Makerspaces Promoting Students' Design Thinking and Collective Knowledge Creation: Examples from Canada and Finland

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Abstract. Despite the growing popularity of makerspaces in education, we currently have little understanding of the conditions and processes that promote students' design thinking and knowledge creation in these digitally-enriched learning environments. To address these research gaps in current research knowledge, we draw on two ethnographic case studies on students' maker activities situated in Canada and Finland. In the Canadian study, the focus is directed to analysing students' design actions carried out in a five day long "microcycle" of learning by individual students in a Maker Lab. In the Finnish study, attention is directed to investigating forms of students' collective knowledge creation during an elective course in a makerspace, The Fuse Studio. This paper shows that design thinking is a potentially fruitful way to build students' global competencies and to approach knowledge creation in a makerspace environment as students engage in interest-driven making, requiring various levels of instructor/peer support, from independent making to guided inquiry.

Keywords: Makerspaces · Design thinking · Knowledge creation Digital learning environment

1 Introduction

Makerspaces are collaborative and creative spaces where people come together to hack, build, innovate and ultimately, to learn—either formally or informally. Maker pedagogies are generally associated with STEM or STEAM (where the Arts are integrated into Science, Technology, Engineering and Math) education; however, making is inherently interdisciplinary, hands-on, inquiry-based, and driven by student interests and passion. Educators in Canada and Finland are now increasingly harnessing makerspaces as learning environments to promote inquiry, imagination, creativity, curiosity, and perseverance in STEAM learning and beyond. Most notably, making is considered to promote the development of important global competencies and

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transferable skills, such as creative and critical thinking, problem solving, collaboration, leadership, and innovation.

Despite the growing popularity of makerspaces in education (Honey and Kanter 2013; Kumpulainen 2017), we have currently little understanding of the conditions and processes that promote students' design thinking and knowledge creation in these novel digitally-enriched learning environments. Furthermore, what accounts as a makerspace in formal education deserves further attention. In this paper, we address these gaps in research knowledge by introducing and combining, in a novel way, two theoretical lenses, namely design thinking and knowledge creation in the study of makerspaces in Canada and Finland. The makerspaces in the two research sites are largely similar. Yet, the pedagogical approaches of the making and design activities in these two research sites are slightly different: The Canadian Maker Lab emphasizes design thinking, a fluid and non-linear methodology that typically involves tackling complex problems in local and global communities. Using design thinking, learners are considered to be able to exercise their agency to define real world problems that they are passionate about by first empathizing and trying to understand the human needs involved. They brainstorm to generate multiple solutions and begin to prototype and test their solutions. The Finnish site underscores students' interest-driven engagement in STEAM design challenges that are introduced to them in a digital infrastructure for learning, The FUSE Studio. The STEAM challenges of the FUSE Studio (named *Keychain Customiser, Electric Apparel, Coaster Boss* and *Solar Roller etc.)* that students can choose from have been structured to introduce students with new ideas and to support them through more complex iterations of those ideas. The challenges 'level up' in difficulty like video games and are accompanied by various tools, such as computers, 3D printers and other materials (e.g., foam rubber, a marble, tape and scissors, which we refer to as "artifacts"), as well as instructions on how to process the challenges (Stevens and Jona 2017).

In sum, our paper addresses the following research questions:

- How does a theoretical design challenge support students in the design process of their own personal passion project? What specific global skills and competencies are developed in the theoretical challenge and in the personal passion project?
- How do students engage in collective knowledge creation through STEAM design challenges?

2 Theoretical Framework

The theoretical framing of our work is informed by design thinking (Doppelt 2009; Kafai and Peppler 2011; Gobble 2014) and knowledge creation approaches (Paavola, Lipponen and Hakkarainen 2004; Kajamaa, Kumpulainen and Rajala forthcoming). We consider these two approaches useful as they represent the core elements entailed in makerspaces and making.

2.1 Design Thinking

Social demands for certain skill sets are changing and with the implementation of maker pedagogies, students are given the opportunity to develop those foundational skills that are necessary for success. Design disciplines are those which provide open-ended ways that students can approach problem solving through authentic, real world applications (Kafai and Peppler 2011). Makerspaces are rooted in design disciplines, so they align with the concept of problem solving through open-ended approaches to create unique learning opportunities for students. It is in these opportunities that the skillsets necessary for success are developed.

Over the years, as our society has evolved from one of consumer to one of creators in many aspects, the concept of design thinking has emerged as a critical aspect of our everyday lives (Gobble 2014). Many people align design thinking with the aesthetics of something, however in reality it encompasses much more than just how something looks (Gobble 2014). Different models that are used in design thinking utilize different tools and frameworks as vehicles to create a more human centred approach to problem solving (Gobble 2014; Brown 2009; Cahn et al. 2016). Creating authentic applications of real world situations elicits design thinking, which promotes collaboration and communication, as well as empathy and citizenship, which are commonly used in real-world problem solving.

2.2 Knowledge Creation

In makerspaces, based on the principles of design thinking students are encouraged to make their knowledge explicit in their innovation processes by constructing novel solutions to the challenges and problems in question. Knowledge creation takes place in the social activity of students and teachers and it is a crucial process for students' learning and knowledge advancement (Engeström 1999; Engeström, Engeström and Suntio 2002; Paavola et al. 2004; Kajamaa, Kumpulainen and Rajala forthcoming). Knowledge creation is mediated by various tools embedded in the activity. These tools can entail both conceptual (signs, language) and material artefacts (Vygotsky 1978). Similarly, the results of knowledge creation processes are often tangible objects (e.g. creation of an artefact or a completion of a challenge presented on a computer screen), but they may also result in "conceptual artifacts" (Wartofsky 1979; Engeström 1999; Paavola et al. 2004; Kajamaa, Kumpulainen and Rajala forthcoming).

Our previous study shows that in a makerspace context, knowledge creation may take place in different, and often intertwined forms (vertical knowledge maintaining). It can also manifest as students making their own initiatives to creatively break away from the given situation and instructions (horizontal knowledge breaking). In some cases, it may evolve into an innovative process where the student groups and sometimes also students together with their teachers collectively challenge and question one another and the existing knowledge to co-create future-oriented learning activity (knowledge expansion) (Kajamaa, Kumpulainen and Rajala forthcoming).

3 Methodology

To answer our research questions, we used two approaches. To analyze the data from the Canadian context, we used a design-based research (DBR) approach that focused on the design thinking processes of individual students (Barab and Squire 2004). To analyze the data from the Finnish context we applied a new framework developed by Kajamaa, Kumpulainen and Rajala (forthcoming) for the study of different forms of knowledge creation in technologically enhanced makerspaces.

3.1 Setting

In Canada and Finland, the research took place in STEAM-focused makerspaces [links will be added]. In Canada, the makerspace was situated in the Faculty of Education at [university name] and in Finland the makerspace was both online and in a city-run comprehensive school with 535 students and 28 teachers at the primary level. In 2016, as a response to the new curriculum requirements, the school introduced the FUSE Studio (www.fusestudio.net) - a design and making environment - as one of its elective courses. The Canadian Maker Lab was established to conduct research into production pedagogies in general, and maker pedagogies in particular.

3.2 Participants

At the Canadian site, the researchers worked with a group of fifteen students ranging in age between 7 and 14 years old. Eight of the students were male and seven were female - 11 of whom had no identified exceptionalities and four of whom had exceptionalities that included giftedness, anxiety, ADHD, ASD and other learning challenges. The students had a range of experience with, and access to, technology and different digital tools both at home and in school from previous grades. The students participated in a March Break Camp to spend five full days using the design thinking process to work on a personal project in the Maker Lab.

In the Finnish site, the research focused on 94 students aged between 9 and 12 years old. Due to the elective nature of the FUSE course, the groups consisted of students from several classes. Group 1 consisted of 32 students (22 boys and 10 girls), Group 2 consisted of 30 students (19 boys and 11 girls) and Group 3 consisted of 32 students (19 boys and 13 girls). Each group was supported by two to four teachers and teaching assistants.

3.3 Research Design

In Canada, the design process was used in two ways during the March Break Camp – first, it was used in a daily theoretical exercise with the students (responding to the challenges of training a new puppy) and second, it was used to frame the participants' week-long design project. At the Ontario site we adhered to the following cyclical five-stage design framework adapted from the Engineering is Elementary website (Museum of Science, Boston) (Fig. 1):

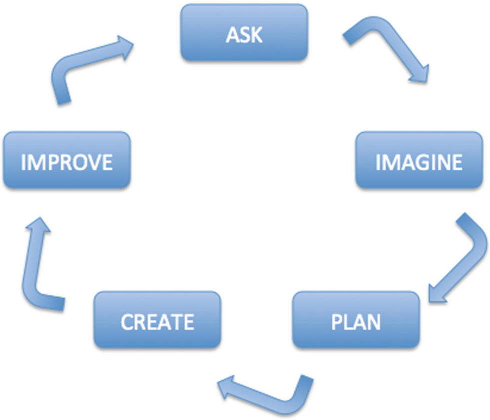

Fig. 1. The design framework used at the Ontario site.

The framework included: 1. Ask (what is a personal project or problem that needs to be solved); 2. Imagine (what already exists that could solve this problem or could be hacked or re-mixed to better respond to the problem); 3. Plan (what resources are needed, what steps will be involved in realizing the end product); 4. Create (a prototype of the product for testing with others); 5. Improve (what worked, what could have been improved). Each day of the camp was devoted to a different (and sequential) stage of this design process

In Finland, we investigated students' maker activities in a novel "makerspace", the FUSE Studio—a digital learning environment focused on enhancing student- and interest-driven science, technology, engineering, arts and mathematics (STEAM) learning. In the FUSE Studio, students were free to select which 'challenges' to pursue, who with (or alone) and when to move on. The core idea was to promote young learners' STEAM learning and to cultivate STEAM ideas and practices among those who are not already affiliated with them, and by so doing broadening the access to participation in STEAM learning (Stevens and Jona 2017). Figure 2 shows a student interface (view) of the FUSE challenges on a computer screen.

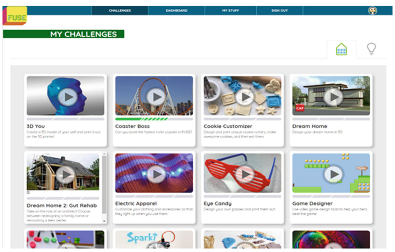

Fig. 2. 'My challenges' student interface

3.4 Data Collection and Analysis

In Canada, the study began with a pre-project survey as a base marker of the students' beliefs about making. We asked students whether they considered themselves "makers" and what kind of making they engaged in at school. We also asked the students whether they were given opportunities to do "passion-based" (interest driven) making. Throughout the project, the researchers recorded detailed field notes, collected the students' planning notes and reflections, photographs, still images/video recordings of their design thinking processes, whole group conversations, and individual exit interviews. The researchers also engaged in informal discussions with the students, of which noteworthy comments, themes, ideas or feedback were recorded through text or voice recorder. This type of open-ended data was collected with the objective of developing common themes (Creswell 2004).

In analyzing the Canadian data, we drew on content analysis (Berg 2007) and as we combed through the various data sources in our first reading, we looked for emergent codes. On the second reading, we looked for patterns and grouped similar codes into categories. On the third reading, we narrowed our focus to examine how design thinking led to the development of a series of global competencies, and in this paper, we specifically focus on problem solving.

In Finland, the primary data was comprised of 111 h of transcribed video recordings and field notes of students (N = 94) aged between 9 and 12 years old and their teachers carrying out making and design activities in the FUSE Studio. The video recordings were collected intermittently over a period of one academic year.

The video data and field notes were transcribed and analyzed using interaction analysis methods (Jordan and Henderson 1995). Our analytic approach can be defined as abductive, involving repeated iterations between theory and data. Our analysis was based on Kajamaa, Kumpulainen and Rajala (forthcoming) framework of the different forms of students' knowledge creation. We inductively analyzed the discursive acts from the students' and teachers' talk, depicting forms of knowledge creation.

4 Findings

4.1 Individual Students Design Thinking in the Maker Lab

Framing the Passion Projects Through Focused Problem-Solving. To help participants develop the problem-solving skills they would need during the creation of their passion projects over the course of the week, they were guided through focused and intentional problem-solving activities each day of camp. The challenges were thematically centered around the training of a new puppy and required participants to think creatively and to persevere in finding solutions to their puppy training problems. As the students worked through their first 'puppy challenge', they were stretched to conceive of realistic and humane ways to train their new puppy. Beginning ideas included low-tech and easy to implement, yet impractical, solutions such as building a box in which the puppy would live and relieve him/herself, thus removing the issue of focused training altogether. Other solutions included the use of more elaborate, futuristic technology. One participant designed a jet-pack for the puppy that would sense when s/he needed to relieve him/herself and would fly the puppy to a designated area of the backyard. While this idea was certainly more creative and innovative, it was again less practical and raised ethical issues, such as animal cruelty. As the group shared their working solutions (drawing on collaboration and communication skills), discussion arose surrounding the well-being of the dog in at least a few of the scenarios. One boy raised the question, "which [of these] could put a lot of strain on the dog?" He pointed to the jet-pack example and explained that this would put "a lot of strain on his organs". So, this was identified at the beginning of the week as an area for development and improvement. While most of the ideas theoretically provided a solution to the problem posed, they each required feedback, reflection and revision to generate viable solutions. Each day, a new challenge connected to training the puppy was introduced and encouraged the campers to continue to use the design process in order to refine their solutions. As a result, the students' problem-solving skills were developed by drawing on some of the other global competencies such as collaboration (i.e. asking peers for assistance in their making process and input in their designs and final products), perseverance (i.e. continuing to troubleshoot and problem-solve when faced with technological and/or design challenges), empathy/citizenship (i.e. in the development of an artefact in response to real-world or imagined problems) and creativity (i.e. in their innovative/unique solutions).

Problem-Solving in the Design Process. As they worked through the stages of their designs, each camper was forced to pause at crucial moments to consider the feasibility of their designs and how they might need to reconsider and refine their choices of direction or materials (similar to the theoretical puppy training challenge). One pair that was working together on Harry Potter wands as their passion projects (the main design projects separate from the theoretical puppy-training design challenges posed each day) decided they wanted to create wands that light up at the tip when they cast their spell. They planned out their week and articulated the steps they would take to achieve their end goal (verbally and in their design planning notebooks). Continuing on in their design process, they used sewing and Lilypad - a codable E-textile tool - to create a prototype of their wands. To complete their prototypes, they were required to learn about circuitry and a traditional skill that many find frustrating - sewing. To complete this task, both students went through a number of problem solving tasks, from learning how to thread a needle to how to wire the circuit to ensure that it worked the way they wanted. This process was not easy for the pair and they encountered many challenges along the way; however, with support from one another, leaders and other campers, they persevered and succeeded in this portion of their project.

Following their prototype creation, the pair were required to modify their design multiple times, adapting their prototypes each time. The problem-solving aspect of the design process became very evident at this point in the project as the duo used TinkerCAD to create the 3D model file of each of their wands. It was quite simple creating the wand shape; however, when they realized that they had to make the inside hollow, they ran into the problem of how to make sure there was enough space inside the wand to fit all of the wiring. The most challenging aspect of the project for them was creating the circuits and although they became frustrated and were close to quitting, through collaboration, patience and hard work, they were able to add the illumination element to their wands.

4.2 Students' Collective Knowledge Creation in the FUSE Studio

Our analysis of the students' knowledge creation processes in the FUSE Studio revealed the dynamic interplay of three forms of knowledge creation: Namely, vertical knowledge maintaining, horizontal knowledge breaking and knowledge expansion. Below, we illuminate one example of the dynamic interplay of these three forms of knowledge creation.

The vignette shown below highlights the exchange between two students and their teacher during the FUSE challenge titled, "Keychain customizer". During this exchange, the boys—about to save their work on the computer programme—are approached by the teacher to check in. Although the boys express that they want to design their artefact in such a way that it could hang the right way up, the teacher explains to the boys that it would be better to hang it upside down. The teacher also tells them how thick or thin to make the ring. The students then question the teacher by attaching the ring to the top of the letters, nevertheless. Despite this effort, the teacher overrides the students' perceptions on what a 'nice' keychain would look like and how it should be hung (pseudonyms are given to the students in the excerpts):

Teacher: I think that this ring is too weakly attached to the letter I. It's too much on the edge.
Eetu (student): But Onni (student) said it was ok.
Onni: But isn't this ok?
Teacher: I would like it to be a lot more firmly attached. I would, in fact, attach it (the ring) to the letters (referring to their initials) and probably from the bottom maybe.
Eetu: But then this name would be upside down.
Teacher: Then it would hang from the bottom, but the keychain is not always hanging from somewhere.

The student attaches the ring to the top of the letters nevertheless.

Teacher: And I would also use the "tube" – tool to make it thinner.
Eetu: It's already as small as it can be.
Teacher: No it's not. Carefully adjust it so that it can be used as a keychain (student uses the tool). Now that's better than the previous one (student keeps adjusting) Not that narrow, that's as it doesn't exist at all. It's not firm enough so that it will hold.

In this example, the students were enthusiastically focused on their joint activity of designing keychains and made active use of the artefacts available in the FUSE Studio. The students' attempted to use their agency and knowledge in their making activity: the activity was initiated by a FUSE challenge, but the students started to follow their own ideas and ways of working. We interpreted this as horizontal knowledge breaking, as it provided evidence of the students' breaking away and expanding their activity from traditional schooling towards design and creativity. The student-driven activity was then interrupted by the well-framed instructions given to them by the teacher. The teacher disregarded the student's initiative. This tension could have potentially triggered opportunities for knowledge expansion, if the teachers and the students had started to negotiate and make attempts to create collective solutions to guide their future actions.

5 Discussion and Conclusions

In this study, we investigated students' design thinking and forms of knowledge creation in two educational makerspaces in Finland and in Canada. In terms of design thinking, the Canadian case revealed that the makerspace is a space where students can develop global competencies such as problem-solving, collaboration, empathy and communication. Both of the studied makerspaces provided useful material conditions supporting students' design thinking and knowledge creation. They provided the students with a rich variety of digital tools and more traditional (craft) materials that the students actively, and often creatively, utilized within these contexts.

In the Canadian Maker Lab, design thinking was introduced through the engineering design process framework (adapted from the Engineering is Elementary website). In the findings section we presented an example of the theoretical puppy training challenge the participants engaged with at the beginning of each design day. The competencies developed through this challenge supported the students in their own, personal design projects. The theoretical challenge also assisted them in considering the real-world application and/or practicality of some of the components of their designs. In the findings, we also discussed some of the skills the students developed and the challenges the students encountered in their personal projects which ranged from learning and debugging the technology (i.e. constructing circuits) to engaging in iterative attempts to add to and improve their final products (i.e. the Harry Potter wand).

The FUSE Studio in the Finnish context included a unique design and making infrastructure and a social context, which enhanced different forms of the students' collective knowledge creation. Overall, in our data, the students' strict following of the structures and instructions given by the FUSE computer program and the facilitating teachers (i.e. knowledge maintaining) dominated the design and making activity. Yet, relatively often, the students exercised horizontal knowledge breaking and used their own initiatives to break away from the situation creatively. Sometimes this created tensions as the students questioned the customary ways of making and designing. The challenging and questioning of the existing knowledge led in some rare cases to knowledge expansion where groups of students, sometimes also with their teachers, encountered the tensions, negotiated, and thereafter co-configured novel, future-oriented learning activities. In the Finnish context, the flexible intertwining of the multiple forms of knowledge creation is a current pedagogical challenge for educators and conscious efforts are needed to improve the processes and conditions giving rise to qualitative different forms of knowledge creation in the students' maker activities.

Our analysis provides novel findings also in connecting design thinking to the theoretical notion of knowledge creation. Our research shows that the main difference between these approaches relates to the initial level of agency of the students in determining what kinds of making they will engage in. However, these approaches also importantly add to one another as teachers grapple to understand what kinds of pedagogical supports to provide students during the design/making process. In both cases, the participants were given varying levels of guided inquiry support from others, both instructors and peers.

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