Teachers’ Perceptions of the Maker Mindset and its Facilitation

Mariam Aljabaly, Pirita Seitamaa-Hakkarainen, and Kaiju Kangas

The maker mindset has been identified as one of the focal elements in maker education, and in formal education, teachers have a key role in nurturing it in their students. The maker mindset has been examined mainly theoretically and in relation to students. The present, empirical study explores teachers’ maker mindset and investigates how teachers perceive this concept and describe its facilitation when implementing maker activities. The concept is approached with four constructs identified in previous maker mindset literature: resilience/growth mindset, creativity, collaboration orientation, and willingness to tinker. Data were collected using an adapted maker mindset instrument administered to 58 pre- and in-service teachers and via semi-structured pair interviews with experienced teachers (N=10). Both data sets were analyzed with qualitative content analysis combining theory-driven and data-driven approaches. The results revealed that the teachers emphasized all four constructs of the maker mindset. They perceived the maker mindset as a complex and multidimensional concept and highlighted the constructs willingness to tinker and resilience/growth mindset. In terms of facilitation, the teachers underlined the constructs collaboration orientation and creativity. In addition to student collaboration, the teachers emphasized collaboration among teachers as a means for the successful implementation of maker-centered activities. The findings highlight the critical role of teachers’ own awareness of maker mindset constructs when promoting students’ maker mindset.

TECHNE SERIES

Techne Series 31(1), 2024

Pages:46–64

Correspondence:
mariam.aljabaly@helsinki.fi

https://doi.org/10.7577/TechneA.5582

Keywords: Maker mindset, maker education, K-12 formal education, in-service teachers, pre-service teachers

Introduction

Myriad stakeholders’ attention to K-12 education and teacher education is captured by maker education because it addresses the evolving demands for teaching 21st-century competences and pedagogical practices (Gutwill et al., 2015; Schad & Jones, 2020). By maker education, we refer to all kinds of maker-centered learning settings that utilize traditional or digital technologies, where the essence is to give students a way to create an object with their hands. Further, the educational sector has adopted the maker movement because it is considered a good incubating environment for raising students’ interest and engagement in STEAM (science, technology, engineering, arts, and mathematics) education (Martin, 2015; Jones et al., 2017).

While introducing the maker movement in education, Halverson and Sheridan (2014) have highlighted three vital elements in maker education: makers as identities that signify their active engagement, making as a collection of activities, and makerspaces that function as communities of practice. Maker identity has been described as the maker mindset (Dougherty, 2013); it is a can-do attitude that includes elements of creativity, resilience, curiosity, and playfulness (Cohen et al., 2018a; Honey & Kanter, 2013; Regalla, 2016). Making in maker education refers to a broad range of activities, such as creating, designing, building, tinkering, crafting, engineering, and programming (Kangas et al., 2022). The concept of making encompasses a comprehensive culture that praises specific essential principles of creative curiosity, problem-solving, determination, and confidence that students can construct a solution on their own (Chu et al., 2015). Makerspaces are locations for creative manufacturing, learning practical skills, and producing new artifacts (Sheridan, et al., 2014).

Nonetheless, in formal contexts, maker education includes a fourth fundamental element: the teacher. Maker education provides vast potential for the growth of creative citizens (Halverson et al., 2016), but these opportunities can only be fully realized with facilitation from competent and innovative teachers (O'Brien et al., 2016). Although the nature of maker education is student-centered, teachers' facilitation is needed to reach the full potential of maker education and cultivate learners' capacity to meet future challenges. According to Hjorth et al., (2016) design thinking and digital technologies have gradually increased the development of children's design literacy. The authors highlight that this shift requires a change in teachers' mindsets, capabilities, and approaches to design and technology as well as new teaching practices. Moreover, Kangas and Seitamaa-Hakkarainen (2018) have argued that some of the challenges that teachers face in such a context is the partly unpredictable nature of maker activities, sustaining students' motivation and engagement, and adjusting the maker-centered activity with the available space and material resources and time frame of schools. While highlighting the potential of maker activities for learning, Kafai (2018) reported that one of the pivotal challenges that educators faced is how to integrate maker activities in the K-12 system and suggested that recognizing the fundamental role of teachers in this process is the first step in acknowledging it.

In this article, we focus on maker activities in formal education, specifically, on K-12 teachers' perceptions of the maker mindset and its facilitation with their students while implementing maker activities. The maker mindset has been previously explored mainly in relation to students at different levels of education (Chu et al., 2015; Hsu et al., 2017; Jones, 2021; Kim & Zimmerman, 2017). However, few studies address how teachers perceive the concept and how they strive to develop it while implementing maker activities in their classrooms. According to Clapp et al. (2017), teachers have a key role in supporting the maker mindset in formal education, and understanding their perception of this concept is vital for successful integration of maker education (Dougherty, 2013). Furthermore, teachers' current understandings may support researchers and practitioners in addressing how to facilitate in- and pre-service teachers' own maker mindsets (Jones, 2021). In the present study, our aim was to investigate how teachers perceived the maker mindset concept and facilitated such a mindset while implementing maker projects with their students. We addressed the following research questions:

1) How do teachers perceive the maker mindset concept?

2) How do teachers describe their facilitation of the maker mindset to their students?

Characterizing the Maker Mindset

Mindset in learning has been previously investigated (e.g., Zhang, 2020), and the growth mindset has been vastly researched since its introduction by Dweck in 2006 (Rissanen et al., 2019; Yu et al., 2022). However, only during the last decade, has the term "maker mindset" begun to appear in the maker education literature. The maker mindset has been described as an inevitable feature of next-generation innovators (Culpepper & Gauntlett, 2020) or as a prerequisite for makers and shapers of the future (Korhonen et al., 2023a). The term was first introduced by Dougherty (2013), who described it as "can-do attitude that can be summarized as 'what can you do with what you know'" (p. 9). Later, he stated that a maker mindset includes all the intangibles that accompany the material and embodied experiences of making. Makers develop this mindset through the practice of making (Dougherty & Conrad, 2016).

The authors described makers as individuals that are self-directed learners with a can-do and do-it-yourself attitude, open, generous, persistent, playful, resourceful, active, and resilient; they have a developed sense of curiosity and are willing to learn, iterate, take risks, and share their work and expertise with others (Dougherty & Conrad, 2016). This concept has been defined with various constructs or features by several authors (Calabrese Barton & Tan, 2018; Chu et al., 2015; Martin, 2015; Peppler & Bender, 2013; Regalla, 2016). However, as noted by Jones (2021), no single accepted definition or comprehensive list of features has characterized the maker mindset. Consequently, few empirical studies have explored the concept, and of these, few have presented empirical findings from formal education.

Chu et al. (2015) investigated how the potential for a maker mindset may be seen in elementary-school-level students' attitudes and behaviors as they engage in maker workshops. They claimed that making has an outstanding influence on elementary education in terms of the establishment of a maker mindset and identity. The authors highlighted how making can promote the formation of a child's maker mindset, which has more impact than focusing only on STEM (science, technology, engineering, and mathematics) learning. According to Chu et al. (2015, p.18), "the maker mindset supports the formation of the children's identity as individuals who are able to make technological things themselves."

Furthermore, Calabrese Barton and Tan (2018) performed a longitudinal study of equity-oriented, STEM-rich making among youth and reported that in makerspaces, underrepresented youth's shared engagement was strengthened by critical, connected, and collective engagement. The authors also highlighted the iterative approach to problem-solving and creativity for the maker mindset.

Kim et al. (2018) conducted a national study on education makerspaces in the United States (30 different makerspaces in formal and informal settings). The authors examined two different curricular models and their effect on students' mindsets: The first model was a pre-designed curriculum that was favored in formal learning spaces, and the second model was an open curriculum that was applied in informal spaces. One of the main findings was a positive shift in the students' mindsets after experiencing maker activities, where the students were able to overcome challenges that they faced in regular classes because of the skills they had acquired in maker activities. While the pre-designed curriculum reduced anxiety and provided online community support for novice teachers, the open curriculum fostered personal interest and creativity.

In the present study, we follow the research of Cohen et al. (2018a; 2020), where the various attributes characterizing the maker mindset were identified through an extensive literature review and then compiled. We adopted the research by Cohen et al. since it was one of the few empirical studies of the maker mindset and, among those, the most comprehensive study. Their studies were aimed at examining the impact of maker-centered activities on learners by developing the Maker Mindset Instrument (MMI) as a formative assessment tool. The constructs to be included in MMI were chosen based on multiple elimination criteria, such as constructs that are not aligned with the aim of their study (e.g., interest), those that can be affected by multiple factors such as motivation and self-efficacy, and constructs that can be better examined with a performance metric such as problem-solving. Cohen et al. (2020) settled on five main constructs: resilience, growth mindset, creativity, willingness to tinker, and collaboration orientation. The authors also combined resilience and growth mindset into one umbrella construct since they theoretically overlap; thus, in total, four umbrella constructs were adopted for the current research. These four main constructs, their definitions, and related attributes are presented in Table 1.

Table 1.

Main constructs of the maker mindset, definitions, and related attributes.

Main construct	Definition	Related attributes
Resilience/ growth mindset	Characteristic or behavior that shows that a person has the flexibility and persistence to overcome challenges and the belief that they can accomplish a task "even if they have never experienced it before" Belief that one's basic qualities can be developed with their own efforts, strategies, and other's help (Dweck, 2006; 2017)	Resilience in the face of frustration (Martin, 2015; Regalla, 2016) Can-do attitude (Dougherty, 2012) Grit (Cohen et al, 2018a)
Creativity	In educational contexts, creativity can be seen "as a capacity to imagine, conceive, express, or make something that was not there before" (James et al., 2019, p. 3).	Generating something novel and relevant for a given task (Sawyer, 2012) Imaging possibilities (Cremin et al., 2006)
Willingness to tinker	Willingness to repeat specific actions accompanied by a sense of curiosity and the belief that one needs to do it him/herself to obtain the needed result	Sense of curiosity (Regalla, 2016) Playfulness (Dougherty & Conrad, 2016; Martin, 2015) Iterative approach to problem-solving (Dougherty, 2012) Do-it-yourself attitude or experimental orientation (Peppler & Bender, 2013)
Collaboration orientation	Willingness to share with others one's personal achievements/artifacts or expertise and collaborate to solve challenges by addressing them from multidisciplinary approaches	Disposition to share and collaborate (Dougherty, 2012; Martin, 2015; Regalla, 2016) Interdisciplinary approach to challenges (Regalla, 2016)

Teachers in Maker Education

The role of teachers' as "organizers" is irreplaceable in creating an interactive environment for students and in mentoring them to stimulate eagerness for exploration (Piaget, 1973). Nevertheless, teachers who are not familiar with maker education and the related teaching practices may struggle to execute them in their classes (Quinn & Bell, 2013). Hira et al. (2014) emphasized that teacher preparation is one of the challenges of implementing maker-centered learning activities. Especially the implementation of making in formal education has peculiar features compared to its implementation in informal education and the teachers need to find a balance between fulfilling the learning objectives and preserving the unique aspects embodied in the maker movement (Schlegel et al., 2019).

A study by O'Brien et al. (2016) was concerned about educating teachers in the maker movement; they stated that introducing the maker movement in K-12 will ensure that it will reach all children regardless of their gender, social level, or ethnic background since informal contexts (out-of-school) are generally limited to a specific type of people. The goal of a study by O'Brien et al. (2016) was to pinpoint the pedagogical practices that specify that pre-service and early career teachers need to implement effective maker activities in their classrooms and what kind of experiences enable teachers to promote these practices. The authors identified four pedagogical practices: preparation, structure, assessed learning, and parental influence; however, the last practice is connected to the Maker Fair that they have planned and implemented with their students.

While Smith et al. (2016) investigated the difficulties that teachers face in educational environments with digital fabrication and the obstacles that they encounter if they are involved in the design processes of digital fabrication. Challenges such as handling analogue and digital design materials, finding a balance among varied teaching modalities, and steering through a complicated design process. The authors added that these challenges are strongly related to the disconnection between a more structured school setting and open-ended and explorative maker education.

Jones et al. (2017) investigated pre-service teachers' beliefs in terms of utilizing maker activities in their classrooms. Participants reported that the tools and exercises in maker activities are consistent with their instructional strategies emphasized in their teacher training programs and expressed interest in carrying out those activities in the future. However, participants also reported obstacles such as availability of resources and unwilling workmates and administrators. Furthermore, Cohen et al. (2018b) investigated the preconceptions and misconceptions of pre-service and early career teachers in terms of making in education. The aim was to assist the teachers in realizing the nature of the maker mindset and to familiarize them with the features of different maker tools (Cohen et al., 2018b). The study highlighted two misconceptions that the participants had: first, maker activities are related only to achieving specific content-based objectives, and second, maker activities are strictly connected to certain digital tools. Consequently, these misconceptions would negatively affect teachers' willingness to implement maker activities in their future lessons (Cohen et al. 2018b).

Hughes et al. (2022) investigated the personal and contextual aspects that possibly support the development of maker educators over a three-year period. The authors reported four characteristics that were crucial for the growth of the maker educators: maker identities, meaningful interdisciplinary learning, institutional maker culture, and a diverse partnership. Hughes et al. (2022, p. 6) discussed how "maker identities scaffold the transition into maker educators," where the participants echoed some of the maker mindset concepts, such as inquiry-based learning, problem-solving, persistence, and the willingness to share both process and product. Further, the authors recognized that their maker identities were part of a useful foundation for becoming maker educators.

Rodriguez et al. (2018) piloted a micro-credential program for pre-service teachers that was meant to assist the teachers in acquiring the tools and skills needed to become maker educators. According to Rodriguez et al. (2018, p. 4), developing the maker mindset includes "courage to take risks with new technologies and the willingness to show vulnerability as they learn alongside others." In addition, Jones (2021) also investigated the teacher's perception of a professional development experience in a maker education context. The multiple case study explored two groups of in-service teachers using interviews and personal reflections. After experiencing maker-centered activities, the participants reported that they developed more confidence in implementing maker-centered activities as well as their own maker mindset. The researchers disclosed two concepts that need to be considered when preparing educators for the implementation of maker-centered activities: the teacher's maker mindset and operational elements.

The present study was conducted in Finland, where maker education has been implemented in both formal learning contexts and informal learning contexts (Sormunen et al., 2023). In the Finnish context, maker activities are easily adopted because crafts is a mandatory subject in the Finnish National Core Curriculum for Basic Education (FNAE, 2016; Porko-Hudd et al., 2018) and craft teachers are required to have a master's degree. Furthermore, the infrastructure of Finnish schools enables teachers to implement maker activities and integrate different subjects (Seitamaa-Hakkarainen & Hakkarainen, 2017). Making activities are enabled and influenced by multi-faceted technological (tools) and social (community) resources that enable students to participate in creative designing and making. Carefully designed makerspaces have proven to support participants' engagement and innovation (Sheridan et al., 2014); in Finnish schools, learning environments should offer "possibilities for creative solutions and the exploration of phenomena from different perspectives" (FNAE, 2016, p. 53).

Method

Context and Participants of the Study

The context of the present study was a maker and technology education program for continuous learning organized by two Finnish universities. The program targeted pre- and in-service teachers at primary, lower-secondary, and upper-secondary levels of education and was aimed at enhancing their capabilities to implement maker education in schools and to raise their students' interest in technologies. The program lasted one academic year and consisted of three optional five-credit courses. In the courses, the participants were introduced to Maker education and various age-appropriate technological tools and were guided in the design and implementation of maker projects in the participants' own schools. Pre- and in-service teachers were encouraged to collaborate to combine expertise from the field with up-to-date academic knowledge.

The study was conducted in the academic years of 2020–2021 and 2021–2022, when altogether 101 in- and pre-service teachers participated in the program. Of these, 58 voluntary participants were involved in the present study (in-service teachers: N=47, 81%; pre-service teachers: N=11, 19%). Both class teachers and subject teachers were involved, and the subject teachers were selected from various specializations, such as crafts, mathematics, or history. Each participant provided written consent for research, and no compensation was given. The participants' experience of teaching in general varied from no experience to more than 20 years of experience. However, most of the teachers reported having less experience in maker education than teaching in general; even teachers with more than 20 years of teaching experience reported five years or less experience in maker education. Nevertheless, because the present study was conducted in Finland, where the school subject of crafts has been mandatory since the 19th century, many of the participants were familiar with maker-centered activities, at least to some extent. Therefore, the findings of the present study cannot be generalized to contexts in which making is not included in regular school activities.

Data Collection

The present, qualitative study relies on two data sets: questionnaire data and interview data. To answer Research Question 1 (RQ1)—How do teachers perceive the maker mindset concept?—a Teacher Maker Mindset Questionnaire (TMMQ) was developed by combining and adapting different instruments used in previous research (Cohen et al., 2018a; Kuusisto et al., 2017). Following Cohen et al. (2018a), the TMMQ included vignettes corresponding to the maker mindset constructs: resilience/growth mindset, creativity, willingness to tinker, and collaboration orientation. The vignettes described small maker education scenes, each followed by a statement and response options on a six-point Likert scale (1 = completely disagree – 6 = completely agree). A justification for the response was prompted with an open-ended question. The vignettes and statements preceding them are presented in Table 2. In addition, the TMMQ included 20 stand-alone statements, five for each construct. Technically, the TMMQ was implemented via Google Forms. For the analysis of the present study, we selected only the responses of the open-ended questions, because we aimed to conduct an in-depth analysis of the teachers' perceptions of the maker mindset concept. All 58 participants anonymously responded to the TMMQ; their responses are subsequently referred to with pseudonyms Q1–Q58.

Table 2.

TMMQ vignettes and statements

Construct	Vignette and statement
Resilience/growth mindset	*Samuel learns about a programming language used to create webpages. He wants to create a website. After writing the first section of the program, he tests it. It is not correctly working. He looks for errors in the code. After a while, he still has not found any errors. He decides to recode*. How much do you agree or disagree with the following statement? **Based on this first experience, Samuel will always struggle with programming.** Please briefly explain your choice.
Creativity	*Susanna is building a prototype for her engineering class. The teacher has provided building materials. Susanna cannot find a support that is exactly the length that she needs. Instead of cutting the materials to make them fit, she notices that one of her pens is the right length and would functionally be the same, so she uses that instead. Because it is a prototype, it does not need to be a high-quality material.* How much do you agree or disagree with the following statement? **Susanna should have only used materials provided by the teacher**. Please briefly explain your choice.
Willingness to tinker	*Akio needs to make a presentation for the science fair. He was going to make part of it with popsicle sticks, but no one can take him to the store to get some. He decided to find a new material to make that part of the presentation.* How much do you agree or disagree with the following statement? **Akio will likely be able to find a new material that will work without having to go to the store.** Please briefly explain your choice.
Collaboration orientation	*Sanna and her classmates are building race cars for a schoolwide race out of crafting materials and hardware, such as cardboard, buttons, and nails. Each of the students has her own strengths and weaknesses. For example, Suki is good at designing the car but not building it.* How much do you agree or disagree with the following statement? **Sanna's class should work in groups to build cars, even though her class would have fewer submissions. Grouping up means that they are more likely to win because they will have higher-quality cars.** Please briefly explain your choice.

To answer Research Question 2 (RQ2)—How do teachers describe the facilitation of the maker mindset to their students?—five semi-structured pair interviews of in-service teachers (N=10) were conducted. The teachers participated in the same maker and technology education program and can be described as experienced teachers because most of them had 11 or more years of teaching experience. Two teachers had less experience, but they implemented the project with an experienced colleague. The interviews were conducted in spring 2021 after the teacher pairs had planned and implemented their maker projects for their students as an assignment in a course (see Table 3). The teacher pairs were asked to broadly describe the implementation of their maker projects, the facilitation they provided for the students, and the evaluation of the entire project. The interview structure (see Appendix 1) was based on the Learning by Collaborative Designing model (Seitamaa-Hakkarainen et al., 2010) and was utilized for both the current research and another study that focused on pedagogical infrastructures. The duration of the interviews varied between 38 and 65 minutes; altogether, they resulted in 282 minutes (approximately four and a half hours) of interview data. To maintain the anonymity of the teachers, they were given pseudonyms from I1 to I10. During the data analysis, it became evident that the data highlighted not only the teachers' facilitation of the maker mindset but also their perception of the concept. Hence, the data were utilized to answer both research questions.

Table 3.

Interviewed teacher pairs, their implemented maker projects, grade, and age of the students.

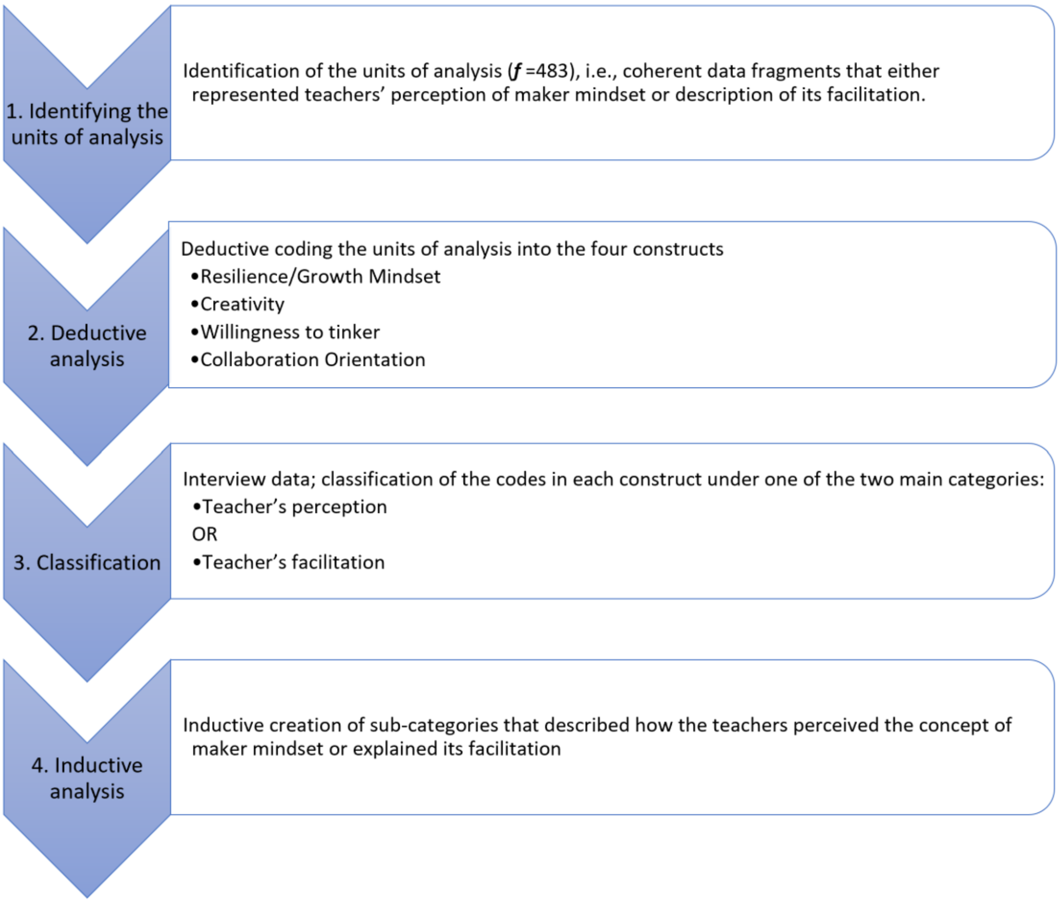
Teacher pair	Maker project theme	Grade / age of students
I1– I2	Vinyl cutting workshop, designing and cutting stickers for different purposes	Grade 5 / 11–12 years
I3– I4	Designing and making containers for food delivery	Grades 3, 5–6 / 8–13 years
I5– I6	Creating the route for a space team to reach a specific planet (deciding which path to go, which planet to visit, and what tasks need to be performed on each planet)	Grade 5 / 11–12 years
I7– I8	Creating and prototyping inventions, which use technology	Grade 7 / 13–14 years
I9– I10	Designing and making board games (textile, wood, and 3D printing are needed)	Grade 5 / 11–12 years

Data Analysis

Both data sets were analyzed with qualitative content analysis (Krippendroff, 2004) and with the help of Atlas.ti 22 software. The analysis included several stages, as presented in Figure 1.

Figure 1

Different stages of data analysis



In the first stage, the units of analysis, i.e., coherent data fragments that either represented teachers' perceptions of the maker mindset or description of its facilitation, were identified in both data sets. A total of 483 data fragments were qualitatively categorized. For the second stage, each unit of analysis was deductively coded in terms of the four maker mindset constructs: resilience/growth mindset, creativity, willingness to tinker, and collaboration orientation. The categories were not mutually exclusive, and each unit could belong to one, two, or three categories. For the third stage, the units were classified into two main categories in accordance with the research questions: either *perception* or *facilitation* of the maker mindset. This stage was applied to the interview data alone, since the questionnaire data provided only information about teachers' perceptions and not their facilitation. The fourth stage of the analysis involved the inductive creation of subcategories that described how the teachers perceived the maker mindset concept and how they described its facilitation. Although they were data-driven, some subcategories, such as s*park*, *sustain*, and *deepen*, were inspired by theory derived from the facilitation framework of the teacher (Gutwill et al., 2015).

Findings

Teachers' Perceptions of the Maker Mindset Concept

The aim of the present study was to investigate how teachers perceived the maker mindset concept and how they facilitated such a mindset while implementing maker projects with their students. Table 4 summarizes how the teachers perceived the maker mindset concept.

In Table 4, the teachers' perceptions of each of the constructs is reported from the TMMQ and the interview data. This table also shows the subcategories of each construct from the most emphasized to the least emphasized. Notably, only the four most emphasized subcategories are reported. Hence, the total frequency of the subcategories in the right column is different from the total frequency of the construct in the left column.

Table 4

Teachers' perceptions of the maker mindset constructs.

Maker mindset construct	Teachers' perceptions of the construct	*f*
Willingness to tinker (*f* = 152, 35%)	Making	38
	Do-it-yourself	38
	Positive attitude toward students' artifacts	18
	Positive attitude toward iteration	11
Resilience/growth mindset (*f* = 120, 28%)	Learning by doing	18
	Adaptability	14
	Reflection and adjustments	13
	Believing that one can improve	11
Collaboration orientation (*f* = 82, 19%)	Combining students' strengths	14
	Strength in Teamwork	14
	Learning from peers	10
	Sharing & discussing projects	10
Creativity (*f* = 79, 18%)	Positive attitude toward creativity	13
	Positive attitude toward students' enthusiasm	12
	Innovation	11
	Finding solutions	11

According to the study by Cohen et al. (2018a), **willingness to tinker** included curiosity, playfulness, iterative actions, and a do-it-yourself attitude. In this research, willingness to tinker means the belief that people need to do it themselves to obtain the desired results and are willing to repeat specific actions accompanied by a sense of curiosity. The teachers mentioned the willingness to create something with one's own hands and the willingness to spend more time than needed to create what they want. The teachers mostly described this construct as *making*; for example, I3 stated "If you have an idea, don't hide it but take it and make something of it." They also understood the willingness to tinker as having *do-it-yourself* attitude; for example, Q1 stated "He knows what he needs and how to find an alternative solution." The teachers also expressed a *positive attitude toward students' artifacts*, such as when I6 stated, "It was really nice how they started building their narratives around who they had met in space or ended up in battle with. Their travel journals started having a life of their own." In addition, the teachers emphasized a *positive attitude toward iteration*, "If you don't succeed at first, it is only natural to start the process again from the beginning." (Q14)

As previously explained, the second construct combined two overlapping yet distinct notions: a **resilience/growth mindset** that subsumed resilience in the face of frustration, a can-do attitude, and grit (Cohen et al., 2018a) and a growth mindset (Dweck, 2006). In this research, teachers mostly expressed different concepts related to this construct, such as *learning by doing*; "You can learn by doing things you could not have done before. Open-minded solutions can surprise experts" (Q32). A*daptability* was also highlighted, such as "if something is not working, you have to try something else" (Q41). Moreover, *reflection and adjustments* were also emphasized, such as when I5 stated "I have completed a few similar projects, and there are always individual assignments I would change, where the brief wasn't successful and the pupils didn't end up doing what I expected them to do." In addition, *believing that one can improve* was repeated by different teachers, such as "everyone has to start somewhere, and then improvement can begin" (Q45).

The **collaboration orientation** construct included the disposition to share and collaborate with an interdisciplinary approach to challenges (Cohen et al., 2018a). Here, the teachers perceived collaboration as a good opportunity to *combine students' strengths,* for example, when a teacher stated, "in teamwork, the strengths of individuals become greater together" (Q38). Additionally, there was *strength in teamwork is,* which was supported by a many teachers, for example a teacher stated, "There is strength in unity/cooperation" (Q45). Many of the teachers mentioned how collaboration helps students *learn from peers,* for example "students could learn a lot from each other while engaging in teamwork and learn other skills, such as social skills" (Q20). Moreover, the teachers were encouraging students to *share and discuss projects*; for example, I6 said:

> During this discussion, I got an idea that the teams could choose something to share with the others or talk about from their log or tell everyone what stuck in their minds or what they liked in particular. Since we had 11 assignments and 11 teams, each team could present one assignment to the others as a form of revision, and this could help them think of something they hadn't thought of before.

Creativity, in educational contexts, can be seen as generating something novel and relevant for a given task (Sawyer, 2012) and as imaging possibilities that were not there before (Cremin et al., 2006; James et al., 2019). For the creativity construct, the teachers showed a *positive attitude toward creativity*, for example "it is always good to use creativity and inventiveness" (Q33). They also demonstrated a *positive attitude toward students' enthusiasm*, such as "So I was positively surprised by how excited the pupils were about the project and how they really got into it and let each other work in peace" (I4). The *innovation* concept was repeatedly mentioned, such as "The students' own invention and exploration is the most important thing, that is when spontaneous ideas are worth their weight in gold." (Q34). The teachers' emphasis on how students *find solution*s was equal to the *innovation* concept, such as when Q24 stated, "Creativity and their own solutions can sometimes work better than the original plan and means."

Teachers' Descriptions of the Facilitation of Students' Maker Mindsets

To answer how teachers describe the fostering of a maker mindset in their students, we utilized only interview data. The results are summarized in Table 5, where the teachers' facilitation of each of the constructs is presented from the most emphasized construct to the least emphasized construct, with corresponding subcategories. The teachers emphasized mostly collaboration orientation and creativity, and the other two constructs were given considerably much less attention. In Table 5, only the four most emphasized subcategories are reported, with the exception of the willingness to tinker construct. For this construct, only three subcategories are presented, because the frequency of the fourth subcategory was less than 5.

Table 5

Teachers' descriptions of the facilitation of students' maker mindsets

Maker mindset construct	Teachers' facilitation of the construct	*f*
Collaboration orientation (*f* = 90 ~ 40%)	Consider combination of students	25
	Collaboration among teachers	22
	Support collaboration among students	16
	Assign students for help	9
Creativity (*f* = 76 ~ 34%)	Freedom of choice and independence	30
	Spark	29
	Support innovation	10
	Deepen	7
Willingness to tinker (*f* = 30 ~ 13.5%)	Frame ideas	9
	Interdisciplinary approach	9
	Willingness to iterate	5
Resilience/growth mindset (*f* = 28 ~ 12.5%)	Sustain	8
	Reflect & fine-tune	6
	Assign time for feedback	6
	Document learning	5

Collaboration orientation was mostly highlighted when the teachers mentioned how they are taking into account *the combination of students* when they design maker activities. The teachers combined the students based on three dimensions: the skill's level of students, students' ability, and students' personalities. For example, I8 stated, "We decided on the pairings, and each partner would be stronger in some aspects," while I9 said,

> We asked for help from their class teacher because we knew that it was a large part of the group work, so we asked that the teacher divide the groups for us. The teacher would maybe know the students' social skills better. We wanted those groups that would work the best.

The interview data also revealed that teachers emphasized collaboration in various forms. First, *collaboration between teachers* was evident in how they were enjoying the collaboration process, and how they would like to repeat it. For example, when asked about how their collaboration was going, in the teacher pair I1 and I2, I1 replied, "Really good; I am looking forward to this autumn because we will also be collaborating on a larger project for these three courses, and I am looking forward to our continued cooperation on that." I2 continued,

> I feel the same way, and I feel even more optimistic about the future than about the project we completed. The project was a positive experience, but I feel like we have obtained good ideas about what to work on next during our studies.

Second, supporting *collaboration among students* was indicated. For example, I9 said,

> Of course, I think we both tried to help in the collaboration. Hey, think about that, and what do you think about this one. I think I always tell them of course you need to compromise because everyone has their own. I think we helped somehow between those. We wanted those groups to be the best that they could be.

Moreover, teachers *assigned students for help* as one of the strategies to promote collaboration, such as when I1 stated,

> We had one pupil who took on a large role in getting the vinyl cutter to work, and that pupil was very helpful to the other pupils. Thus, we appointed that pupil pupil-in-charge and promised the pupil a reward for it later in the spring. The pupil was basically working for us and took a larger role and was able to engage the other pupils in the process.

To facilitate students' **creativity**, the teachers emphasized how they tried to *spark* ideas, i.e., to trigger ideas within their students. For example, teacher I6 explained,

> We watched one of the Star Wars movies on a Friday, and the next Monday, we told the pupils that we would be beginning a space game. That Monday, I talked about it and read the original story, and then we started forming teams.

In another interview, two teachers, I7 and I8, complemented each other's answers when I7 said, "We had to use examples to support them so they could get started." Then I8 said, "Or they share an idea, and we ask them some questions to get them thinking about what might be missing and if something could be done differently. Asking questions can also help obtain more information from the pupils." The teachers also emphasized giving the *freedom of choice and independence* for the students as one of the strategies, such as choosing the materials or choosing what they want to create. For example, I4 elaborated,

> We focused on broadening the pupils' points of view by not setting limits. We wanted to open a discussion that would get the pupils thinking about how getting warm food delivered to someone's front door might require many different elements, and we didn't want the brief to put limits on this.

Moreover, *supporting innovation* was evident in the teachers' interviews, for example, when I8 said, "I also encouraged them not to restrict themselves, to innovate freely, and to allow themselves to come up with new and better ideas". The teachers also aimed to *deepen* their students' processes by helping them further develop their ideas, such as when I5 stated,

> Then, if they seemed to need help, we would ask them questions that were more specific, such as how did you plan on illustrating this part of the Earth's crust. The guidance was very individual and based on the pupil's skill level.

The **willingness to tinker** construct included the teachers' strategies or actions that supported students' tinkering in one way or another. For example, the teachers explained how they tried to *frame ideas* by setting some constraints on students' work. Although the students were given much freedom in many aspects of their projects, some boundaries were still needed because of, for example, students' skills or time constraints. I9 explained,

> I try to lead them in another direction. I have to say I did it because I knew the time, the resources and the student. We also wanted them to finish it because of course we assess it. I don't think that it is fair to just say, okay, you can do whatever, because of course, we push it in some direction.

The teachers also discussed the *interdisciplinary approach,* such as when I4 stated, "But as a class teacher, I think that just as in technology education, everything is connected. The boundaries between different subjects can be very vague, and that's how it should be."

Willingness to iterate was evident in the teacher's description of their actions, e.g., when I2 stated,

> Then, we had to keep trying to make the cutter work. For some reason, we were able to make the first successful picture very early. After that first successful picture during the second class, it took about two months for us to figure out the process out and get more pictures done.

To support the **resilience/growth mindset,** the teachers tried to *sustain* students' interest in the projects when they were struggling or were stuck at a certain stage. For example, I7 and I8 explained,

> I7: We tried to approach the subject from a different angle. Some pupils would become stuck and decide that they didn't want to do it anymore, so we had to try to help them move forward by giving them simple goals of what needed to be done next.
>
> I8: Yeah, to be able to finish.
>
> I7: To move forward instead of just grumbling about it and to make it slightly easier.

Among the strategies the teachers applied was *reflect & fine-tune*, that is, when they reflected on what happened during the project and on things that they might do differently in future activities. For example, I6 said,

> But we can fine-tune the assignments, make some of them harder and some of them easier, and have a whole host of assignments tailored to the needs of different pupils. That's something I will pay attention to next semester.

A*ssigning time for feedback* was also evident as another strategy for facilitating the projects. For example,

> We have this feedback time when they had done like the first ideas or kind of ideas. They presented them to other groups, to all of them. The other students gave direct feedback, so is it like a good idea and what the students have to think about some more. (I10)

Another strategy was to encourage to *document learning* by the students or to do the documenting themselves. When I1 and I2 were asked if they documented the information gathered during the project, they replied,

> I2: Yes, we kept a journal and took (unclear word)
> I1: No, just during the first period.
> I2: We also took pictures and put them in different places. We took them for ourselves and posted them, I think, on the school blog and
> I1: On Instagram
> I2: Yeah, so we documented the results, and at first, we recorded each step.

Discussion and Conclusions

The present study was aimed at investigating how teachers perceive the maker mindset concept and how they strive to develop it while implementing maker activities in their classrooms. The concept was approached with four constructs, which all were emphasized by the teachers who participated in the study. The results indicate that the teachers *perceived* the maker mindset as a complex and multidimensional concept and highlighted especially the constructs willingness to tinker and resilience/growth mindset. While describing the *facilitation* of their maker projects, the teachers underlined collaboration among students and collaboration among teachers and emphasized support for students' creativity.

All teachers had positive attitudes toward making activities. They shared the view presented in the maker mindset literature (Chu et al., 2015; Dougherty & Conrad, 2016)—that a maker mindset develops through the practice of making. However, to harness students' willingness to tinker for learning purposes, the teachers highlighted careful steering of the process and support for students' iterative efforts. Maker-centered activities are based on nonlinear and creative processes and require knowledge and solutions that cannot be determined beforehand but that interactively emerge through repeated personal and collaborative efforts (Hakkarainen & Seitamaa-Hakkarainen, 2023). Such activities can develop students' resilience and growth mindset if the project allows some risk-taking and failure in a safe environment, where teachers' support is fine-tuned to students' needs. The teachers in the present study appeared to show a positive attitude toward creativity and the awareness needed to spark students' creativity and offer them some freedom of choice. Creativity is a multi-dimensional phenomenon that involves questioning, problem-solving, imagining possibilities, divergent thinking, making meanings, and experimentation, and refining of solutions (Sawyer, 2017). Furthermore, previous research on the maker mindset emphasizes student collaboration (Dougherty, 2012; Martin, 2015; Regalla, 2016); however, the teachers in the present study considered teacher collaboration almost equally important. Teachers' responses during the interviews clearly showed a strong sense of collaboration and that their relation was positive in a way that enabled them to complement each other's ideas. They considered how to combine interdisciplinary approaches to create a project and wondered how to nurture creativity within the students during the project (Korhonen et al., 2023). In recent years, maker-centered activities in Finnish schools have started to involve team teaching, and research (Aarnio et al., 2021; Härkki et al., 2023a) shows that teachers are likely to be willing to collaborate with other teachers for successful implementation of maker activities. Teachers benefit from mutual support while they learn to orchestrate the nonlinear, open-ended processes of maker-centered learning.

Increased focus on maker activities in education means that it is of interest to investigate how the maker mindset can be supported. To better understand this concept and highlight an under-investigated area, we approached the maker mindset with the four constructs identified in the literature. This approach helped us systematically concretize the concept. However, applying pre-defined constructs might have framed our analysis in a way that disregards other possibly significant attributes. Moreover, teachers' perceptions can be impacted by multiple social, economic, and cultural factors. The present study was conducted in Finland, where all teachers are familiar with maker-centered activities through the mandatory school subject of crafts (FNAE, 2016, Härkki et al., 2023b; Porko-Hudd et al., 2018). Although not all teachers in Finland teach crafts, they work in schools where making is part of the curriculum, visible in the learning environment, and supported by specialized craft teachers. The participants of the present study included teachers of various subjects, but they all were familiar with the nature of making activities and they appeared to have good understanding of the maker mindset concept. Hence, the results of the present study are limited to this sample of participants and cannot be generalized. Further, as our analysis relied on questionnaire and interview data, it provides limited information about actual classroom practices.

In conclusion, the teachers who participated in the present study emphasized all four constructs of the maker mindset. Further, they showed awareness of supporting collaboration orientation, creativity, willingness to tinker, and the resilience/growth mindset in their students. According to the participants the four constructs and their facilitation can take myriad forms in students' and teachers' activities. The findings indicate that teachers acknowledge the role of the maker mindset in implementing maker-centered activities and that this type of mindset can be nurtured in formal education. However, more empirical research is needed to investigate how teachers' perceptions of the maker mindset is transformed into teaching practices in authentic classroom conditions. In addition, further research could provide insights from settings where making is not an integral part of formal education as in Finland. As the first empirical study on the maker mindset in relation to teachers, the present study can establish a foundation for future avenues of research.

Acknowledgements

This study was funded by the Research Council of Norway under grant #324758. The authors thank all the pre- and in-service teachers who participated in the study for their irreplaceable and precious input.

References

Aarnio, H. E., Clavert, M., Kangas, K., & Toom, A. (2021). Teachers' perceptions of social support in the co-planning of multidisciplinary technology education. *Design and Technology Education: An International Journal*, 26(3), 8–29. https://openjournals.ljmu.ac.uk/DATE/article/view/1361

Calabrese Barton, A., & Tan, E. (2018). A Longitudinal Study of Equity-Oriented STEM-Rich Making Among Youth From Historically Marginalized Communities. *American Educational Research Journal*, *55*(4), 761–800. https://doi.org/10.3102/0002831218758668

Chu, S. L., Quek, F., Bhangaonkar, S., Ging, A. B., & Sridharamurthy, K. (2015). Making the Maker: A Means-to-an-Ends approach to nurturing the Maker mindset in elementary-aged children. *International Journal of Child-Computer Interaction*, *5*, 11–19. https://doi.org/10.1016/j.ijcci.2015.08.002

Clapp, E. P., Ross, J., Ryan, J. O., & Tishman, S. (2016). *Maker-centered learning: Empowering young people to shape their worlds*. Jossey-Bass.

Cohen, J. D., Margulieux, L., Renken, M., Jones, W. M., & Smith, S. (2018a). Measuring Maker Mindset: Establishing Content Validity with Card Sorting. *ICLS 2018 proceedings*. 1505–1506. https://repository.isls.org/bitstream/1/703/1/365.pdf

Cohen, J. D., Jones, W. M., & Smith, S. (2018b). Preservice and Early Career Teachers' Preconceptions and Misconceptions About Making in Education. *Journal of Digital Learning in Teacher Education*, *34*(1), 31–42. https://doi.org/10.1080/21532974.2017.1387832

Cohen, J. D., Margulieux, L., Renken, M., & Monty Jones, W. (2020). Conclusions from the validation of a vignette-based instrument to measure maker mindsets. *ICLS 2020 proceedings*,1649–1652. https://repository.isls.org/bitstream/1/6389/1/1649-1652.pdf

Cremin, T., Burnard, P., & Craft, A. (2006). Pedagogy and possibility thinking in the early years. *Thinking Skills and Creativity*, 1, 108-119. https://doi.org/10.1016/j.tsc.2006.07.001

Culpepper, M. K., & Gauntlett, D. (2020). Making and learning together: Where the makerspace mindset meets platforms for creativity. *Global Studies of Childhood*, *10*(3), 264–274. https://doi.org/10.1177/2043610620941868

Dougherty, D. (2012). The maker movement. *Innovations: Technology, governance, globalization*, 7(3), 11-14. https://doi.org/10.1162/INOV_a_00135

Dougherty, D. (2013). The Maker mindset. In *Design, Make, Play: Growing the next generation of STEM inventors* (pp. 7–11). Routledge.

Dougherty, D. & Conrad, A. (2016). *Free to make: How the maker movement is changing our schools, our jobs, and our minds*. North Atlantic Books.

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.

Dweck, C. (2017). *Mindset-updated edition: Changing the way you think to fulfil your potential*. Hachette UK.

Finnish National Agency of Education [FNAE] (2016). *National core curriculum for basic education.* Publications 2016:5. Finnish National Agency of Education.

Gutwill, J. P., Hido, N., & Sindorf, L. (2015). Research to Practice: Observing Learning in Tinkering Activities. *Curator: The Museum Journal*, *58*(2), 151–168. https://doi.org/10.1111/cura.12105

Hakkarainen, K., & Seitamaa-Hakkarainen, P. (2023). Learning by inventing: Theoretical foundations. Invention pedagogy. In T. Korhonen, K. Kangas & L. Salo (Eds.), *Invention Pedagogy-The Finnish Approach to Maker Education* (pp.15-27). Routledge. https://doi.org/10.4324/9781003287360-3

Halverson, E. R., & Sheridan, K. M. (2014). The Maker Movement in Education. Harvard Educational Review, 84(4), 495-504. https://doi.org/10.17763/haer.84.4.34j1g68140382063

Halverson, E., Kafai, Y. B., & Peppler, K. A. (2016). *Makeology : Makers as learners (Volume 2)*. Routledge.

Hira, A., Joslyn, C. H., & Hynes, M. M. (2014). Classroom makerspaces: Identifying the opportunities and challenges. *Proceedings of IEEE Frontiers in Education Conference (FIE) 2014* (pp. 1-5). IEEE. https://doi.org/10.1109/FIE.2014.7044263

Hjorth, M., Smith, R. C., Loi, D., Iversen, O. S., & Christensen, K. S. (2016). Educating the reflective educator: Design processes and digital fabrication for the classroom. *ACM International Conference Proceeding Series*, 26–33. https://doi.org/10.1145/3003397.3003401

Hsu, Y. C., Baldwin, S., & Ching, Y. H. (2017). Learning through Making and Maker Education. *TechTrends*, *61*(6), 589–594. https://doi.org/10.1007/s11528-017-0172-6

Hughes, J., Robb, J. A., Hagerman, M. S., Laffier, J., & Cotnam-Kappel, M. (2022). What makes a maker teacher? Examining key characteristics of two maker educators. *International Journal of Educational Research Open*, *3*. https://doi.org/10.1016/j.ijedro.2021.100118

Härkki, T., Korhonen, T., & Karme, S. (2023a). Team Teaching in Invention Projects. In T. Korhonen, K. Kangas & L. Salo (Eds.), *Invention Pedagogy-The Finnish Approach to Maker Education* (pp.148-161). Routledge. https://doi.org/10.4324/9781003287360-13

Härkki, T., Seitamaa-Hakkarainen, P., Vartiainen, H., Saarinen, A., & Hakkarainen, K. (2023b). Non-linear maker pedagogy in Finnish craft education. Techne Series - Research in Sloyd Education and Craft Science A, 30(1), 1–17. https://doi.org/10.7577/TechneA.4998

James, S.J., Houston, A., Newton, L., Daniels, S., Morgan, N., Coho, W., Ruck, A. and Lucas, B. (2019). *Durham commission on creativity and education*, Arts Council UK.

Jones, W. M., Smith, S., & Cohen, J. (2017). Preservice Teachers' Beliefs About Using Maker Activities in Formal K-12 Educational Settings: A Multi-Institutional Study. *Journal of Research on Technology in Education*, *49*(3–4), 134–148. https://doi.org/10.1080/15391523.2017.1318097

Jones, W. M. (2021). Teachers' perceptions of a maker-centered professional development experience: a multiple case study. *International Journal of Technology and Design Education*, *31*(4), 697–721. https://doi.org/10.1007/s10798-020-09581-2

Kafai, Y. B. (2018). Building a home for the maker movement. *Journal of Digital Learning in Teacher Education*, *34*(1), 4–5. https://doi.org/10.1080/21532974.2017.1398970

Kangas, K., & Seitamaa-Hakkarainen, P. (2018). Collaborative design work in technology education. *Handbook of technology education*. https://doi.org/10.1007/978-3-319-38889-2_44-1

Kangas, K., Sormunen, K., & Korhonen, T. (2022). Creative learning with technologies in young students' STEAM education. In S. Papadakis & M. Kalogiannakis (Eds.), *STEM, Robotics, Mobile Apps in Early Childhood and Primary Education* (pp. 157–179). Springer. https://doi.org/10.1007/978-981-19-0568-1_9

Kim, S. H., & Zimmerman, H. T. (2017). Towards a stronger conceptualization of the maker mindset: A case study of an afterschool program with squishy circuits. *ACM International Conference Proceeding Series*, *Part F132090*. https://doi.org/10.1145/3141798.3141815

Kim, Y. E., Edouard, K., Alderfer, K., & Smith, B. K. (2018). *Making culture: A national study of education makerspaces*. Philadelphia, PA: Drexel University.

Korhonen, T., Kangas, K., & Salo, L. (2023). Roots and Key Elements of Invention Pedagogy. In T. Korhonen, K. Kangas & L. Salo (Eds.), *Invention Pedagogy-The Finnish Approach to Maker Education* (pp.1-13). Routledge. https://doi.org/10.4324/9781003287360-1

Krippendroff, K. (2004). *Content Analysis: An Introduction to Its Methodology (2nd ed.)*. California: Sage Publications.

Kuusisto, E., Laine, S., & Tirri, K. (2017). How do school children and adolescents perceive the nature of talent development? A case study from Finland. Education Research International, 2017 [4162957]. https://doi.org/10.1155/2017/4162957

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research*, *5*(1), 30–39. https://doi.org/10.7771/2157-9288.1099

O'Brien, S., Hansen, A. K., & Harlow, D. B. (2016). Educating Teachers for the Maker Movement: Pre-service Teachers' Experiences Facilitating Maker Activities. *The 6th Annual Conference on Creativity and Fabrication in Education*, 99–102. https://doi.org/10.1145/3003397.3003414

Peppler, K., & Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan*, *95*(3), 22–27. https://doi.org/10.1177/003172171309500306

Piaget, J. (1973). *To understand is to invent: The future of education* (G. Roberts, Trans). The Viking Press. (Original work published 1948, 1972)

Porko-Hudd, M., Pöllänen, S., & Lindfors, E. (2018). Common and holistic crafts education in Finland. *Techne Series - Research in Sloyd Education and Craft Science A*, *25*(3), 26–38. Retrieved from https://journals.oslomet.no/index.php/techneA/article/view/3025

Quinn, H., & Bell, P. (2013). How designing, making, and playing relate to the learning goals of K-12 science education. In M. Honey, & D. Kanter (Eds.), *Design make play: Growing the next generation of STEM innovators* (pp. 17–33). New York, NY: Routledge.

Regalla, L. (2016). Developing a maker mindset. In E. Halverson, Y. B. Kafai &K. A. Peppler *Makeology: Maker Spaces as Learning Environments (volume 1),* (pp. 257–272). Routledge.

Rissanen, I., Kuusisto, E., Tuominen, M., & Tirri, K. (2019). In search of a growth mindset pedagogy: A case study of one teacher's classroom practices in a Finnish elementary school. *Teaching and Teacher Education*, *77*, 204–213. https://doi.org/10.1016/j.tate.2018.10.002

Rodriguez, S. R., Harron, J. R., & DeGraff, M. W. (2018). UTeach Maker: A Micro-Credentialing Program for Preservice Teachers. *Journal of Digital Learning in Teacher Education*, *34*(1), 6–17. https://doi.org/10.1080/21532974.2017.1387830

Sawyer, K. (2012). *Explaining creativity. The science of human innovation*. Oxford University Press.

Sawyer, K (2017) Teaching creativity in art and design studio classes: A systematic literature review. *Educational Research Review* 22, 99-113. https://linkinghub.elsevier.com/retrieve/pii/S1747938X17300271

Schad, M., & Jones, W. M. (2020). The maker movement and education: A systematic review of the literature. *Journal of Research on Technology in Education*, *52*(1), 65–78. https://doi.org/10.1080/15391523.2019.1688739

Schlegel, R. J., Chu, S. L., Chen, K., Deuermeyer, E., Christy, A. G., & Quek, F. (2019). Making in the classroom: Longitudinal evidence of increases in self-efficacy and STEM possible selves over time. *Computers and Education*, *142*. https://doi.org/10.1016/j.compedu.2019.103637

Seitamaa-Hakkarainen, P., Viilo, M., & Hakkarainen, K. (2010). Learning by collaborative designing: Technology-enhanced knowledge practices. *International Journal of Technology and Design Education*, *20*, 109–136.

Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2017) Learning by making. In K. Peppler (Eds.), *The SAGE encyclopedia of out-of-school learning* (pp. 421–424). SAGE. https://dx.doi.org/10.4135/9781483385198

Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. Harvard Educational Review, 84(4), 505-531. https://doi.org/10.17763/haer.84.4.brr34733723j648u

Smith, R. C., Iversen, O. S., & Veerasawmy, R. (2016). Impediments to Digital Fabrication in Education: A Study of Teachers' Role in Digital Fabrication. *International Journal of Digital Literacy and Digital Competence (IJDLDC), 7*(1), 33-49. http://doi.org/10.4018/IJDLDC.2016010103

Sormunen, K., Kangas, K., Korhonen, T., & Seitamaa-Hakkarainen, P. (2023). Designing and Structuring the Invention process. In T. Korhonen, K. Kangas & L. Salo (Eds.), *Invention Pedagogy-The Finnish Approach to Maker Education* (pp.117–131). Routledge. https://doi.org/10.4324/9781003287360-11

Yu, J., Kreijkes, P., & Salmela-Aro, K. (2022). Students' growth mindset: Relation to teacher beliefs, teaching practices, and school climate. *Learning and Instruction*, 80, 101616. https://doi.org/10.1016/j.learninstruc.2022.101616

Zhang, J. (2020). *Mindset in learning: a cross cultural study in China and Finland*. [Doctoral Dissertation, University of Helsinki]. https://helda.helsinki.fi/server/api/core/bitstreams/92ac1dd8-878d-4e1a-affb-b9203adfc742/content

Mariam Aljabaly (MA Ed.) is a PhD researcher at the Doctoral programme of school, education, society and culture at the Faculty of Educational Sciences, University of Helsinki. Her research interest focus on the collaborative teaching and collaborative learning in technology-enhanced learning environments.

Pirita Seitamaa-Hakkarainen (PhD) is a professor of Craft Science at the University of Helsinki, Faculty of Educational Sciences. Her research interests focus on design processes, as well as the facilitation of collaborative design through technology-enhanced learning.

Kaiju Kangas (PhD) is an associate professor of Technology Education at the University of Helsinki, Faculty of Educational Sciences. Her research focuses on the learning of design and technology in basic education and teacher education, as well as on the mediated and embodied nature of learning.

Appendix 1: The pair interview framework

- **How many years have you worked as a teacher?** (*Ask everyone.*)
- **You have now implemented a technology education project together, how are your feelings about the project?**
- **Briefly review the idea of your project. Tell in your own words:**
    - What was the project about?
    - What were the objectives of the project?
        - Were there any technology-related goals in the project?
    - Did the students work in groups or individually?

      Note: if the students were working individually, ask the teachers to think about the class in general. If the students were working in teams, then ask teachers to describe the teams.

- **Next, let's go through how the implementation of your project progressed step by step.**

Creating design context

- How did you introduce the project theme to the students?
- Did you organize any orienting activities, e.g. workshops of new tools?

Defining design task and design constraints

- What kind of (design) task did you give to the students?
- Did you set any constraints for the project? E.g., constraints related to materials or tools.

Creating conceptual and visual design ideas

- How did the students create ideas?
    - individually, in pairs, in groups, whole class?
    - sketching, drawing, discussing, writing, making models etc.?
    - Did you use any specific ideation methods? What? Why?
    - Did you use any other forms of support?
- How much time did you use for ideation?

Evaluating design ideas and constraints

- How did the students know if it was a good idea or not?
- Did anyone else participate in the evaluation in addition to students? Who? How?

Connection to expert culture and data collection

- How and from where the students searched for information needed in the project?
    - Who provided the information sources?
    - Did the students use external resources (e.g., information from the Internet or expertise beyond the project/school/group?
- Was the information gathered during the project documented? How?

Experimenting and testing design ideas & Evaluating function of Prototype

- When the students had chosen their final idea(s), did they experiment and test it? How? Why?
    - Did they try out various technologies, materials, structures, functionalities, etc.?
    - Did they build models or prototypes?
- If the students ran into problems while experimenting, how did you support them?
- Were the students eager to start experimenting and testing? What happened? Why?

Elaboration of design ideas and re-design

- During the project, did the students elaborate their ideas / change or develop the idea? How? How many times? Why?
    - Were the students eager to elaborate? Why / why not?
- How did you support their idea elaboration?

Distributed expertise

- How did you support the students' collaboration?
    - within and between teams?
    - exchange of information or expertise?
- How did you as teachers share your expertise during the project?

- **When thinking about the project as a whole:**

    - Was your plan implemented as you had thought?
        - How well did you achieve the goals you set for the project?
        - Were there any unexpected situations?
    - Best and worst parts/moments?
        - What made it good/special?
        - What did you do when the challenges came up?
    - If you would do the project again, would you change something?