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LEARNING COMPUTATIONAL THINKING AND 21ST CENTURY SKILLS IN THE CONTEXT OF FAB LAB

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Abstract

The increasingly automated world has made humans more and more passive consumers. Students are great at using technologies but are not able to design and create artifacts by using technologies. At the same time, programming and computational thinking skills are seen ever more important in society and working life. The new National Core Curriculum for Basic Education in Finland focuses on future skills. It emphasizes pupils' participation and responsibility of their schoolwork. It aims to regenerate work methods and learning environments used in basic education by using technologies and seeking new inspiring learning environments outside the classroom. The curriculum involves opportunities for pupils to develop their information and communication technology skills in all subjects, where also programming has been integrated as part of the objectives. It aims to respond to the requirements of study, working life, and active citizenship by focusing on to develop students' transversal competences for commanding and combining different knowledge and skills.

The aim of this study is to investigate in theory, how can computational thinking and twenty-first century skills be learnt in the context of maker culture. The study is conducted by a literature review on the maker culture approach in education to see, if there is a possibility to learn these skills in maker activities in the context of Fab Lab Oulu, Finland, which has potential to be new student-centered and technology-enhanced learning environment for schools in Oulu area.

The study forms an understanding of growing maker culture phenomenon in education to realize its potential when considering to integrate making into formal education. It indicates differences between two similar but slightly different concepts, maker culture and maker movement, to notice that at first there was a maker culture philosophy, which has been later started to foster by a social movement called maker movement. Then, the study explores the historical and theoretical base of learning by doing and making to understand the roots and nature of maker culture.

The study investigates what can maker culture give for education and how can digital fabrication learning activities in the context of Fab Lab Oulu foster and inspire learning computational thinking and 21st century skills. It presents how making cannot only bring about interest in science, technology, engineering and math subjects but also make students understand and connect their knowledge to the world around them. In Fab Lab, they can involve theory to practice, and experience project-based and collaborative learning, for solving meaningful challenges. To boot, they can find how are they able to design and build tangible artifacts and make their ideas become true and thus, be active producers.

Keywords maker culture, maker movement, computational thinking, 21st century skills, Fab Lab

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Introduction

Nowadays, when humans grow up with all those different technologies available and the world around them becomes more and more automated, it is alarming how people have become passive consumers. Current generation of young people seem to be great at using general technological tools, such as computers, and smartphones and they are quite familiar, for instance, editing digital photos and creating web pages, but less than half of them can create something by exploration and fabrication technologies, such as do 3D designing, robotics or programming (Blikstein, 2017; Blikstein, Kabayadondo, & Martin, 2017). How to wake up passive consumers and make humans active producers again?

Barr and Stephenson (2011) remark, that "All of today's students will go on to live a life heavily influenced by computing --- They must begin to work with algorithmic problem solving and computational methods and tools in K-12." (p. 112). Thus, computational thinking (CT), which for example programming, is seen as a valuable way and skill to learn (Finnish National Board of Education, 2016). Not only the technique itself but even more the logical thinking and understanding behind it how the world and machines function.

Highlighting the issue, it is necessary that how learning is understood has been changing. Instead of seeing learning as transferring information, external controlling of learning processes, and emphasizing teacher's responsibility (teacher-centered learning), student-centered learning (SCL) underlines the responsibility of the student, student's internal controlling, interpretation, and building one's own knowledge. SCL is broadly based on constructivism referring on the idea of constructing and reconstructing personal meaning by relating new knowledge to what one already know and believe in order to learn effectively (Attard, Di Iorio, Geven, & Santa, 2010; Hannafin & Land, 1997). Furthermore, the concept of working is changing, which requires society and educational institutions focus on new essential twenty-first century skills (21st century skills) when preparing students to working life in future.

The new National Core Curriculum for Basic Education (Finnish National Board of Education, 2016) in Finland, which has been implemented in since autumn 2016, focuses on future skills. The curriculum aims to respond to the requirements of study, working life, and active citizenship by focusing on to develop students' transversal competences for commanding and combining different knowledge and skills. It emphasizes pupils' participation and responsibility of their schoolwork. By reform, it aims to regenerate work methods and diverse use of technologies, involving better opportunities for pupils to develop their information and communication technology skills in all subjects, and to develop learning environments used in basic education by seeking new inspiring environments outside the classroom. (The new curricula in a nutshell, n.d.). There, learning environment refers no only to facilities and locations, but also to communities and operating practices where learning take place, including tools and materials used for studying (Finnish National Board of Education, 2016). The curriculum defines seven wide-ranging, transversal key competencies, which includes knowledge, skills, values, attitudes and will of pupils, and the ability to use knowledge and skills in meaningful ways. These skills are practiced both in pursuance of all subjects at school and during multidisciplinary learning modules where several subjects are combined to learn together.

In recent years, Maker Culture and Maker Movement have stimulated grown interest among individuals and organizations, as well as schools and education (e.g. Halverson & Sheridan, 2014; Katterfeldt, Dittert, & Schelhowe, 2015; Martin, 2015; Papavlasopoulou et al., 2016). *Maker culture* refers to philosophy in which the participators, individual makers or groups of individual makers create tangible items by using software and hardware (Papavlasopoulou, Giannakos, & Jaccheri, 2016). It is a contemporary technology-driven hands-on doing culture, a sort of subculture of longer known DIY culture (do-it-yourself). Where DIY refers to making by hands, for instance woodworking, the methods of maker culture goes to the next industrial level where creating processes are in digital fabrication. The term *digital fabrication* carries two meanings, on the one hand, it refers to processes that use digital, computer-controlled tools for operating analog materials, and on the other hand it relates to manufacturing processes, where the used materials themselves are digital (Gershenfeld, 2012).

As for *maker movement*, it is a social movement started to explode since 2005 from the launch of MAKE Magazine, involving communities of all kind of creative “hobbyist, tinkerers, engineers, hackers, and artists who creatively design and build projects” (Martin, 2015, p. 30). According to Dougherty (2013, as cited in Mota, 2015) “in a world where everything is very specialized, isolated and siloed, the maker movement is a force around interdisciplinary and integrated activities.” (p. 158).

Fab Labs (fabrication laboratories) are situated in this phenomenon called maker culture, offering digital tools and opportunities for creation processes to realize one’s own ideas to tangible products (Katterfeldt, 2013). By making and project-based learning activities Fab Labs can offer an inspiring environment with a series of technical tools, in the spirit of exploring, trial and error, involving meaningful relevance for education and current curriculum in Finland.

This study is meaningful in two ways. First, the new National Core Curriculum for Basic Education in Finland (Finnish National Board of Education, 2016) advices schools to offer opportunities to learn outside of the classrooms and by using technology. The study forms a theoretical framework for CT and 21st century skills in relation to maker culture to see, if there is a theoretical possibility to learn these skills in maker activities in the context of Fab Lab Oulu, which has potential to be new student-centered and technology-enhanced learning environment for schools in Oulu area.

Second, the study offers background for future studies to investigate how CT and 21st century skills can be practically implemented in maker activities in the context of Fab Lab. To use a new learning environment purposefully in education, it should be secure and scientifically granted. This study will review previous studies to find out, how the theoretical framework of CT and 21st century skills can be related to Fab Lab Oulu to give theoretical perspective for investigating and improving their maker activities further.

1 Aim of the Study and Research Questions

The aim of this study is to explore in theory, how can computational thinking and twenty-first century skills be learnt in the context of maker culture. This aim can be divided into research questions as follows:

1) What are maker culture and maker movement?
2) What is the role of maker culture in education?
3) How can CT and 21st century skills be learnt in the context of Fab Lab?

The study is conducted by literature review. In a literature review, the idea is to explore and represent an overview of existing studies and findings related to the topic or field (Lichtman, 2013). At first, this study defines concepts 21st century skills and CT, forming a theoretical framework for this study. Then, the study discusses maker culture and distinguishes it from the similar concept maker movement, answering to the first research question.

Second research question refers to previous studies in a field of maker culture, where earlier studies are reviewed to explore the historical and theoretical base of learning by doing and making in education. Then, this study investigates what can maker culture give for education.

The concrete context where CT and 21st century skills are finally connected to maker culture is Fab Lab. Understanding the history and meaning of maker culture is essential to be able to see Fab Labs into educational context and to investigate, how can CT and 21st century skills be applied in digital fabrication learning activities in the context of Fab Lab Oulu, Finland. Hence, in addition to prior studies (e.g. Georgiev, Sánchez, & Ferreira, 2017; Iwata & Pitkänen, 2017; Sánchez, Georgiev, Riekki, Ylioja, & Pyykkönen, 2017) done in the context of Fab Lab Oulu and FabLab^{4}School, by research question three, this study investigates Fab Lab's theoretical possibilities to form a learning environment which fosters and inspires students to learn CT and 21st century skills.

2 Theoretical Framework

This chapter defines the key concepts of this study: 21st century skills and computational thinking. In the present, making, and maker culture, have faced increased interest faster than ever. In this study, maker culture bridges two broad concepts CT and 21st century skills together.

Where CT relates to different thinking and problem solving phases during planning, designing and producing processes, it occurs naturally in the context of maker culture, and it is a vital element of thinking and working in the context of Fab Lab. Through multidisciplinary, collaborative project-based and problem-based learning activities, also 21st century skills can be applied to the context of maker activities.

2.1 Twenty-First Century Skills

Numerous countries and organizations have their own recommendations and frameworks of 21st century core skills. For instance, European Union (2016) has Key Competences for Lifelong Learning, OECD (2005) has formed Definition and Selection of Competences and USA has Partnership for 21st Century Learning (P21, 2015). Through frameworks the quarters state their recommendations for governments and their education policy, to forge and develop education and schooling, which prepares students living in current information society to working life in future.

As a definition of 21st century skills, this study uses the framework defined by perhaps the broadest purposeful project, international Assessment and Teaching of Twenty-First Century Skills (ATC21S, n.d.; Enkenberg, 2014). The project was launched in 2009, sponsored by three of the world's major technology companies, Cisco, Intel and Microsoft, to respond on behalf of an education system to the change of many countries moving from an industrial-based economy to information-based economy (Griffin, Care, & McGaw, 2012). There, an academic partnership was created among founder countries Australia, Finland, Portugal, Singapore, and England, with the USA joining the project in 2010. The project gathered more than 250 researchers from over 60 educational, political and business communities in collaboration to conduct research on the most required transversal skills in the 21st century (Kapenieks, 2016.), aiming to "create models for international applications, such as the Programme for International Student Assessment (PISA), the IEA study of ICT and formative assessments in all countries" (ATC21S, n.d.).

The ATC21S framework defined ten future skills, called 21st century skills, into four broad categories: 1) creative, problem-solving and learning to learn kind of ways of thinking, 2) interactive and collaborative ways of working, 3) effective and meaningful use of tools for working and 4) adopting responsible, participative, local and global citizenship ways of living in the world (Binkley et al., 2012) (see Figure 1). These ten skills have been grouped under the acronym KSAVE, which stands for Knowledge, referring to required specific knowledge and understanding related to each of the ten skills; Skills, including necessary abilities, skills and processes; and Attitudes, Values and Ethics, involving essential behavior and attitudes in relation to the skills.

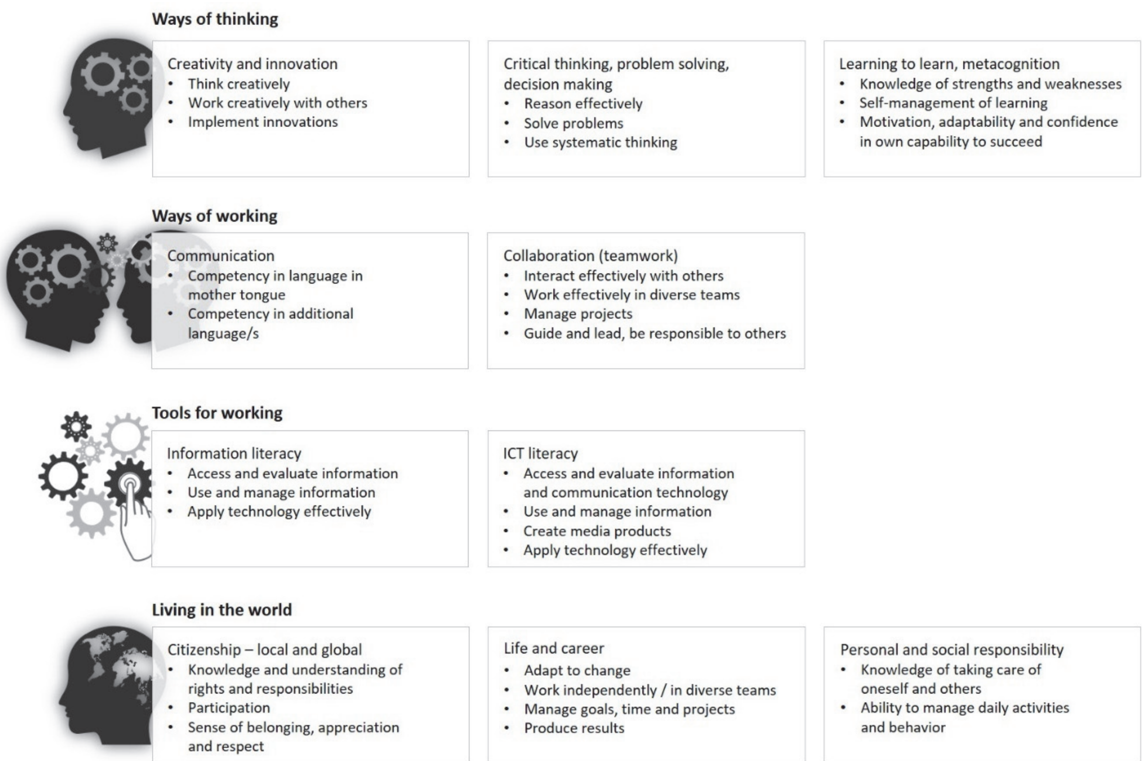

Figure 1. Categorization of 21st Century Skills in ATC21S framework

Griffin, Care and McGaw (2012) define *21st century skills* to be any skills that are needed and used in the twenty-first century. The essential perspective of authors alongside the ATC21S is that the identified skills do not need to be necessarily new. There will emerge essential new skills, but also some traditional skills will remain, which only will be developed and used in new ways. The industrial age demands individuals to develop skills for new ways of working, living, learning and thinking. They increasingly need new skills to manipulate new information-based work tools and analyze, evaluate and apply information. (Griffin et al., 2012.)

2.2 Computational Thinking

Computational thinking (CT) is *thought processes* involving defining, understanding and solving problems and expressing their solution in an abstract and logical way. According to Wing (2006, p. 33), who wrote her influential article on computational thinking in 2006, CT "involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science." At that time, she envisioned computational thinking to be a fundamental skill not only for them working in the field of computer science but for everyone, stating that CT will be as fundamental as reading, writing, and arithmetic, and should be added to every child's analytical ability. CT is kind of analytical thinking, which shares with mathematical, engineering and scientific thinking when attaching to a complex problem or system and trying to perceive not only human behavior but also intelligence and computability (Wing, 2008). And further, Wings' completed definition, from a work-in-progress paper by Cuny, Snyder and Wing (2010), defines CT as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (p. 1) highlighting the logic and tracing behind the process.

However, to be useful for education, Barr and Stephenson (2011) have stated that a definition of CT needs to be thoroughly coupled with practical examples showing how can it be built in the classroom, and which skills can certain projects teach and develop. The

International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) have participated in bringing computational thinking nearer to K–12 education by developing an operational definition of CT for K–12 curriculum in collaboration with leaders from higher education, industry, and education. According to their definition, CT is a problem-solving process that includes formulating problems to a form which computers and other helping tools are able to process. It is organizing and analyzing data and representing it by modelling and simulating. Moreover, it includes algorithmic thinking meaning a series of ordered phases during problem-solving processes, involving identifying and evaluation of different possible solutions towards efficiency and the goal of a project. After all, the process should be documented and generalized to be able to transfer to a wide variety of problems. (ISTE & ISTA, 2011.)

Through the attempt to develop a definition of CT by literature review Selby and Woollard (2013) found three terms appearing consistently indicating a consensus that “a definition of computational thinking should include the idea of a thought process, the concept of abstraction, and the concept of decomposition” (p. 2). Simplified, CT is a problem-solving process, where a problem faces decomposition. It is breaking down a problem into smaller, manageable parts, and figuring out what all the parts are, and how to attack them by using abstract ways of thinking (Computational Thinking for Educators, n.d.).

As a 21st century ways of thinking and working, CT should be every human’s competence, to be able to handle 21st century information society based life, for instance, in the context of troubleshooting, project management, documentation and applying appropriate tools in various situations. What comes to education, CT should understand as an essential element of learning, since it reflects the ability to learn - not only inside certain content or subject but instead - the relations of several subjects. Additionally, rather than only prompting people to use computers and tools for the sake of helping problem-solving processes, CT involves an idea of bringing up active tool builders. While going through several phases, such as abstraction, recursion, and iteration during processing and analyzing data, the aim is to end up creating either tangible or virtual artifact (Barr & Stephenson, 2011).

3 Maker Culture in Education

Two slightly similar terms, the maker culture and the maker movement, have been defined comprehensively by many experts of the field, such as Anderson (2012), Dougherty (2013), Hatch (2014) and Papavlasopoulou et al. (2016). However, in many previous studies, the similarities or differences between these two concepts have not been defined in depth. While reviewing literature, sometimes it can be seen that the terms are used even as synonyms. Notwithstanding, this study states and justifies that they are not equal. Instead, maker culture is a current concept for a long-run phenomenon of making things by yourself (DIY-culture) and maker movement is a quite new trend deriving from the maker culture (Papavlasopoulou et al., 2016). This chapter attempts to define concepts in detail and furthermore, make their similarities and differences visible.

The role of making in learning has been debated for decades (Halverson & Sheridan, 2014). Montessori (1912, as cited in Martin, 2015) has argued that "children and youth can learn by playing and building with interesting tools and materials" (p. 31). After defining maker culture and distinguishing between it and maker movement, this chapter discusses the role of maker culture in education. Finally, CT and 21st century skills are applied to the context of maker culture and the relation between these concepts has been described (see Figure 2).

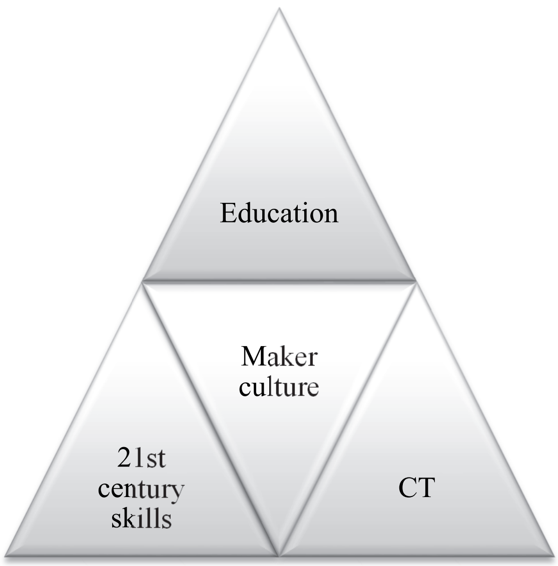

Figure 2. The relation between the concepts of the study

3.1 Maker Culture versus Maker Movement

According to *Merriam-Webster's* dictionary, *Culture* (n.d.) is "the set of shared attitudes, values, goals, and practices that characterizes an institution or organization". Whereas, *Movement* (n.d.) is "a series of organized activities working toward an objective; also : an organized effort to promote or attain an end".

Maker culture is made up of peoples participating in it, interacting with each other and making things – whether they be technological gadgets, home decorating or playful articles – in that context (Mota, 2015). It is characterized by intrinsic motivation and a culture of sharing knowledge, skills, and resources. Besides interacting with local communities, connecting people, and sharing their doing, it is also mediated through networked technologies, such as social media and repositories where ideas and knowledge are located for distribution over a network. Thus, although maker culture is described as do-it-yourself culture, von Busch (2012) puts it even better to the expression of do-it-together culture.

In addition to participants, *makers*, and their shared expertise and repositories, maker culture covers materials, tools, created artifacts and shared maker spaces (von Busch, 2012). It involves making by different digital fabrication technologies, including most typically some high-tech, engineering-oriented topics such as electronics, robotics, programming, laser cutting and 3D printing, and open hardware which for example Arduino and Adafruit, open software like Inkscape and KiCad, but also more traditional manufacturing methods such as sewing, woodworking, metalworking and arts (Dreessen, Schepers, & Leen, 2016; Papavlasopoulou et al., 2016).

Maker culture is about utilizing existing technologies to generate new ideas and artifacts, but also applying technologies in novel ways, creating new applications of them to meet the needs of individuals and groups, both local and online participants. The culture drives from playful engagement, risk taking and trialing, connecting it to computational thinking cycle, where learning happens also through making mistakes and figuring out how to solve a problem and improve the previous trial. However, even the culture in some contexts tends to have attention as a playful hobby of some makers, one more profound meaning of it stands towards the truth that at a moment, technologies used by a majority of users have been created by a comparatively small number of producers (Mota, 2015).

What comes to *maker movement*, it includes massive desire to foster maker culture, where the terms share same basic features of making and making together. There, the movement covers the activities people do for mobilizing others, for instance, to get them into the community or to show a public that the current phenomenon differs substantially from something that has been before (C. Kohtala, personal communication, April 28, 2017).

Papavlasopoulou, Giannakos and Jaccheri (2016) argue that individual's ability to be a maker, a creator of things, forms a base for defining the maker movement. Furthermore, the movement refers to social communities – beginning with the launch of MAKE magazine in 2005 and the first Maker Faire event in 2006 in US, which started to gather growing number of people engaged in the creative production of artifacts in their daily lives around the phenomenon, to build and share their processes and products with others and – who see it as a new revolution and attempt to capture the attention of citizens, organizations and governments, targeting also schools and education.

Hatch (2014) states in his book, *Maker Movement Manifesto*, maker movement to ground on nine key elements: 1) *making*, since it is fundamental for humans, and making particularly physical things, which distinguishes between the movement and prior computational and Web eras; 2) *sharing* created artifacts, as well as the knowledge and skills a maker have; 3) *giving* the artifacts a maker built to someone as a small piece of himself; 4) *learning*, and seeking to learn even more about new techniques, materials, and processes in the spirit of lifelong learning; 5) *tooling up*, to have access to the right tools a maker needs for making, since they are cheaper and easier to use than ever; 6) *playing*, since playfulness is the key for surprises and enthusiasm; 7) *participating*, referring to a joint joy of making; 8) *supporting*, in a way a maker can, whether it is emotional, intellectual, financial or political, to make a better future; and 9) *changing*, which comes in the end, after a making journey, when a maker completes himself by fulfilling himself. However, in the spirit of 'making', Hatch urges not only to take the manifesto but also modify it and make it look like oneself.

In Anderson's (2012) definition maker movement shares three transformative characteristics: 1) the use of digital tools for creating designs for your new prototypes and products, 2) a cultural norm to share your designs and collaborate with others in online communities, and 3) the use of common design file standards for sharing and allowing anyone to access and use your ideas. Like Hatch (2014), also Anderson underlines the core difference of current movement, which is not anymore only about growing by capitalizing on machines or connecting people and expanding one's thoughts through Internet, but involves an idea and possibility to design and build tangible products by oneself, and make them public and grow through them. Consequently, Anderson argues maker movement to be the third major industrial revolution rising from the combination of the two previous ones: after the first, when mechanization replaced muscle power with machine power and increased human productivity by transferring the work from humans to machines, and after the second, when computers and the Web democratization unleashed the hidden talent and creativity, finally maker movement combines and utilizes them both.

Thus, it seems, that at first there was a maker culture. Then, when all kind of makers were asked to get together, they found each other and formed better-known communities, which found maker culture's value and a potential for individuals, organizations, society and education, for everyone, and started to foster it by maker movement. When C. Kohtala (personal communication, May 4, 2017) contemplates her findings of the use of these terms, she sums up people writing more about the movement when they want to talk about innovation, learning skills for a digital society, or phenomenon's potential for business and entrepreneurship, whereas people writing about the culture might be talking more about maker skills, crafts, craftsmanship, creativity, and empowerment of phenomenon.

In conclusion, maker culture and maker movement share same ideas but have their own meanings. In maker culture its participants make, and they share with openness, but they make more for themselves without pushing forward it what they are doing (C. Kohtala, personal communication, April 28, 2017). Whereas, in Anderson's (2012) words, maker movement can be seen and has been introduced to the public as an industrial revolution. There, the movement rises from its advocates who are fostering it to be that revolution.

3.2 Roots of Maker Culture

The roots of maker culture are in constructivist and constructionist pedagogy which is founded through last century on the work of Piaget, Vygotsky, Bruner and Papert (Maker culture, n.d.). It is based on a social constructivist perspective emphasizing "the social, cultural, and historical factors of experiences" (Vygotsky 1979, as cited in Niemeyer & Gerber 2015, p. 218) and constructionist view of learning by focusing on "direct experiences, hands-on projects, tinkering and invention" (Stager, 2013, p. 487).

Constructivism, found by Jean Piaget, is the theory of knowledge development, construction of individual's own isolated knowledge, wherein Seymour Papert's *Constructionism*, built upon constructivism, learning is about constructing relationship between what one already knows and new knowledge, and making that knowledge their own in their own way (appropriation) (Kafai, 2006). In addition to building knowledge structures, constructionism involves constructing knowledge in interactions with the physical and social environment (Papert & Harel, 1991). There, learning happens effectively when learners build and make artifacts and publicly share objects with others (Blikstein, 2013). Thus, constructionism also refers to tangible items, which value Papert (1980) saw for serving a learner as an "object-to-think-with" (p. 11) when constructing knowledge through assimilation, accommodation, and appropriation (Kafai, 2006).

Blikstein (2013) notes Papert's constructionism to crystallize the meaning of making and digital fabrication for education, since the relationship between making and learning is precisely described in Papert's statement (e.g. Blikstein & Worsley, 2016; Martin, 2015):

> Construction that takes place 'in the head' often happens especially felicitously when it is supported by construction of a more public sort "in the world" – a sand castle or a cake, a Lego house or a corporation, a computer program, a poem, or a theory of the universe. Part of what I mean by 'in the world' is that the product can be shown, discussed, examined, probed, and admired. (Papert, 1993, p. 142)

Knowledge is not fixed or external. It is individually constructed requiring to construct understanding through personal experience (Hannafin & Land, 1997). Lastly, mentioning ancient practices such as cave paintings almost en passant it can be seen, that humans have been making, and have had a desire to make, forever (Halverson & Sheridan, 2014).

3.3 What Can Maker Culture Give for Education

What comes to making in education, the visible fostering trend might be the maker movement, for sure. However, the background, the theories, and practices of learning is not initially about this movement, but rather where the movement drives from, the maker culture. That is why this study discusses maker culture and making in education.

According to Hirshberg, Dougherty and Kadanoff (2016), making increases humans' curiosity, affects positively to their confidence of their creativity, and enables self-expression and invention. STEM (science, technology, engineering, and math) subjects, which are seen important skills to meet existing and forthcoming social and economic challenges are not taught meaningfully in schools (Martinez & Stager, 2013; English, 2016). A school has traditionally separated art and science, theory and practice, what Martinez and Stager (2013) state to be artificial and unnatural what comes to how the world functions. They express their concern for some schools even removing arts from the curriculum, where they themselves remark arts to be an essential part of working life alongside STEM. As an example, they mention a trade of craftsmen who are dealing both with aesthetics, tradition and mathematical precision, continuing the list with architects, video game designers, engineers and industrial designers, wherein each of the fields arts and science are inseparable. That is why they add arts to STEM and rather foster STEAM, proposing their solution to make a shift and improve learning through making.

Martinez and Stager (2013) state that making – by computer controlled fabrication devices, such as 3D printers and laser cutters, physical computing such as robotics and wearable computing, or programming for controlling computational devices – can bring electronics, programming and computational mathematics, as well as arts and handicrafts, together for learning them in interesting, powerful ways (Martinez and Stager, 2013). Furthermore, Hirshberg et al. (2016) see, that making cannot only inspire more students to excel STEM subjects but also make them understand and connect their knowledge to the world around them and utilizing the knowledge for solving meaningful challenges. Where Martin (2015) suggests bringing making into education to enhance engaging in the STEM practices, and English (2016) argues for STEM integration, they meet the aims of new curriculum in

Finland, which emphasizes learning transversal competences to combine several subjects and experiencing multidisciplinary learning (Finnish National Board of Education, 2016).

Martin (2015) sees the value of making for education in three ways: 1) providing new opportunities to learn by digital tools, such as 3D printers and laser cutters, and logic tools like microcontrollers, and get access point to influential ideas, for example, about math and electronics, 2) creating communities to share ideas and knowledge, solve problems together, and support making and learning, and 3) building a maker mindset. What comes to the last one, making is fun, playful and interesting, driving intrinsic motivation and influencing positively to the persistence of human when they are facing challenges and troubleshooting. Maker mindset doesn't talk about weaknesses or inabilities, instead, it raises possibilities to choose freely, encouraging its participants to believe that anyone can learn to do anything what he wants to, what is particularly in his interest. The mindset is also failure-positive, seeing that failure indicates the need of more effort rather than giving up, which would bring positive waves to schools where failures tend to be avoided. Additionally, the mindset highlights collaboration, not necessarily in a sense of group working but in a spirit of sharing, to exchange information, to offer own expertise for others good, to get feedback from others and to feel a sense of community. (Martin, 2015.)

However, just adding digital fabrication and making to curriculum and school practices is not enough, if it doesn't involve effort on developing learner's own thinking and knowledge constructing processes. Even in making activities, there is a great danger oversimplify and script too much, and lead learners to narrowed learning path. Instead of scripting and offering well-structured problems unconnected into the real world, and giving only one right way to solve, making can offer authentic, complex and even ill-structured problems with dozens of unforeseeable possible solutions. Therefore, as long as making activities are not as artificial as the learning activities at school tend to be, the benefits of maker culture and digital fabrication for education can be seen in creating inspiring, engaging learning activities arousing innovation, creativity, collaboration and interest for STEM subjects in technology-enhanced, multidisciplinary learning environments.

3.4 Maker Networks Enhancing Making in Schools

There are several institutions, initiatives and networks, who aim to enhance implementing digital fabrication practices in schools and education, such as:

- *Fab Academy* held by the Fab Foundation, being an internationally distributed campus for supporting advanced technical education and providing a training path for new fab lab managers and
- *FabEd*, network collaboration coordinated by the Fab Foundation and TIES (the Teaching Institute for Excellence in STEM) and providing support for formal education, teachers and educators, to further the movement of digital fabrication into formal education (What is A Fab Lab?, n.d.)
- *FabLearn Labs*, formerly known as FabLab@Shcool (some of them are still operating under that name, such as very active FabLab@School.dk), launched by Stanford University, being worldwide growing network of educational digital fabrication labs "that put cutting-edge technology for design and construction -- into the hands of middle and high school students" (About FabLearn Labs, n.d.) and spreads ideas and best practices to support an international community of educators, researchers, and policy makers committed to integrating the principles of constructionist learning, making, into education (What is FabLearn?, n.d.)
- *Maker Ed*, an American non-profit organization providing training, resources, and community of support for educators and institutions for creating engaging, inclusive, and motivating learning experiences through maker education, and

The local implementation in Oulu is *FabLab⁴School* project, leads by Center for Ubiquitous Computing at University of Oulu, promoting innovation, creativity, collaboration and active learning, Fab Lab⁴School arranges learning activities for visiting school groups, aiming to offer schools in the Oulu area a completely new type of learning environment, and creating a community among school teachers, students, and researchers. (Fab Lab⁴School, n.d.)

4 Learning CT and 21st Century Skills in Fab Lab

Referring to Papert's work, Blikstein (2014) has stated that "What Logo did for geometry and programming – bringing complex mathematics within the reach of schoolchildren – fabrication labs can do for design and engineering." (p. 204). Thus, after reviewing the broad concept maker culture, and seeing what it can give for education, this chapter adds Fab Labs to the context of the study (see Figure 3).

Firstly, the theoretical framework of the study, CT and 21st century skills, are applied to the wider context of maker culture. Then this chapter discusses one of the existing maker spaces, Fab Labs, located in maker culture. Finally, the chapter puts learning CT and 21st century skills in the particular context of Fab Lab Oulu and attempts to see its theoretical potential to form a new learning environment, where students can learn these skills.

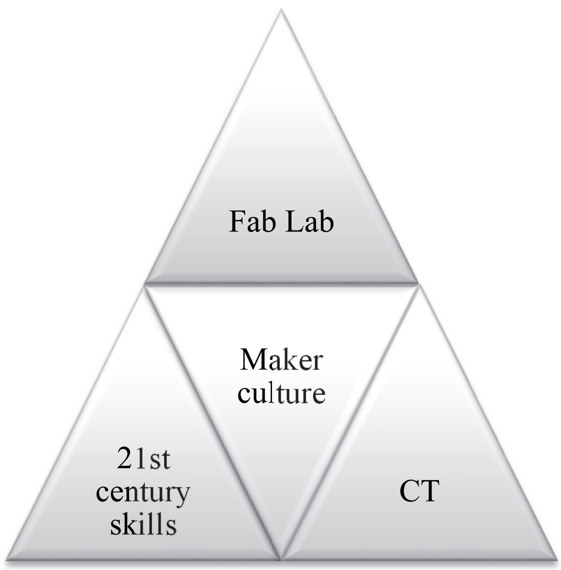

Figure 3. The context and framework of the study

4.1 Fab Labs in Maker Culture

Following Neil Gershenfeld (2007) and the class called “How to make (almost) Anything” he taught at MIT’s (Massachusetts Institute of Technology) Center for Bits and Atoms (CBA) first time in 1998 – and the overwhelming interest it aroused leading to setting up first fabrication laboratories – Fab Labs can be called *places to make (almost) anything*. Then, Fab Labs have begun as an educational outreach project from MIT's CBA since 2002, when the first Fab Lab was established at CBA (Blikstein & Krannich, 2013).

A Fab Lab is technical prototyping platform offering digital fabrication, including different technical tools, for instance, laser cutter, 3D printer, vinyl cutter and high-resolution milling machine. Besides it aims to provide a place and stimulus for innovation and invention for local entrepreneurship it also aims to target educational institutions for learning and innovation by offering “a place to play, to create, to learn, to mentor, and to invent” (“What Is A Fab Lab?”, n.d.).

To be defined as a Fab Lab requires meeting the criteria of four qualities and requirements, which each of the labs needs to fulfil.

1) The most important requirement is public access to the Fab Lab, at least part of the time each week, either for free or barter, with which it emphasizes democracy.
2) Fab Lab needs to support and subscribe Fab Lab Charter, which involves essential paragraphs about the nature of Fab Labs and what comes to their practices (The Fab Charter, n.d., see Table 1).
3) Fab Labs have to share common core capabilities (“What Is A Fab Lab?”, n.d.; see Table 2) to make sure that people in its global network communities can share their designs, projects, and processes across international borders and even reproduce each other’s artifacts by shared files and documentation. For the procurement of critical machines and materials, Fab Foundation offers inventory with their recommendations, as well as a list of open source software and freeware they use.

Fab Labs cannot isolate themselves but must participate in the larger, global network, to be part of that worldwide, knowledge-sharing community. (“Who/What qualifies as a Fab Lab?”, n.d.)

Table 1.

The Fab Charter

What is a fab lab?	Fab labs are a global network of local labs, enabling invention by providing access to tools for digital fabrication
What's in a fab lab?	Fab labs share an evolving inventory of core capabilities to make (almost) anything, allowing people and projects to be shared
What does the fab lab network provide?	Operational, educational, technical, financial, and logistical assistance beyond what's available within one lab
Who can use a fab lab?	Fab labs are available as a community resource, offering open access for individuals as well as scheduled access for programs
What are your responsibilities?	*safety:* not hurting people or machines *operations:* assisting with cleaning, maintaining, and improving the lab *knowledge:* contributing to documentation and instruction
Who owns fab lab inventions?	Designs and processes developed in fab labs can be protected and sold however an inventor chooses, but should remain available for individuals to use and learn from
How can businesses use a fab lab?	Commercial activities can be prototyped and incubated in a fab lab, but they must not conflict with other uses, they should grow beyond rather than within the lab, and they are expected to benefit the inventors, labs, and networks that contribute to their success

Table 2.

Common set of tools

Laser cutter	for making two-dimensional (2D) and three-dimensional (3D) structures
3D printers	for printing 3D models
Large CNC (computer numerical controlled) milling machine	for building furniture and housing
High-resolution milling machine	for making circuit boards, precision parts, and molds for casting
Vinyl cutter	for making antennas and flex circuits
Electronics workbench and a suite of electronic components and programming tools	for prototyping circuits and programming microcontrollers

Fab Labs are situated in the broad context of maker culture, being one of the many types of open workshops, such as makerspaces, hackerspaces, and hacklabs, under the concept (Troxler, 2016). Where maker culture and making relates to hands-on and project-based learning, and Fab Labs offer inspiring working and learning environment with a series of technical tools and in the spirit of exploring and trialing, they involve meaningful relevance for education and current curriculum.

Fab Labs involve constructionist learning theory by offering a playful environment, where learners can become creators and makers, designers of objects meaningful to them and producers of tangible artifacts, which they can make in Fab Lab (Zeising, Katterfeldt, & Schelhowe, 2013). In Fab Labs, students can learn, for example, aesthetic, algorithms and mathematical concepts through three-dimensional thinking and modelling, and got attracted to learn further by personal physical products they can after designing processes print by 3D-printer (Zeising et al., 2013).

Fab Labs have an influence on how one thinks, ideates, does, makes, and creates (Georgiev, Sánchez, & Ferreira, 2017). Dougherty (2013) cites Piaget's (1973) book, *To Understand Is to Invent*, to indicate the importance to facilitate children constructing for themselves the tools transforming them from the inside, instead of only on the surface. By that, he means that children should be able to learn to be initiative in exploring. Instead of guided to perform a task, they should be facilitated to figure out what to do on their own initiative, which in Dougherty's (2013) words is the transformation what making is about and what it can give for education as well.

4.2 Fab Lab Oulu as a New Environment to Learn CT and 21st Century Skills

Fab Lab Oulu, located in University of Oulu, Finland, supports the objectives of Finnish National Board of Education (2016) richly, where it by FabLab^{4}School project aims to offer technology-enhanced, multidisciplinary learning environment for schools. FabLab^{4}School is launched in the beginning of 2016, and it is led by Center for Ubiquitous

Computing at University of Oulu. The project aims to promote innovation, creativity, collaboration and interest for research, science, and technology. (FabLab4School, n.d.)

For example, students from secondary schools can visit Fab Lab during multidisciplinary learning modules week for a different type of learning activities, for instance, around quick prototyping, 2D and 3D designing, electronics, and embedded programming workshops. Through learning activities arranged by FabLab4School, the facilitators want students to learn especially team working, and make them realize that in order to achieve something big they need to collaborate. They also want to help students to develop the ability of logical thinking and comprehend abstract concepts, by facilitating them to visualize their own ideas and to understand the possibilities in achieving them with the assistance of computers. They see great value to make students aware of that fact that they are able to manage many working phases and troubleshooting independently, when facing expected mistakes, checking the cause and correcting by themselves. (Iwata & Pitkänen, 2017.)

Skills from all the four categories of 21st century skills defined in ATC21S framework can be experienced in the Fab Lab4School learning activities. Activities involving 2D/ 3D designing, electronics, and programming, will teach to use different technical software and hardware tools without a question, but additionally, they teach critical thinking to choose tools purposefully and to apply technology effectively for creating products by exploration and fabrication technologies. (Iwata & Pitkänen, 2017.)

In project-based activities, students can involve theory and experience practical hands-on and project-based learning. Thus, they can see how theories and different subjects are connected to each other in the real world, in workplaces, and in everyday life, and how learning is not about repeating information from memory but being able to apply it meaningfully. Learning problem-solving and CT through making activities takes place when students are facing different problems during processes and they need to put their previous knowledge into practice as well as seek new information to find a solution (Iwata & Pitkänen, 2017). There, students can see how can they capitalize on their knowledge for concretizing their creativity, realizing their ideas and solving complex problems, and apply CT processes to go through these cycles. Then, their knowledge is not any more irrelevant, disconnected facts, instead they can found it to be relevant and connect information and construct their knowledge further by applying it immediately.

Learning activities in FabLab^{4}School differ substantially from classes at school, and the nature of activities and learning is closer to working life, for instance, what scientific researchers do in real laboratories, than traditional teaching and studying. The activities require more responsibility from students, such as working on the project without teachers' immediate assistance, exploring and learning mainly by themselves, and evaluating their working progress. To accomplish multiphase projects, the activities require collaboration and teach the importance of delegation of responsibilities for the tasks, as well as recognizing and appreciating team member's different strengths. (Iwata & Pitkänen, 2017.)

Learning environments should be seen as implementation arenas of individual learning processes, and teachers as facilitators of learning. According to Hannafin and Land (1997) "technology-enhanced student-centered learning environments require that individuals are active in the learning process" (p. 190) and those environments should "emphasize concrete experiences that serve as catalysts for constructing individual meaning" (p. 173). FabLab^{4}School facilitators offer students the freedom to choose topics which are meaningful for them. The facilitators set some broad guidelines for projects, and introduce necessary information and tools but otherwise, the idea is to work on and search needed information, whether it is instructions for software or hints for programming, mainly independently (Iwata & Pitkänen, 2017). Also, students need to think next steps in their projects. The facilitators will be present but instead of giving answers they facilitate students' thinking processes and spur them to seek answers by themselves by providing only cues.

Through digital fabrication activities, students can find how are they able to design and build tangible artifacts and make their ideas become true and thus, be active producers. Moreover, students can discover their interests, and through engaging, authentic practices some of them might even found their desire to study science, mathematics or engineering.

5 Discussion and Conclusion

When humans grow up with an amount of different technologies available, and the world around them becomes more and more automated, people have become passive consumers. Previous studies of making in education (e.g. Dougherty, 2013; Papavlasopoulou et al., 2016; Papert, 1991; Smith, Iversen, & Hjorth, 2015) highlight the issue that children should explore actively rather than receive passively. Making something by yourself offers a different perspective on the learning process: instead of being only passive recipient, it gives the opportunity to the learner to have control over his own knowledge construction. (Papavlasopoulou et al., 2016).

According to one teacher (personal communication, February 2, 2017), who visited in Fab Lab Oulu with the group of secondary school students, Fab Lab learning activities are like the opposite force for current regression: they can wake up nowadays passive consumers and make humans active producers again. Moreover, in present information society, the ability to search, manipulate and use information, and even more significant, collaborate and solve problems together, have become crucial competencies (Griffin et al., 2012).

In Fab Lab, students can participate in doing and making, awoke their creativity, use information accurately and creatively, and learn to apply appropriate tools and technologies to enhance their working processes. Additionally, they can start to think about in completely new, more active ways. As an example, if you cannot solve the problem with your cranky irrigation system, it is not a sign to go to a store and buy a new one. Instead, it is worth to break the problem into smaller, manageable parts and figure out what all those parts are.

The first step is to check is the tap open, is there some knot in a hose, or is a nozzle of watering hose stuck. But you can go way further, where the second step could be for example to measure and calculate, how long is the hose and how is it located, is there enough pressure in the hose? When you are figuring out what is the problem, you can search help from different resources, you can discuss with people in the neighborhood or online communities, and you can try some solutions they propose. And then, you might found that the only problem is a broken trigger in the nozzle. Finally, instead of going to a store and buying a whole new nozzle because of one small broken trigger, you can check if there is already some suitable model in Web repository made by some member of a community, or you can think how the trigger works, again measure, and use free, open-source software for designing a new similar trigger– or one with even better features – by yourself, and just print it with 3D printer.

The role of CT should see as an essential element in education since it reflects the ability to learn - not only inside certain content or subject but instead - the relations of several subjects. Also, by using CT there is a possibility to reach multiple meaningful affordances when combining the knowledge and skills from traditionally separated subjects in the multidisciplinary area. That area should be located inside of every student's head, to be able to handle 21st century information society based life in the context of thinking, learning, working and collaborating in various situations.

Furthermore, by challenging students – or in another word by giving them chance – to use and develop their computational thinking processes will increase student's confidence in dealing with big, complex and open-ended assignments, their persistence in working with difficult problems, their tolerance for ambiguity, and their ability to communicate and collaborate with different characteristics, disciplines and cultures to achieve a common goal or solution to their problem. (ISTE & ISTA, 2011.)

Maker culture, enriched with digital tools, is current hands-on doing phenomenon and has faced increased interest faster than ever, and not the least because of maker movement. However, there hasn't existed a comprehensive or univocal definition of these two terms.

When makers (identified all respondents as 'makers' for the sake of anonymity) in social media channels (Twitter and Facebook) were asked to describe, what is the difference between maker movement and maker culture for them, the answers showed that a meaning can be individual and vary among participants in maker communities. One of the respondents didn't differentiate between the terms: "The whole definition of maker movement is so vague that I have just bundled them together" (Maker A, 2017, May 4). Whereas, some others expressed their tentative ideas of the difference by discussion "does movement precede culture? So there is a movement which results in culture?" (Maker B, 2017, May 4) and framed it by presenting "Could a movement be something bringing new things up and a culture state where things are more established and maybe even more mainstream?" (Maker I, 2017, May 4). During the discussions, interesting viewpoints were posed: "Culture is roots, goes deep, movement is what spreads above? --- So if something grows, it's both." (Maker B, 2017, May 4) leading to think the issue further.

For Maker J (2017, May 4) maker culture means "the way how different innovators interact with the materials and surroundings.", and "how they [*innovators*] believe in human–human interaction as for any products/system/service to be successful, it needs a purpose first.", whereas maker movement is "a movement of getting people from different parts of the world to a common workplace where they could either work on their own idea or maybe choose to collaborate". Also, some other respondents other were on the same line with this study though, such as Maker C (2017, May 4) stating that "Culture seems more like a way of life, movement is more active, seeking to make people more aware." alongside Maker F's (2017, May 4) thoughts: "Culture is created by all the people, who are already inside." Lastly, "Maker movement and Maker Culture go hand in hand. Maker movement cannot survive without maker culture as the culture for exceeding limitation and boundaries is the ultimate goal of innovation." (Maker J, 2017, May 4).

Where maker culture encourages to participate, share expertise among group members and engage in collaboration and collaborative knowledge construction with others, this participatory approach is one of the characteristics that it can provide for education. Also, where schools and traditional learning tends to be a curriculum-based teacher-centered transmission of knowledge, learning by making and exploring provides a different approach, being experiment-based learning through student-centered knowledge construction (Smith, Iversen, & Veerasawmy, 2016). Maker culture in education refers also to equal participation (Blikstein, 2017). It is not only for 'the elite' or a few peoples known to be brilliant. Rather it aims to provide an opportunity for everyone to participate and make "almost anything", attempting to engage more and more people to solve problems and generate new ideas (Mota, 2015).

Seeking the meaning and possibilities of Fab Labs and maker culture for education is not only about optimizing the current practices of existing environments and teaching, but more improving them and moving them to a completely new level. In that level, lessons are less scripted and subjects are learned more by exploring them actively. There, a teacher is not using working hours to plan classes thoroughly and to transform knowledge, instead, he gives space for students to explore, to innovate, to find, to create, and focuses on facilitating their learning, and guiding them in their learning path.

The aim of this study was to explore how can computational thinking and 21st century skills be seen in the context of maker culture. The study formed theoretical framework of 21st century skills and CT, and defined how can they be seen in relation to maker culture and Fab Lab. Based on the theoretical framework, the study examined the idea of learning these skills in digital fabrication activities in Fab Lab Oulu.

The study presents that 21st century skills including computational thinking can be learnt in interesting and meaningful ways by making activities arranged in the context of Fab Lab Oulu. However, to use a new learning environment purposefully in education, it should be secure and scientifically granted. Therefore, this study serves as a theoretical background and is waiting for future studies to investigate how should learning CT and 21st century skills be designed and practically implemented in maker activities in the context of Fab Lab. Then, the study will serve as a theoretical framework for continuing the topic in Master's Thesis, and investigating potential of Fab Lab learning activities further.

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