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Learning to innovate: Students and teachers constructing collective innovation practices in a primary school's makerspace

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The need to foster citizens' innovation skills is widely recognized. Although current research acknowledges the potential of makerspaces to promote innovation activities, research still lacks an understanding of underlying mechanisms that can lead the creation of innovations in makerspaces by students. Moreover, research to date has overlooked how innovation practices are formed in K–12 makerspaces. In this sociocultural study, we used ethnographic video data from a Finnish primary school's makerspace and applied methods of abductive Video Data Analysis to investigate how innovation practices are constructed in first to sixth grade students' and teachers' interactions. The results of this study show that the innovations created by the students in the makerspace were an outcome of students' and teachers' collective innovation practices. The study provides a typology of these collective innovation practices, namely: taking joint action to innovate, navigating a network of resources, and sustaining innovation activities. Further, our results reveal that the collective actions encouraged students to use skills deemed to be important for innovation creation. Also, adding to existing research knowledge, our results reveal two mechanisms that potentially promote students' learning to innovate. These mechanisms include the teachers' orientation to facilitating open-ended STEAM projects and practices that emphasize students' ownership over their personal projects.

KEYWORDS

collective innovation practices, innovation, makerspace, students, teachers, primary education

1. Introduction

The need for formal education to foster students' competence to participate in the creation of innovations is widely recognized (e.g., Keinänen et al., 2018; OECD, 2019). It is argued that individuals must learn to use knowledge in innovative ways to cope with current and future ecological, social, and economic problems (Sinervo et al., 2021).

Specifically, current research knowledge posits that students' opportunities to engage in innovation activities in school can enhance students' ability to identify needs, explore alternative solutions, and collaborate to solve problems (Kangas et al., 2013; Yrjönsuuri et al., 2019). Therefore, several flagship initiatives in Europe have set innovation as a key priority in formal education (Bocconi et al., 2012; OECD, 2019), and in Finland, innovation competence is set as a learning objective in the national curriculum. In the Finnish national curriculum, innovation competence is defined as students' ability to contribute to the creation of innovations through making arguments and conclusions and exploring and creating innovative solutions individually and in interaction with others (FNAE, 2016). Further, the OECD emphasizes the need to promote students' creative and critical thinking skills – that is, their ability to engage in inquiry, imagine and reflect on different perspectives, and transform their ideas into innovative solutions (Vincent-Lancrin et al., 2019).

Makerspaces have been recognized as potential learning environments to foster participants' engagement in innovation practices and developing related skills (e.g., Hughes and Morrison, 2020; Oswald and Zhao, 2021). Makerspaces have been conceptualized as knowledge building communities in which new knowledge is collectively built and shared (Martin, 2015; see also Kajamaa et al., 2018; Kajamaa and Kumpulainen, 2020). It is argued that the exchange of ideas, information, and resources that typically occurs in makerspaces promotes innovation (Beltagui et al., 2021). Despite the growing understanding of makerspaces as being conducive for innovation practices, there is a lack of theoretical explanation for how they do so and what underlying mechanisms are at play (Oswald and Zhao, 2021; Gantert et al., 2022). Further, the way in which innovation practices are formed in makerspaces has been particularly overlooked in the K–12 context (Rouse and Rouse, 2022). Thus, this sociocultural study brings new knowledge about how innovation practices are constructed in the interaction between students and their teachers, as well as how the social setting of a school's makerspace allows the formulation and development of such practices.

In this paper, we first discuss existing research related to innovation practices in makerspaces and explain how the term 'innovation practices' has been conceptualized in our study. We then explain how we used methods of abductive Video Data Analysis (Timmermans and Tavory, 2012; Nassauer and Legewie, 2021) to analyze ethnographic video data from a Finnish primary school makerspace, called the FUSE Studio. Our results provide a typology of innovation practices in the FUSE Studio and highlight the collective nature of innovation practices. Moreover, the results show that students' and teachers' collective innovation practices encouraged students to use skills that are pivotal for creating innovations. We also discuss two mechanisms that potentially promote students' learning to innovate. These mechanisms include the teachers' orientation to facilitating open-ended STEAM projects and practices that emphasize students' ownership over their personal projects.

2. Makerspaces promoting innovation practices

Makerspaces are commonly described as sites for students' creative engagement in science, technology, engineering, arts, and mathematics (STEAM; Sheridan et al., 2014). At the same time, creativity and innovation are frequently connected in research, as research shows that creativity is an inseparable part of innovation (e.g., Sarooghi et al., 2015). Therefore, we wish to clarify how we conceptualize innovation practices in this study. Following West and Hannafin (2011), we understand creativity to be an idea, initially generated by an individual or a group of individuals. Innovation, on the other hand, not only represents such novel ideas, but also their implementation in practice (see also West, 2009). Further, rather than restricting our focus on innovative outcomes and products, we follow a research line that took a more holistic stance, and we thus focus on innovating as a phenomenon. We therefore highlight the process-like nature of innovation practices (e.g., Bjornali and Støren, 2012; Marin-Garcia et al., 2016; Hughes et al., 2018).

We view innovation practices as nonlinear, interpersonal, and practical processes (Hughes et al., 2018), that typically involve introducing new ideas, evaluating advantages and disadvantages, estimating risks, making decisions, carrying out actions, mobilizing and managing people, and using external help and resources (Marin-Garcia et al., 2016; see also OECD, 2019; Vincent-Lancrin et al., 2019). From a sociocultural perspective, we understand practices as sets of actions performed by multiple individuals and that are ongoing in nature, regardless of spatial or temporal gaps (Schatzki, 2019; see also Green and Bridges, 2018). We thus posit that individuals negotiate actions *in situ*, but some of those actions become interconnected across time (Castanheira et al., 2000). Further, following Wertsch (1994), we understand that the practices resulting from such interconnections are linked to specific cultural, institutional, and historical settings that run through the school and the makerspace. Individual action can thus take part in reproducing or transforming the sociocultural setting, because the actions and the setting are interrelated.

Previous research suggests that the innovative potential of makerspaces lies in their rich technological resources, conjoined with a particular social climate conducive to innovation activity. For example, Gantert et al. (2022, p. 1565) explain makerspaces' innovative potential with a conceptual model called "the trinity of makerspaces," consisting of technical, social, and cognitive aspects. According to this conceptual model, the rich technological resources (technical level), the self-governing structure and participants' sense of community (social level), and features such as collaboration, open transfer of knowledge, and mentorship (cognitive level) are key features that advance the creation of innovations in makerspaces (see also Vinodrai et al., 2021). These rich resources, coupled with access to training, tutoring, and social companionships, can improve one's opportunities to innovate individually and in collaboration with others (Halbinger, 2018; Gantert et al., 2022). Further, in a study located in a university design studio context, West and Hannafin (2011) found that features such as flow and "the hacker ethic" contribute to what they call a "Community of Innovation." According to the researchers, flow and the hacker ethic account for participants' interactive engagement in lively discussions around project ideas, and playful engagement in projects, respectively. Based on a study conducted in a higher education context, Farritor (2017) adds that makerspaces' innovative culture can also be due to appreciating multiple sources of knowledge, encouraging participants to collaborate, and providing students with ill structured activities that leave room for creativity.

Previous research also proclaims that if it is possible for students to engage in a variety of activities in personally meaningful ways promotes their opportunities to innovate (e.g., Gantert et al., 2022). For example, a study conducted in a school makerspace by Hilppö and Stevens (2021) showed that when students' personal choices over their learning endeavors are appreciated, and students are provided with access to digital and tangible resources, it creates conditions that have the potential to promote students' innovative engagement in making activities, both on an individual and on a collective level (Hilppö and Stevens, 2021). Giving students autonomy over their work can also promote primary school students' agency (Clapp et al., 2016) and transformative agency that drives their initiatives to transform learning activities for personal or academic ends (Kajamaa and Kumpulainen, 2019). Further, Stevens et al. (2018) argue that when given opportunities to make personal choices over making activities, students can develop their expertise in a variety of STEAM topics and skills sets (Stevens et al., 2018). In turn, using students' and teachers' expertise dynamically through mentoring and tutoring (West and Hannafin, 2011), promotes wide exchange of ideas, information, and resources, which is understood as pivotal for innovation creation (Beltagui et al., 2021). Moreover, not only are students' personal and innovative ideas valued in makerspaces, but also participating in making activities can reduce the fear of failure, which is seen as important for an innovative activity (Geser et al., 2019; Hilppö and Stevens, 2020). More specifically, makerspaces bring about a culture in which repeated iterations are not viewed in a negative light, but failures during making processes are framed as significant learning opportunities and thus productive for the making process (Rieken et al., 2019; Hilppö and Stevens, 2020).

Makerspaces are also often depicted as spaces which allow individuals to negotiate roles during learning activities. According to Gantert et al. (2022) makerspaces provide opportunities to detach from established social roles, and this is seen as being fundamental for the innovative potential of makerspaces. For example, during making activities participants can act as learners, mentors, or experts, depending on their knowledge and skills related to the task at hand (Sheridan et al., 2013; Leskinen et al., 2021, 2022). Such circumstances that allow individuals to deviate from established social roles, enhance community interaction and construction of community knowledge (Oswald and Zhao, 2021), which in turn, nourishes a culture of open exchange of information typically viewed as essential for innovation (Halbinger, 2018; Geser et al., 2019). In addition, the study by Bull et al. (2017) conducted in an elementary context showed that such community interaction can promote remixing of existing ideas, which can be viewed as important for innovative practices. Although the empirical research results described above highlight how students can detach from established social roles, previous research stresses the teachers' important role in supporting innovation practices (Greene et al., 2019; Jaatinen and Lindfors, 2019; Sinervo et al., 2021). Based on a study conducted in a crafts education context, Jaatinen and Lindfors (2019) add that co-teaching practices in makerspace learning environments can support both students' and teachers' learning during innovative making activities. This is because co-teaching can enhance teachers' ability to recognize students' needs, promote students' co-working practices, and allow teachers to learn from one another and thus give more support to their students.

Taken together, previous research shows that there are particular features of makerspaces that promote students' innovations in schools. These features include rich technological resources, open knowledge transfer between teachers and students, access to tutoring, students' playful participation in projects, appreciating students' personal projects, and promoting their agency. However, current research falls short in providing theoretical explanations for how these features are connected to the everyday interactions between students and teachers in makerspaces (Oswald and Zhao, 2021; Gantert et al., 2022), especially in K–12 makerspaces (Rouse and Rouse, 2022). Thus, this study will provide new knowledge by mapping how innovative practices are constructed in an elementary school makerspace called the FUSE Studio. This study will also provide new insights about how innovation practices are negotiated within the sociocultural setting of a school's makerspace, including tensions between a creative learning environment and established practices of formal schooling. The analysis will concentrate on students' and teachers' interactions in the FUSE Studio as well as on the sociocultural setting within which the interaction takes place. The following research questions are addressed:

1. Which actions take place when students create innovations in the FUSE Studio?
2. What are the collective innovation practices that emerge from these actions?

3. Study overview

3.1. Research context: The FUSE studio

This study uses video data collected at two Finnish primary schools in the capital region. At the time of data collection, the schools had introduced the FUSE Studio makerspace environment as an elective course for first to sixth grade students (7–12 years old). The FUSE Studio is based on a website[1] on which students have access to approximately 30 projects related to a range of STEAM topics. The projects range from constructing e-textiles, roller coasters and solar-powered cars, to using 3D modeling software to design jewelry or a home of the students' dreams. The students use both digital resources and hands-on materials provided in separate kits. The FUSE Studio website includes written instructions and video tutorials to each project. However, the students can take an active role in interpreting the project instructions, and they thus have opportunities and responsibilities to actualize their personal aspirations in the STEAM projects. The students choose the projects according to their individual interests and choose who to collaborate with. In the schools in which the research took place, the projects were not formally graded, but the students used photos, videos, and digital learning diaries to share their work and evaluate their participation and learning. Overall, the FUSE Studio model enables participants to work in a community of STEAM learners (Stevens et al., 2016). The students are encouraged to develop their expertise and share this expertise by leading and mentoring their peers. The teachers, then, are to act as facilitators of students' projects, guiding and supporting students in using traditional and novel technological tools, materials, and equipment in the projects.

3.2. Data overview

We collected ethnographic video data by filming the interaction between students (N = 124) and their teachers (*N* = 11) in the two FUSE Studio makerspaces from August 2016 to May 2017[2]. The whole data corpus consists of 152 h of video data. The students worked in five groups based on the grade level they attended at the time of data collection. Each group of 30–32 students worked in the FUSE Studio for 60 min once a week. We used four cameras to film the students' and teachers' activities. We decided on the focus of the cameras based on our desire to form a comprehensive understanding of the interaction and activities in the FUSE Studio makerspace. During data collection, we produced an Excel spreadsheet that identified the students, the teachers, and the FUSE Studio projects that the students chose to work on during each session. Not only did the spreadsheet guide the focus of the video cameras for the next session, it supported the selection of a data set for in-depth analysis. As we were specifically interested in the practices that were connected to the creation of innovations, we first chose the videos in which we could follow the work of students for an entire 60-min session. Hence, we excluded tapes in which the camera moved in the space following the teachers' activities. The videos we chose for our data set account for 19 h of video data. The analytical procedure is described in the following section.

1 www.fusestudio.net

2 Informed consent was obtained from all research participants and the students' legal guardians. All names used in this chapter are pseudonyms.

3.3. Analytical procedure

We imported the selected videos into the Atlas.ti program for a systematic analysis. The analytical approach follows methods of Video Data Analysis (VDA) as proposed by Nassauer and Legewie (2021). To answer our first research question, *which actions take place when students make innovations in the FUSE Studio?*, we first located episodes in which we could observe the students implementing novel and creative ideas in practice (West and Hannafin, 2011; Halbinger, 2018). These innovations included: (1) installing multiple capacitors to maximize the power stored by a solar-powered car, (2) combining paper and a lamp to create an effective charger for a solar-powered car, (3) using furniture and foam rubber to create a fast roller coaster for a small marble, (4) constructing a kinetic game controller for a Google game, and (5) constructing house models using spaghetti and marshmallows. We then employed principles of abductive analysis (Timmermans and Tavory, 2012) in examining the students' and teachers' interactions during the episodes. Following Nassauer and Legewie (2021), the coded interactions accounted for students' and teachers' verbal communication, use of materials and technologies, and movement in space (see also Jordan and Henderson, 1995). Our coding procedure can be viewed like the conduct of interactional ethnography, in which all actions taken by individuals were first interpreted and then given descriptive cover terms (Green and Bridges, 2018).

Following the just described microanalytical phase of analyzing actions *in situ*, we engaged in an analysis of "part-whole relationships" in the episodes we analyzed (Bridges et al., 2012; Green and Bridges, 2018). In specific, to address our second research question, *what are the collective innovation practices that emerge from these actions?*, we turned our focus to chains of interactions (see Green and Bridges, 2018). We picked up actions from the data that recurred across the episodes and were thus organized and ongoing in nature (see Schatzki, 2019 for our definition of innovation practices). We thematically grouped these recurring actions to comprise a typology of innovative practices in the makerspace environment, namely: taking joint action to innovate, navigating a network of resources, and sustaining innovation activities. Following Nassauer and Legewie (2021), we also coded the data for contextual features within which the recurring actions appeared. Such contextual coding enabled analyzing the interrelationships between the innovation practices and the sociocultural setting (Wertsch, 1994). These contextual codes included the actors present, the roles the actors took in the interactions, as well as tools, materials, and equipment used by the participants.

4. Results

During our analysis, we found the following innovation practices: *taking joint action to innovate, navigating a network of resources, and sustaining innovation practices*. These practices

FIGURE 1
A typical roller coaster construction in the FUSE Studio makerspace.

FIGURE 2
The innovative roller coaster constructed by four students in the FUSE Studio makerspace.

emerged from the teachers' and students' verbal and nonverbal actions that recurred across time in both makerspaces under study. Our results highlight how ideas of individual students, pairs, or small groups became collectively practiced innovations through these innovation practices. This was evidenced in how individual students or small groups first took joint action to innovate, then navigated a network of resources, typically gathering other peers and teachers to see and discuss their innovations, and finally collectively celebrated the process and outcomes of innovation creation. Next, we provide empirical examples that characterize the collective innovation practices and exemplify the recurring actions that constituted the innovation practices over time.

4.1. Taking joint action to innovate

Taking joint action to innovate represents practices that sparked the students' initial innovation creation. Although the innovations can be viewed as innovations of individual students, the innovation creation was reinforced by collective interactions supporting the students innovating. The actions constituting these practices included acknowledging a joint aim, whether connected to overcoming technical difficulties or pursuing students' personal aspirations, critically evaluating core concerns and actions needed to be taken, gathering materials, peers, and teachers around the project, as well as encouraging students to innovate. Next, we present two empirical examples that enlighten this innovation practice and the actions that constituted it.

4.1.1. Example 1: Materials inspire students to innovate with their design project

The following example depicts the actions four students, their peers, and their teacher took to support the students' actualizing their aspiration to construct an innovative foam rubber roller coaster using the furniture available in the FUSE Studio classroom. In this example, four students Aleksandra, Ella, Fiona, and Erik picked up a FUSE Studio project called *Coaster Boss.* The students started off the day's FUSE Studio session by viewing the project instructions and instructional videos on the FUSE Studio website. The instructional video guides the students to tape foam rubber pieces to the wall as shown in Figure 1. However, while viewing the instructions, Aleksandra suggested that they could tape the foam rubber pieces to a staircase located in the classroom. The other students enthusiastically agreed, and Fiona quickly went to the teacher to ask if they could build a roller coaster on the staircase. The teacher agreed. Aleksandra, Ella, and Erik abandoned their laptop with the project instructions and began to take materials, such as roam rubber, tape, and pillows to the staircase to construct their roller coaster as shown in Figure 2. Their work was thus clearly driven by the materials available to them in the space and their agentic actions. Importantly, the teacher's permission to deviate from the original project instructions supported the students' innovation creation. Taken together, the actions they took included verbal communication in acknowledging their joint aim, and their nonverbal communication in gathering materials in and outside the FUSE Studio *Coaster Boss* project kit to pursue their project. These were typical ways for students to take joint action to innovate.

Further, an important aspect of the innovation practice *taking joint action to innovate* was how other students and teachers encouraged students to do so. This is evidenced in the following example:

1. Aleksandra: "It rolled from there (the loop)!"
2. Ella: "Really!"
3. Aleksandra: "Yeah, let us show it. Everyone (to the whole class), look this way."
   The other students and the teacher enthusiastically gather around the roller coaster to see.
4. Aleksandra: "Let's start."
   The marble falls off the loop.
5. Ella: "It worked the previous time."

6. Aleksandra: "It just went straight from here *(the loop)* and down there (*to the end*)."
7. Teacher: "Ok, stop and think why it *(the marble)* fell off. What do you need to do so that it will stay on the coaster?"

The teacher walks off and the students continue to ideate and test other solutions and eventually come up with an innovative solution in which they tape two square pillows (as shown in Figure 2) to hold the loop up by strengthening its structure.

Overall, this example depicts how the available materials, including FUSE Studio project materials and other available materials can spark students' innovation creation. Importantly, Aleksandra's innovative suggestion was supported by her group members and by their teacher and thus enabled the groups' innovation creation. Further, when encountering a difficulty, the teacher's comment on line 7, encouraged the students to persist working on their roller coaster and promoted their innovation creation. In addition, we argue that the other students enthusiastically gathering around the project, signaled appreciation for the students' innovative activity and potentially empowered this group of students in taking joint action to innovate.

4.1.2. Example 2: Taking joint action to overcome a technical problem

This second example depicts a FUSE Studio session during which several students and a teacher gathered to discuss a technical problem that had occurred, and then collaborated to solve the issue. Their collaboration led to taking joint action and creating an innovative solution to the problem. The actions the students and the teacher took included critically evaluating the core concern and discussing actions to be taken to tackle the technical issue.

Six students, who appear in Figure 3, were simultaneously working on a project called *Solar Roller*. Milo (sitting on the far left in Figure 3), and Nikolas (second from the left in Figure 3), were working on their cars individually. Kiira and Sabina (the two girls in the middle in Figure 3) were working as a pair, as were Tomi and Mika (sitting on the floor on the right in Figure 3). In this project, the students were instructed to build a solar powered car using materials provided to them in a separate FUSE Studio project kit. The material kit included a car frame, solar panels of several sizes, a breadboard, wires, a capacitor, and a lamp. However, the schools ordered the FUSE Studio materials from the United States, and at the time of data collection the school did not have a transformer that would have enabled the use of the lamp in the project kit. Instead, they used a lamp found at the school. The students had repeatedly tried to charge their cars using the lamp, and despite their efforts, were not able to charge the car with enough power. The students then gathered to tackle this issue. They also called upon the teacher (standing on the right in Figure 3) to think with them.

FIGURE 3
Students and teacher gathered around the solar-powered cars.

Figure 3 depicts a typical way in which students working on individual projects gathered to collaborate when facing technical challenges. Thus, the students' and teacher's movement in the space enabled them to collectively engage in innovation creation. Here, the students and the teacher critically evaluated the core issue, which turned out to be the power of the lamp they used. Further, illuminating the actions students and teachers took to construct this innovation practice, they engaged in an active discussion around actions that had to be taken. In this case, their taking joint action led to two separate innovations: (1) creating an effective charger for the solar powered car, using the lamp and some white paper and (2) using multiple capacitors to build a more powerful solar powered car. As was the case in this empirical example, the interactions constituting *taking joint action* often led to *navigating a network of resources* during innovation creation, which we will discuss in the next section.

4.2. Navigating a network of resources

As mentioned, taking joint action to innovate often resulted in *navigating a network of resources*. The actions constituting this innovation practice were connected to the available materials in the makerspace and the students' and teachers' verbal communication. More specifically, the actions included creative explorations with the tools and materials that were available and using the expertise of teachers and other students to find alternative solutions to problems. For example, the students combined materials from several FUSE Studio material kits or used other digital tools and materials to invent creative solutions. The following empirical example illuminates the recurring actions of students and teachers, which formulated this innovation practice.

4.2.1. Example 3: Jointly navigating resources to improve a solar-powered car

In this example, four students, Milo, Kiira, Sabina, and Nikolas were all working on a project called *Solar Roller*. The content of this FUSE Studio project is described in the previous empirical example (*Example 2: Taking joint action to overcome a technical problem*). Milo and Nikolas were working on their projects individually and Kiira and Sabina were working as a pair. However, the students acknowledged an issue with the lamp they were using, and thus gathered to navigate the various resources within the environment to overcome the technical issue. The empirical example below illuminates typical actions that constituted this innovation practice. The actions included exploring the options to use the materials found in the project kit, other project kits, and other materials found in the space, as well as using their peers' and teacher's knowledge to invent a solution.

Milo, Kiira, Sabina, and Nikolas had repeatedly tried to charge their cars with the lamp that was available in the makerspace. They then decided to ask the teacher for help:

1. Milo: "Our car does not work, because the lamp is bad."
2. Teacher: "Lamp is bad. Yes."
3. Milo: "It *(the car)* cannot go through the tunnel without a better lamp."
4. Teacher: "Yes, well, I cannot come up with a solution just now so that we could get more kick. Let us see."
5. Milo: "The wires are all connected correctly."
6. Teacher: "Yes. Let us see."
7. Milo: "You have to wait really long for the wheels to even start turning."
8. Teacher: "Have you tried different panels? There might be differences between the panels too."
9. Teacher: "Hey! You know what we could try?"
10. Milo: "Yeah?"
11. Teacher: "White paper."
12. Milo: "How?"

Teacher goes and gets some paper from a printer.

13. Teacher: "We'll use these (paper sheets) as reflectors to increase the effectiveness of the lamp. We'll be able to heap up the light onto the panel."

Teacher holds the paper sheets; Milo picks up the car and the lamp.

14. Milo: "So now the panel gathers more energy and that charges the capacitor."
15. Teacher: "It might not be enough."
16. Milo: "I was thinking that you could put another capacitor here too, but there's not enough space."
17. Teacher: "Not enough space? Are you sure?" *(Takes the car, lifts up the solar panel to see).*
18. Teacher: "We can get another capacitor to fit here just fine. Is there a friend who would have another capacitor?"

Milo walks off to get a capacitor from the other students.

19. Teacher: "You try to connect it. You see, it could easily fit here."
20. Milo: "Oh yeah, we must connect this *(wire)* here then. But this should be between both capacitors, does not it?"
21. Teacher: "Mm-hm. But you can move this then, cannot you? The capacitors do not have to be so far away from each other."
22. Milo: "A-ha. Both just have to be connected to the same row. That makes this easier."

After a period of testing and trying, the students' succeeded in constructing a car with two capacitors and successfully charged it with the charger boosted with white paper.

This example highlights how the creation of two innovations—(1) creating an effective charger for the solar powered car, using the lamp and some white paper and (2) using multiple capacitors to build a more powerful solar powered car—was the result of a collective innovation practice, constructed in joint interactions between the students and the teacher. Moreover, the innovations appeared to result from joint attempts to think with and use the various materials available in the makerspace. On line 3, Milo asked for the teacher's help, as he was convinced that their core issue was the lamp, which was not powerful enough. Milo and the teacher's navigation and use of various resources included using the teacher's knowledge (lines 8, 11, 13, 18, and 21), the students' knowledge (lines 16, 17, 19, 20, and 22), and the creative use of various materials, including materials of the original FUSE Studio project kit (line 8), materials from other kits (lines 16 and 18) and other materials found in the space (line 11). The innovation creation and the associated innovation practice, *navigating a network of resources,* thus needed joint efforts from the student and the teacher. In our view, the teacher used a pedagogical approach that promoted this innovation creation. Specifically, the teacher's approach appeared as a pendulum in which the teacher brought his own scientific knowledge into the collaboration, yet simultaneously giving room for the students' skills and knowledge. The teacher also repeatedly used the pronoun "we," which underscored their joint engagement in navigating the makerspace's resources, contributing to collective innovation creation.

4.3. Sustaining innovation activities

The third type of innovation practice constructed in the interaction between students and teachers in the FUSE Studio, was *sustaining innovation activities.* The actions constituting this practice included participants' movement in the makerspace, such as the students and teachers gathering around the innovations and sharing the tangible materials to test and play with the created innovations. In addition, the actions included teachers' and students' verbal communication around celebrating the innovators' accomplishments, and ideating modifications to future use of the created innovations. Therefore, this innovation practice consisted of actions that were not only connected to the creation of innovations, but the actions contributed to a culture in which students are encouraged to be innovative and their innovations are valued. Moreover, we argue that this innovation practice can help sustain students' innovation activities in school. We demonstrate this in the following example.

4.3.1. Example 4: Collective imagining with a game controller

In the following example, a student, Lukas, had been working on a project called *Get In the Game*. In this project, the students were instructed to create a game controller and use it to play a game found on the FUSE Studio digital platform. With a teacher, Lukas had acknowledged a problem with the software that was supposed to be used in the project. The teacher then suggested that one option would be to use an open game created by Google. Lukas and the teacher connected the kinetic controller Lukas had built to Lukas's laptop:

1. Teacher: "Have you played this before?"
2. Lukas: "No."
3. Teacher: "When you are using Google Chrome and do not have an internet connection, it provides you with a game you can play with while you wait for your connection to come back on. Go on and switch those wires there."

Lukas adjusts the wires on his controller and starts playing the game.

4. Teacher *(to other students)*: "Hey, come and see what Lukas is doing over there."

Other students begin to gather around Lukas's laptop (see Figure 4).

1. Max: "Lukas, lol. That's so cool, omg."
2. Lukas: "Henri will try it now."

Lukas moves away from the laptop to let Henri play. The five students, Lukas, Max, Henri, Stiina, and Emma, switch players multiple times, cheering for each other.

3. Stiina: "Lukas, did you print out that hammer *(in the controller)* with the 3D printer?"
4. Emma: "Can you keep it *(the hammer)*? It would be so cool to keep it and use it at home."

Lukas does not respond, as the teacher interrupts to tell them that the class is about to end.

5. Lukas: "Can I play one more time?"
6. Teacher: "Of course, it's your game."
7. Lukas: "Can I still work on this to make improvements?"
8. Teacher: "You do not need to disassemble that *(the controller)*. This is our last session, but it's possible you could keep working on this in crafts or arts class, or some other class."
9. Lukas: "This would be better with copper tape."
10. Teacher: "Well, that's a great idea."
11. Lukas: "The wire needs replacing too."
12. Teacher: "Yeah, that sounds good."

FIGURE 4
Students gathered around the innovation.

The innovation in this example, the combination of Lukas's controller and the Google game, was initiated by the teacher on line 3. However, on line 4, the teacher asked other students to gather around to see what Lukas was doing. Thus, in addition to prompting the sharing of this innovation, the teacher specifically proclaimed the project as Lukas's, underlining Lukas's ownership over the project. Lukas's ownership over the project was also reinforced in the teacher's interaction on line 10. In addition, on lines 11–16 the teacher acknowledged Lukas's ideas to improve his game controller and suggested ways for Lukas to keep working on his project even after the FUSE Studio course ended. Such interaction allowed Lukas and the teacher to think about ways to continue working on Lukas' personal project in contexts outside the FUSE Studio classroom, therefore supporting the sustainment of innovation activities in the school more widely.

In addition, the students who gathered around the game were visibly excited about the innovation. Lines 2–4 depict how the students' movement around the innovation, including gathering around the innovation and switching players, encouraged Stiina and Emma to imagine ways to extend the use of Lukas's innovation outside the FUSE Studio classroom (lines 7 & 8). Based on the interactions in this example, we argue that peers gathering around the innovation promoted a climate that is fruitful for innovation practices. This is because the joint interactions underscored and celebrated innovative accomplishments. Further, such gathering around the innovation clearly promoted not only Lukas's ideas to modify his innovation, but also allowed his peers to ideate opportunities for making innovations in the makerspace. We argue that this type of interaction between the students can potentially help sustain innovation activities in the school by inspiring students to innovate.

5. Discussion and conclusion

With the aim being to develop theoretical explanations for how a makerspace learning environment can promote students' engagement with the creation of innovations, the present study was set to investigate innovation practices in a primary school's makerspace, the FUSE Studio. Overall, our study makes two key contributions: (1) it shows how innovation practices are connected to the use of innovation skills in a collective way and (2) it demonstrates two key mechanisms—that is, established processes that enable the emergence of the innovation practices—which promote the students learning to innovate. These mechanisms include the teachers' orientations to facilitating open-ended STEAM projects and practices that emphasize the students' ownership over their personal projects. We will now turn to a more elaborate discussion of our key contributions.

First, our results show that the actions that constituted the innovation practices resemble skills typically regarded as important for creating innovations. This was particularly highlighted in innovation practices through which students *took joint action to innovate* and *navigated a network of resources* to advance their innovation projects. These practices required the students to acknowledge problems, critically reflect on alternative perspectives, and network to find solutions (see Marin-Garcia et al., 2016; Vincent-Lancrin et al., 2019). Based on our findings we thus join in with other researchers who argue that there is much potential in makerspaces two answer current calls to promote students' participation in the creation of innovations. However, previous research has so far overlooked the way innovations are collectively practiced in interaction between teachers and students. For instance, previous research has underscored the importance of using manifold sources of information and combining various material elements during creative work (Pierroux et al., 2022). Our results add to this understanding by highlighting that such a use of manifold resources was a collective endeavor of teachers and students. Further, we argue that the participants' collective thinking with and extending the use of various materials was a key feature of innovation practices and promoted the students' engagement in the creation of innovations.

Second, our results show that the open-ended nature of the activities the students engaged in, gave room for the students' imagination and creative engagement in STEAM projects, and contributed to sparking the students' innovation projects. Thus, our findings echo previous research, which shows that makerspaces can allow the students to take leading roles over their learning activities (Sheridan et al., 2013; Leskinen et al., 2021, 2022). Further, such leadership over the projects promoted the students' ability to envision innovative ways to use materials in the makerspace and taking action to create innovative technical solutions in STEAM projects. However, transforming the students' creative ideas into innovations (see West and Hannafin, 2011) demanded collective efforts from the teachers and students. Considering this finding, we argue that the way the teachers' enacted their orientation to the making activity, i.e., how the teachers made sense of the makerspace environment and accordingly made choices in their interactions (Eteläpelto, 2017), mattered in this collective process. This is because even though previous research suggests makerspaces promote the use of dynamic expertise and peer tutoring (e.g., Farritor, 2017; Stevens et al., 2018; Gantert et al., 2022), it was evident in our third and fourth empirical example that when transforming creative ideas into innovations, the students mainly relied on the expertise of the teacher. This emphasizes how the well-established ways of being and interacting at school, and viewing the teacher as the knowledgeable expert, remained prominent in students' interactions (see also Leskinen et al., 2022). Yet, our third example, *jointly navigating resources to improve a solar-powered car*, showed how the teacher's interactions promoted the recognition and the use of the students' expertise, potentially contributing to the student learning to innovate in this interactional process. Previous research has shown that makerspaces have the potential to help teachers rethink their pedagogical practices (Becker and Jacobsen, 2020). Further, research suggests that teachers' agentic orientations to teaching have consequences for how they support the students' authority and personal aims or reinforce existing ways of interacting at school (Rajala and Kumpulainen, 2017). Although this was not the primary focus of our study, the way that the makerspace promoted the teacher's enactment of their agentic orientation, is one explanation to how the students' expertise came to be acknowledged and utilized in the empirical example presented in this study. Further, previous research findings indicate that a focus on the creative (and in this case, innovative) process rather than the outcome, is deemed fruitful for creative processes (Greene et al., 2019). In our data, it was evident that the way the teacher oriented to the activity allowed the teacher to let go of the boundaries set by the FUSE Studio project instructions, enabling him to facilitate the students' innovation process. In addition, our results stress the importance of positing all emerging ideas as equally valuable regardless of who (student or teacher) proposed them. This can advance a sense of shared authorship over the innovation (see also Pierroux et al., 2022), and promote the creation of innovations.

Researchers have argued that the innovative potential of makerspaces lies in the appreciation of students' personal projects (Kumpulainen et al., 2019; Hilppö and Stevens, 2021; Gantert et al., 2022). Yet, previous research has been limited in explaining how these personal projects actually lead to innovations. Our fourth empirical example about *sustaining innovation activities*, suggests that acknowledging students' accomplishments and emphasizing their ownership over their STEAM projects created a mechanism that promoted the students' innovation projects. Our example shows that this acknowledgement was first carried out by the teacher gathering other students around the students' innovation, and further promoted by stressing the authorship of the student over the innovation. In our view, this interactional process allowed other students to relate to the innovation creation by allowing them to imagine ways to modify the innovation and use it across contexts, beyond the school and the makerspace. In our view, appreciating students' personal projects and underlining the students' authorship over their learning endeavors can create on-ramps that help sustain innovation activities in school and potentially promote students learning to innovate. We call for more research to further our understanding of innovation practices and the implications these practices can have for innovation creation in primary school settings.

We also wish to highlight that there are many potential obstacles in implementing a makerspace environment into everyday formal schooling (see also Hilppö and Stevens, 2018). Our fourth empirical example shed some light on how makerspace activities can be positioned as part of the wider school context, which in turn, can increase students' interest and possibilities to work on their innovation projects. This was evidenced in how the teacher thought beyond the makerspace and ideated ways to further develop the students' innovation activity as part of other school activities, including arts and crafts classes. As the findings of our case study can only scratch the surface of the potential of makerspaces in promoting innovations, we suggest future research focuses on larger social practices of the school level and how these can support the sustainment of innovation practices and students learning to innovate.

We understand that there are limitations to this study, which require attention. First, the study was conducted in a specific type of a makerspace, the FUSE Studio, which might have consequences for the formation of innovation practices. In addition, we understand that contextual features such as school culture and the support teachers receive for their work can have significant implications for the innovation practices. Such features and their consequences for innovation practices and students' learning require further investigation. As our data covered a large corpus of video data from two separate makerspaces, it allowed us to discover innovation practices that emerged across the two makerspaces and across different grade levels. Yet, we did not specifically analyze innovation practices between students from different grade levels, and hence it would be important for future research to investigate the differences between different grade levels, and further our understanding of how to support the students' learning to innovate throughout primary school. Last, we wish to discuss methodological and ethical issues when conducting video studies with children. It is possible that individuals adapt their behavior based on their relationship with the person recording their work, and this poses a major challenge for video research (see Nassauer and Legewie, 2021). We argue that this is particularly important to note when video recording students in schools. The students in our study might have adapted their behavior according to their assumptions about the researchers' expectations. It is also important to note that the findings are based solely on our interpretations of our observations. It would be necessary to develop further video research methods that underline the students' own voice when observing their work in makerspaces.

Most of the research on the potential of makerspaces for innovation creation has been conducted in secondary and higher education contexts (see Rouse and Rouse, 2022), and to our knowledge, our study is one of the first to investigate innovation practices in a primary school setting. The findings of this sociocultural study contribute to the understanding of tensions and opportunities in innovation practices in a primary school makerspace. Thus, our research insights will be useful to researchers, practitioners, and policy makers investigating and developing similar educational contexts. We call for more research on students' innovation practices in different types of primary school makerspaces.

Data availability statement

The datasets presented in this article are not readily available because we do not have ethics approval to share the raw data from the current study as it consists of video data of children aged 7–12 years old. The study follows the ethical standards of scholarly research established by the Finnish Advisory Board on Research on Integrity (https://www.tenk.fi), Data Protection Act and the Convention on the Rights of the Child. Requests to access the datasets should be directed to kristiina.kumpulainen@helsinki.fi.

Ethics statement

The studies involving human participants were reviewed and approved by the Education Division of the City of Helsinki. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

JL took main responsibility for framing the research paper, analyzing and interpreting empirical data, and writing up the manuscript. AK and KK contributed to the argumentation logic of the manuscript and took part in editing the manuscript. KK was responsible for framing and formulating the larger research project in which this study was conducted. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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