem, students needed to select and use suitable tools and equipment when making something. Students remembered having problems such as: 'How to put an LED light the right way on the printed circuit board', 'How to fasten a wheel to the right place' and 'How much varnish one should use for the surface'. Interestingly, only a few

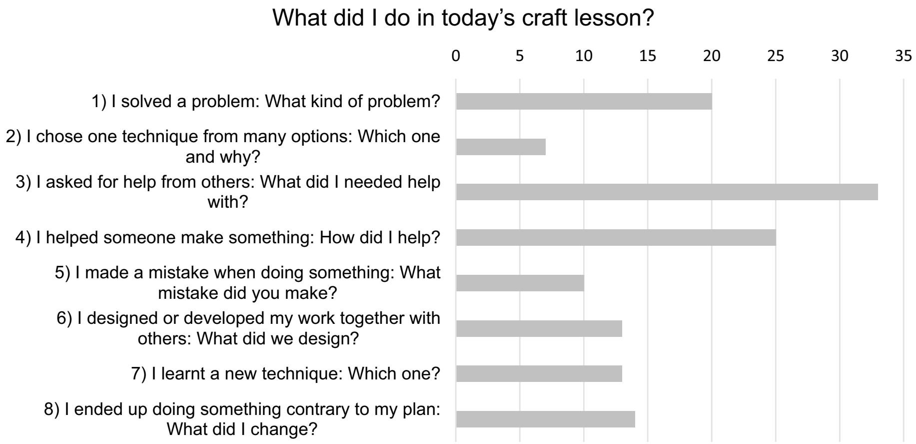

Fig. 1 Students' responses to the questionnaire (N = 45)

(7/45) of the students responded to question (2) 'I chose one technique from many options: Which one and why?'. This indicates that, despite having some freedom in relation to the techniques that they could use for their projects, most students used the same techniques. Some (14/45) of the students responded to question (8) 'I ended up doing something contrary to my plan: What did I change?'. This result evidences how students are encouraged towards experimentation and invention and may thus need to change their plans during the process. In craft and technology education, it is important to note that problem solving, project-based learning and creating things with one's own hands are inherently contextual activities due to the fact that lessons are held in special technical workshops/laboratories.

Another three questions (3, 4 and 6) reflected the second tenet of pragmatism, namely that *knowledge acquisition is inherently interactive* (Roberts 2012). This tenet appeared to be most evident and shows how multiple interactions are taking place during the craft lessons. More than half (33/45) of the students reported that 'I asked for help from others: What did I needed help with?' (question 3). In general, students asked for help using tools or machines or with techniques they were unfamiliar with. A few of the students reported that they asked for help with what to do next or with how to inscribe the measures for their plan. More than half (25/45) of the students answered question (4) 'I helped someone make something: How did I help?'. This finding shows that many students helped their peers when there were problems with using a certain kind of a machine or tools or with the making process. A few of the students reported that they helped someone by showing them their own project or helped them to find information from the instructions. Some (13/45) of the students responded to question (6) 'I designed or developed my work together with others: What did we design?'. Mostly, students reported that they planned the measures or the size of the project with someone or decided where to put light emitting diodes (LED).

There was one question (7) in the questionnaire related to *the importance of context* (Roberts 2012). It is important to note that this question is strongly dependent upon the crafts lesson, the project students are working with and also how working is organized. Thus, in relation to this element, students' learning during the lesson, the context and what students should learn varies a lot. In this study some (13/45) of the students responded to this question: 'I learnt a new technique: Which one?'. Almost all of the responses were from students who had studied how to use the soldering machine during their craft lesson.

There were also a few responses about learning to sand painted wood and use wood wax. Even though many of the students didn't answer this question, it might help teachers to follow their students' learning when planning and organising new techniques to be studied in the lessons.

There was also a one question (5) in the questionnaire in related to *fallibilism.* Some (10/45) of the students responded to this question: 'I made a mistake when doing something: What mistake did you make?'. Students reported that they had made mistakes such as putting an LED the wrong way around on a circuit board, cutting an electrical wire, sawing off too much wood, or partly breaking the wood.

Discussion

The overall purpose of the study was to explore the pedagogical approach of learning by doing and making in the context of craft and technology education in Finland. The study focused on the learning processes when students were acting (making and doing) during their craft and technology education lessons. First, the analysis of Finland's NCCBE 2014 Craft section showed that learning-by-doing approach as it is defined by Roberts (2012) is an inherent component of craft education. During craft lessons, students are guided to design and produce their own craft product independently and/or with others by using a diverse range of techniques, tools, machines and equipment. Interestingly, one of the general aims of the subject is to develop pupils' skills and ability to manage a complete craft process. By doing so, students are guided to design and produce, practice their spatial awareness, and develop their sense of touch, creativity, experimentation, persistence and capacity to work responsibly—i.e. to learn by making. In this pedagogical strategy, examining and problem solving are seen as integral parts of learning. Thus, students are learning skills by doing things. In terms of the pragmatist ethos and the tenet of *examining things based on practical consequences,* half of the students reported that they had solved problems by using suitable tools and equipment when creating their projects. This finding supports what have been evidenced also in previous studies namely that working with concrete materials aids students in evaluating their ideas and taking next steps in their projects (e.g. Looijenga et al. 2015; Yrjönsuuri et al. 2019) and that students value highly practical activities and project working (McGeown 2019). Also, based on previous studies concerning Finnish craft education, students enjoy doing crafts and they find the subject interesting (Virtanen et al. 2015; Metsärinne and Kallio 2016).

The findings of this study revealed also that social interaction and learning from peers, i.e. students learning with and from each other by explaining their ideas and knowledge, is a highly present component in craft lessons. The current National Core Curriculum for Basic Education 2014 emphasizes collaborative working and interaction between pupils when designing and working in craft lessons. This means that while working pupils are documenting, reflecting and giving feedback of their working processes. Concerning the philosophical stance of *knowledge acquisition is inherently interactive* by Roberts (2012), it appeared to be the most evident in students' responses when they responded for the questionnaire after their craft lesson(s). Many students reported asking for help from other students to use tools and machines that they needed for their work or for instructions regarding techniques they were unfamiliar with. Also, many students helped someone else to make or do something. In peer learning, students are continuously constructing their own understanding of things and by doing so they seem to remember well what they have done during the lesson. However, it must me noted that not all pupils enjoy working in groups or have a preference for working in pairs. Thus, having pupils working in groups or with a peer may not automatically contribute to learning but it can reinforce pupils' motivation towards the task (Virtanen et al. 2015).

Teachers are key to showing and enhancing the technological skills and knowledge that are needed later in life. It is also teachers who will provide 'bridges' and 'links' between the knowledge that is to be studied and the learner by use of various pedagogical strategies (Ertmer and Newby 2013, p. 44). This means that teachers have to consider both the elements of different learning strategies and measurable learning outcomes, and how to provide students possibilities to develop their knowledge and skills further. In order to help students to see the theoretical aspects as an integral part of studies in craft and technology education, it is important that teachers ensure the theoretical knowledge being taught has the direct relevance to the practical tasks (see also McGeown 2019). Although for example problem solving is believed to be an effective pedagogical method to engage students in learning, particularly in technology education, there is lack in research about the effectiveness of systematic inventive thinking and problem solving with regard to fostering self-regulated learning in technology education (see Barak and Albert 2017).

The findings of this study support the argument that technology education has the potential to develop students' skills in many ways by providing pupils with opportunities to work in a practical way, accessing the domain of technological knowledge and working technologically, collaboratively. It is possible to argue that learning by doing and making in interaction with peers supports the development of students' technological understanding. Thus, as a recommendation for technology educators, by emphasizing learning-by-doing approach with reflective elements and by using this questionnaire tool the development of students' technological understanding can be emphasized and made more visible.

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