Chapter 9
Creative Learning with Technologies in Young Students' STEAM Education

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Abstract The STEAM approach combining science, technology, engineering, arts, and mathematics is a promising method for promoting students' creative technological competencies, but it has received little research interest in the field of early education. This chapter explores this approach in pre-school and grades 1 and 2 of primary school (ages 6–8), and examines how creative use of technologies is related to various learning areas in young students' learning projects. We present 13 interdisciplinary projects in which invention pedagogy, a Finnish approach to STEAM education, was implemented. Invention pedagogy emphasizes the learning of twenty-first century competencies through multidisciplinary, creative, technology-enhanced design and creative processes. Three data sets (i.e., teachers' project plans, descriptions and reflections) and visual representations of the projects, were analyzed with qualitative content analysis and co-occurrence network analysis. The findings indicate that young students are able use various technological activities representing five technological dimensions: crafting, design, engineering, documenting and sharing, and programming. The underlying connections between the activities and implemented learning areas revealed three orientations to STEAM education: the maker orientation, competence orientation, and digital orientation. These orientations represent varying emphases of young students' STEAM education and suggest new directions for further developing the approach.

Keywords STEAM education · Creative technology · Pre-primary education · Primary education · Invention pedagogy

9.1 Introduction

For the past several years, educational research in many countries has highlighted the interdisciplinary nature of knowledge and learning of twenty-first century competencies. Creativity and digital competence in particular have been brought to the

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forefront as requisite attributes of competent future citizens. It has been argued that we need to educate, from early years on, citizens of the future who can understand, reflect critically, and influence creatively the technologically changing world (e.g., Organisation for Economic Co-operation and Development (OECD), 2019). Technology has quickly become a part of young children's lives, and technological change already reflects strongly in children's ways of playing, the most natural way to be and live and perceive the world, and thus, construct knowledge. Therefore, it is only natural that technology is present in contemporary children's play as a tool or theme (Slutsky & DeShelter, 2017). Thus, technology education has been emphasized as necessary in early years education (Fleer, 2011; Marsh, 2015; Sundqvist & Nilsson, 2018).

Young students' technology education aims to help children understand everyday technologies and how these can be used to solve daily life problems and invent one's creative solutions (Fox-Turnbull, 2019). In Finland, pedagogical activities in technology education emphasize child-centered ways of working, use of imagination, and constructive play (Finnish National Board of Education (FNBE), 2016b; Turja et al., 2009). Children are encouraged to observe and marvel at the surrounding technology and technological implementations and ask related questions. Their interest towards technology is evoked in practical, hands-on ways. Young students' technology education emphasizes human activity, inquiry-based and experimental activities, and innovative solutions (Kilbrink et al., 2014). The focus of educating twenty-first century citizens is not to teach them how to use technological devices and consume content, but learn to apply and create new value with technology. Early technology education is wide-ranging and practical education that is intertwined with design, engineering, and scientific practices, as well as interdisciplinary approaches (Quinn & Bell, 2013). It includes creative problem solving and designing, inquiring, experimenting with structures and materials, hands-on making, as well as reflection on the process and outcomes. Educators should support children to find their technological problems and encourage them to examine and make various constructions or solutions to these problems using versatile materials and tools (FNBE, 2016a, 2016b; Turja et al., 2009).

There is a highly similar emphasis in the integrative STEAM approach (science, technology, engineering, arts, and mathematics), which is regarded as promising for enhancing students' creative technological competencies starting from the early stages of education (Lindeman et al., 2014). In STEAM, the 'A' refers to arts, design, and the humanities, changing the focus from technology education as applied science towards more multidisciplinary and creative problem solving (Jones et al., 2013). The STEAM approach is often understood as adding the artistic or creative process and perhaps design thinking as part of STEM education (Bequette & Bequette, 2012). However, the full potential of STEAM cannot be justified in terms of what the "A" can do for mathematics or science, but rather in terms of what it directly delivers (Hetland et al., 2013). Art and other creative approaches to education have a learning heuristic where experience-based practices are used for problem-solving, learning, investigating, and discovery. The practices include, for example, envisioning mentally what cannot be directly observed or imagining possible next steps, expressing ideas or personal meanings, exploring playfully without a pre-structured plan, and embracing mistakes as learning opportunities (Daugherty, 2013).

However, the STEAM approach among young students has gained only little interest in research, and the empirical evidence of its application is particularly limited. In the present chapter, our aim is to understand how teachers apply integrative, technology-enhanced STEAM projects in pre-primary education and grades 1 and 2 of primary school (age 6–8). In the following section, we first briefly explore technology education and its objectives in early childhood education and introduce the Finnish perspective to young students' STEAM education. Then, we ground the present chapter in the longstanding research and development of invention pedagogy, a Finnish approach to STEAM education, for teaching and learning twenty-first century competencies through multidisciplinary, creative technology-enhanced design and making processes in formal educational settings. We present 13 invention projects where invention pedagogy was implemented in pre-primary education and grades 1 and 2 of primary school, and examine the creative use of technologies in relation to the learning areas implemented in the projects. We pose the following research questions:

1. What kind of creative technological activities were implemented in pre-and primary school invention projects?
2. How were the creative technological activities related to the learning areas pursued in the projects?

9.2 Technology Education in Early Childhood

The ability to use technology interactively is one of the key competencies that students need to learn for a successful life in a well-functioning modern society (OECD, 2019). Technology plays an increasingly important role, for example, in transmitting information, in communication, and in routine work, which should be considered in all aspects of teaching. In the field of STEM education, the use of digital technology has been studied quite extensively (e.g., Li et al., 2020). In recent years, research interest towards harnessing physical tools for promoting creativity and inquiry in conventional STEM education for young learners has risen. According to Fox-Turnbull (2019), teachers recognize the importance of creativity within technological practices in young students' technology education. Creativity, imagination and playfulness are essentials when working with new tools and materials. Furthermore, they improve practical and physical skills for using digital technologies as well as art and craft tools, and foster meaning-making when manipulating materials and creating artefacts (OECD, 2019).

Interesting experiments have been conducted and promising results found in this relatively new field of research. The findings indicate that participating in iterative design processes and using a wide variety of technologies has been beneficial for young students' learning. For example, Kalmpourtzis (2019) found that designing games can foster intrinsic motivation and positively impact young students' cognitive development, particularly their thinking skills related to mathematics, such as skills and strategies for problem-solving and problem-posing. Papadakis et al. (2016) have similar notions from preschoolers' animation and game making with ScratchJr. Their findings indicate that teaching programming concepts to young children positively influences the development of basic cognitive skills associated with mathematical ability and logical thinking. The results of a study by Kewalramani et al. (2020) reveal that technology constructed play experiences with robotic toys and littleBits electronic and magnetic blocks supported young students' scientific inquiry, design thinking, and creativity as well as scientific vocabulary. Furthermore, Hatzigianni et al. (2021) found that during a 3D design process, various STEAM activities invoked young students' creative and critical thinking as well as problem-solving and decision-making skills. In a related study, they interviewed children who participated in the 3D designing project and found that children could describe challenging and rewarding aspects of their design, identify solutions, offer alternatives, and brainstorm new ideas (Hatzigianni et al., 2020).

However, the aforementioned studies as well as others demonstrate that recent research of young students' technology education has a strong emphasis on digital technologies. In early learning settings, analog and more traditional technologies still play an essential role, and they can be equally important for developing children's technological competence and other twenty-first century skills. The focal question is not the superiority of some technologies over others, but how can we best support children to develop their own creative ideas through technological means. A broad approach to technology education provides children the opportunity to understand the all-pervasive and daily apparent nature of technology. In the following, we describe the multidisciplinary and multimaterial context of technology education in Finland.

9.3 Finnish Perspective on Young Students' STEAM Education

In Finland, early childhood education (ages 0–5), pre-primary education (age 6) and basic education (i.e., primary and lower secondary education, ages 7–16) each have their own national curricula; however, they are thematically linked to support children's and adolescents' continuous learning. Technology education is not an individual subject but rather a multidisciplinary and cross-curricular learning entity at all levels of education. This is underlined in the curricula in several contexts, from the basic values to the general competence objectives, and to many individual subjects. Traditionally, and still today, it is strongly connected to craft education, a mandatory school subject for all students in grades 1–7. Craft as a school subject provides the means for creative ideation and experimentation with technologies, for developing students' understandings of the technological world (FNBE, 2016a). In the latest basic education curriculum reform in 2014, textile craft and technical craft were combined as one, multimaterial craft in which "activities are based on craft expression, design, and technology" (FNBE, 2016a, p. 146; see also Kokko et al., 2020). The early childhood and pre-primary curricula were organized into five interdisciplinary core entities (FNAE, 2018; FNBE, 2016b). Technology education is particularly present in the entities *Exploring and interacting with my environment*, which emphasizes STEM subjects and related skills and practices, and *Diverse forms of expression*, which includes music, visual arts, crafts, and physical and verbal expression. In pre-primary and basic education, the concept of holistic craft is emphasized (i.e., a student or group is responsible of the whole craft process from ideation and design to making and evaluation) (see Pöllänen, 2009). During the one-year pre-primary school, children undergo at least one holistic and long-term craft process under teacher's supervision (FNBE, 2016b). From time to time, the question of technology education as a stand-alone school subject is raised. Proponents argue that technological literacy is one of the core skills needed today and in the future, and thus it should be taught on its own. However, as reflected in the national curricula, a future-oriented approach to technology requires a broader, multidisciplinary perspective and strong connections to twenty-first century competencies (cf. Kokko et al., 2020).

In addition to technology education, the multidisciplinary premise is visible all over the Finnish curricula, from early childhood to basic education. The core entities provide a rich thematic arena for early childhood educators to build creative STEAM projects with students. In the first years of primary school, more subject-oriented learning starts to take place; however, strong connections between various subjects are still emphasized. For example, environmental studies is an integrated subject combining the fields of biology, geography, physics, chemistry, and health education, with viewpoints from both natural and human sciences (FNBE, 2016a). The subject emphasizes learning tasks connected to everyday life, use of scientific and engineering practices and technology, and engagement through scientific questions and problem-solving activities (Lavonen et al., 2021). In addition, at the primary and secondary level interdisciplinarity is encouraged by an obligation to organize multidisciplinary learning modules at least once during each school year. Multidisciplinary learning modules promote achieving the set educational objectives when schools and teachers define the goals and contents of the modules by integrating various subjects and twenty-first century competences.

The contents of each curriculum are framed by the concept of transversal competence, the Finnish interpretation of twenty-first century skills (Binkley et al., 2012). The concept refers to "an entity of knowledge, skills, values, attitudes, and will" (FNBE, 2016a, p.36) needed in modern society and in the future. Depending on the level of education, the concept is organized around six or seven themes: (1) thinking and learning to learn, (2) cultural competence, interaction and self-expression, (3) taking care of oneself and managing daily life, (4) multiliteracy, (5) ICT competence, (6) working life competence and entrepreneurship, and (7) participation, involvement and building a sustainable future (FNBE, 2016a). In early childhood and pre-primary curricula, the theme (6) working life competence and entrepreneurship is omitted, and the other themes are described in a slightly modified manner more suitable for younger students. In early education, the transversal competence themes are approached in child-centered and integrative ways, often combining children's interests with the objectives of the curriculum. The aim is to support children's personal growth, lifelong learning, working life, and civic activity in the twenty-first century (cf. Kumpulainen & Sefton-Green, 2019).

The future-oriented curriculum, combined with an integrative STEAM approach, provides a fruitful basis for implementing transversal and multidisciplinary technology training. The essence of STEAM, and young students' technology education, is in creative actions and perceiving children as active constructors of their environment. Enabling children to use technologies in creative ways at an early stage of education is a crucial part of developing the competences needed in the society and working life of the future (Papavlasopoulou et al., 2017). Learning by creating, making, and constructing various structures and solutions from a variety of materials facilitates children's evolving understanding of technology as an outcome of creative human activity (FNBE, 2016a, 2016b). Documenting and verbalizing the solutions they have made also provides children with a basis for critical reflection on technological solutions in general. Moreover, comprehensive and creative technology education provides children with a wide variety of opportunities to be inspired and interested in the possibilities of technology.

9.4 Methodology

9.4.1 The Context and Participants: Implementing STEAM Through Inventing

To implement STEAM-oriented multidisciplinary learning and the curriculum, our research group, together with teachers, has developed invention pedagogy at various educational levels for several years (e.g., Riikonen et al., 2020a). Invention pedagogy combines evidence-based teaching and learning strategies for knowledge-creation (Paavola & Hakkarainen, 2014), collaborative designing (Seitamaa-Hakkarainen et al., 2010), creative problem-solving in science and technology education (Lavonen et al., 2004), and support for learning (Sormunen et al., 2020). Through the invention process, students learn to deal with challenging scientific, technological, and design problems and collaboratively develop creative solutions using various digital and traditional technologies. Every student is an inventor, a maker, who is encouraged to share his or her knowledge when constructing a shared artefact (Riikonen et al., 2020b). The invention process follows a loose structure with seven phases: (1) Orientation to the theme and team working, (2) defining the invention challenge, (3) ideation, information gathering, and idea evaluation, (4) testing and elaborating the ideas, (5) evaluating the design, (6) elaborating the design, prototyping, and constructing the invention, and (7) presenting and evaluating the final invention. However, the process is non-linear and iterative in nature; the phases are not a prescription of rigidly specified stages and can vary from one project to another. In this regard, invention projects are multidisciplinary projects combining craft, design, and technology education, STEM-education, art education and many other learning areas.

Over the years, the teachers and researchers have together organized dozens of STEAM-oriented invention projects in schools. All teachers have participated in 2–4 workshops organized by our research group, focusing on the creative invention process and suitable technologies. Here, we employ a collective case study approach (Goddard, 2010) and focus on 13 projects conducted in pre-primary schools, or grades 1 and 2 in primary schools. Some projects also included a few younger or older children, but most participants were 6–8 years old. The main goal of collective case study is to explore cross-case comparisons and draw generalizations from the entire group of cases to deeply understand the phenomenon from a variety of perspectives; the cases may or may not locate in one site (Goddard, 2010). The projects, the participating children, and the duration of the projects are presented in Table 9.1. The projects varied in nature; some were shorter projects focusing on creating individual inventions (e.g., Moving toys) while others lasted several weeks and included varying joint activities of the whole group (e.g., Garden plot). In most of the projects, several teachers and classes from the school participated (e.g., Everyday inventions), but some were organized by one teacher in one class (e.g., Two worlds). This was the first time all of the teachers had used invention pedagogy.

9.4.2 Data and Analysis

The projects were conducted during the years 2017–2020, and therefore during several research projects various data types were collected. For the present study, we selected three data sets available from each project, including (1) teachers' project plans, (2) teachers' descriptions and reflections, and (3) visual representations of the projects. The descriptions and reflections were written either by the teachers with the help of some structure and guidelines from the researchers, or by researchers who conducted teacher interviews. The visual representations included, depending on the project, photos of students' finished products and work in progress or videos where students explained their inventions.

Our aim was to analyze how the creative technological activities implemented in the projects were related to the projects' learning areas. We employed a qualitative content analysis (Stake, 2005) in which theory guided the analysis that was complemented with categories emerging from the data. The analysis was conducted in three stages. We first searched for keywords or visual indicators of technological tools and activities used in the projects. These were categorized under five main categories: (1) crafting, (2) design, (3) engineering, (4) documenting and sharing, and (5) programming. The categories have been developed in our previous work (Korhonen et al., 2020) for outlining five technological dimensions present in the invention projects; however, we slightly modified them to suit young students' projects better.

Table 9.1 Pre-and primary school invention projects, their participants and duration

Project title	Description of activities and tools	Participants			Duration
		N	Grade	Age	
Creative cards	Small groups created task cards for unused objects found in the school with art and craft supplies, tablets, and laptops	50	Pre-school, 1, 2	6–9	2 weeks
Dream school	Small groups created dream school elements in miniature size with art and craft supplies, electronics, and 3D pens	20	1	7–8	7 weeks
Dream space	Small groups designed dream spaces for the pre-school with art and craft supplies, electronics, and vinyl cutter	34	Pre-school	6–7	6 weeks
Everyday inventions	Small groups created everyday inventions with art and craft supplies, recycled materials, smart phones and tablets	110	2, 4	8–11	4 weeks
Future city	Small groups created elements for a common miniature city with art and craft supplies, electronics, smart phones, and tablets	70	2, 3	8–10	6 weeks
Garden plot	The group explored growing and taking care of plants with recycled materials, art and craft supplies and Micro:bits	20	Early years education, pre-school	2–6	16 weeks
Gingerbreads and group skills	Small groups 3D designed and printed gingerbread molds and baked gingerbread	45	1	7–8	3 weeks

(continued)

Table 9.1 (continued)

Project title	Description of activities and tools	Participants			Duration
		N	Grade	Age	
Moving toy	Students created moving toys with art and craft supplies and recycled materials	40	1	7–8	3 weeks
My neighborhood	Students created elements for a common stop motion animation about their neighborhood in 2050 with art and craft supplies, electronics and robotics	80	Pre-school	6–7	3 weeks
New pre-school	Small groups created miniature rooms, tools and garden elements for a new pre-school with art and craft supplies, electronics, 3D pens and robotics	26	Pre-school	6–7	16 weeks
Storytellers	Students created elements for a common stop motion animation "Rulers of the Ice Age" with art and craft supplies and filmed the animation with tablets	70	Pre-school, 1	6–8	6 weeks
Techno module	Small groups explored programming with unplugged activities, simple robotics, smart phones, and tablets	61	1	7–8	1 week
Two worlds	Students created miniature worlds with art and craft supplies and electronics around their 3D designed and printed objects	17	1	7–8	15 weeks

For example, we renamed the dimension originally named communication and documenting to documenting and sharing, as it better described the activities conducted by the young students and their teachers.

The main categories were then further grouped into thematic sub-categories (i.e., technological activities) which emerged from the data, resulting in 2–5 sub-categories within each main category. Table 9.2 presents all the main and the sub-categories. The main categories, the technological dimensions, are organized in columns from the most frequently used (crafting, left column) to the least frequently used dimension (programming, right column). Similarly, the technological activities within the dimensions are organized according to their frequency, with the most frequent activity on the top row and the least frequent activity on the bottom row. For example, in the engineering dimension, the most frequent activity was structure building, and the least used activity was explaining basic functions.

Second, to analyze the nature of learning within the projects, we searched for curriculum-related learning areas (i.e., the interdisciplinary core entities, individual school subjects, and transversal competence themes) from the project plans and teachers' descriptions and reflections (Table 9.3). In the analysis, we named the learning areas with the terms used by the teachers in the data, resulting in a mixture of terms from the pre- and primary education curricula. The interdisciplinary core entities follow the naming of the pre-school curriculum, and the transdisciplinary competence themes follow the primary school curricula, which includes all seven themes (compared to six themes in the pre-school curriculum). In addition, one individual school subject, mathematics, was mentioned by both pre- and primary school teachers.

In the third phase of the analysis, we employed co-occurrence network analysis to detect and reveal underlying connections between objects (Sormunen et al., 2019; see also Moeller et al., 2017), here defined as relations between the learning areas and technological activities. The sub-categories from five technological dimensions (Table 9.2) and identified learning areas (Table 9.3) were set as two sets of

Table 9.2 Technological dimensions and activities used within each dimension

Crafting	Designing	Engineering	Documenting and sharing	Programming
Manual crafting	Sketching and drawing	Structure building	Child-centered documentation	Programming simple robotics
Digital producing	Observing design elements	Exploring electronics	Adult-oriented sharing	Computational thinking
	Digital designing	Exploring basic functions	Organizing final event	Programming games
	Molding	Investigating digital devices		Observing programming
	Ideating	Explaining basic functions		

Table 9.3 Learning areas based on the Finnish national pre- and primary education curricula (FNBE, 2016a, 2016b)

Interdisciplinary core entities	Transversal competence themes
Diverse forms of expression	Thinking and learning to learn
Me and our community	Taking care of oneself and managing daily life
Exploring and interacting with my environment	Multiliteracy
I grow and develop	ICT competence
	Working life competence and entrepreneurship
School subject: mathematics	Participation, involvement and building a sustainable future

keywords. The data were tabulated into three columns: project, technological activities and learning areas, which we investigated with the help of network visualization software tool VOSviewer (Waltman et al., 2010). The relatedness of items was determined based on the number of projects they occur in together, resulting in a network consisting of 24 keywords, with a minimum of 2 co-occurrences of a keyword. The keywords were mapped and clustered into three modularity-based clusters based on the occurrences and the link strength, resulting in the final network graph (Fig. 9.6).

In the following section, we first explore the technological dimensions implemented in the projects. Then we introduce three orientations to young students' STEAM education implemented through invention projects, each representing a different perspective to the approach.

9.5 Technological Dimensions in Pre-and Primary Schools' Invention Projects

The invention projects in the present study varied in nature, but they all included several creative technological activities, which represented all the five technological dimensions (Table 9.2). The dimensions—crafting, design, engineering, documenting and sharing, and programming—describe the diversity of digital and analog technological activities used in the processes. In what follows, we introduce the dimensions from the most frequently implemented to the least used dimension.

Crafting According to our analysis, the crafting dimension had substantial emphasis. It was implemented in all the projects except one (*Techno module*, which focused on programming), in several phases. Within this dimension, the children used various techniques and tools to create a final tangible or digital form to their technological ideas and solutions. They used art and craft supplies as well as recycled materials, such as packaging materials and parts from digital devices, to construct unique products. In addition, painting, printing, baking and other traditional art and craft techniques were used. Digital producing was conducted with 3D printers and 3D pens, vinyl cutters, and various applications that made sound or animation. Figure 9.1 illustrates the crafting process in the *Two Worlds* project, where the children constructed miniature worlds in cardboard boxes, creating meaning to their 3D-printed objects. In addition to using art and craft supplies, the children constructed circuits with electronic components, such as LED lights and small motors, to create functionalities in their miniature worlds.

Designing Designing and engineering dimensions were both equally important in the projects, and they were utilized almost as much as crafting. In designing, technology was used as either the object or the tool of design or both. The children designed their technological solutions, but they also used technological means to make their ideas visible. The dimension included traditional sketching, drawing, and molding activities, as illustrated in Fig. 9.2. The designs in the figure were produced in the *My neighborhood* project, where the children created elements for a stop motion animation about their neighborhood in 2050. The children designed their own characters, or "wanderers", and the various adventures these characters got into during the animation. In some projects, the children used digital tools, such as Tinkercad and Cookie Caster, for 3D designing, but these were not as frequent as the more traditional design activities. In addition to using various means to give visual form to their ideas, the children used digital photography for observing different design elements in their surroundings.

Fig. 9.1 A miniature world from the *Two worlds* project with a 3D-printed "automatically" rising and lowering swimming tower and traffic lights guiding the jumpers. The child illustrated water with blue paper and white circles made of craft braids (Photo: Arto Vaahtokari)

Fig. 9.2 Children's designs for the *My neighborhood* project. Molded "wanderers" with a storyboard for a stop motion animation (Photo: Kindergarten Myllynratas)

Engineering The most frequent activity within the engineering dimension was building various structures, such as beam, trellis, or arch structures with art and craft supplies or building blocks. The children also used simple technological tools to investigate basic functions, such as traction, pneumatics, and capillary action, and components to explore electronics by constructing circuits. Children are often naturally interested in these and include technological systems with engineering components in their play (cf. Stylianidou et al., 2018). For example, in the *Garden plot* project, the children investigated and tested water absorption by building various watering systems in their plantings with syringes, plastic straws and tubes, and old water bottles (Fig. 9.3). In some of the projects, the children were also encouraged to examine old digital devices by dissembling them and guided to explain their explorations within the engineering dimension.

Documentation and sharing The documentation and sharing dimension was implemented in most of the projects, and it included activities of both the children and the adults. They used technological tools to build the trail of their knowledge creation, enabling the reflection on what has been or should be learned (cf. Saarinen et al., 2019). The children documented the process by taking photos, making short videos, writing small texts, and using portfolio applications such as Seesaw. Figure 9.4 illustrates documentation by a child about his finished miniature world in the *Two worlds* project. The child has taken a photograph and explained his design with a small text, and the child's guardian has commented on the documentation. The adults supported reflection by encouraging the children to give each other feedback and documented the projects by writing weekly messages to guardians. Together, the children and the adults also organized exhibitions about their projects, inviting other groups from

Fig. 9.3 A child explores absorption with a syringe and plastic straws for a watering system in the Garden plot project (Photo: Anneken Skaara)

the school or parents to visit. Some of the primary school groups participated in invention fairs, organized by our research group at the university, where the children presented their projects and explored the projects conducted in other schools.

Programming The least utilized dimension was programming, although programming activities have been found to be beneficial for developing basic cognitive functions (Papadakis et al., 2016). The dimension was implemented in six projects and included unplugged activities as well as testing, practicing, and playing with age-appropriate applications and early robotics. To learn the basics of computational thinking, the children practiced by "programming" a friend and playing with simple robotics, such as BlueBots, Lego WeDo, and Kubo. For example, in the *My neighborhood* project, the Kubo robot was programmed to move on a map of the preschool's surroundings (Fig. 9.5). In one group, Micro:bit microcontrollers were intended to use for measuring soil humidity. However, this proved to be too challenging for the children. Rather, they observed the coding conducted by adults and subsequently discussed the effects of the program with them.

The technological activities presented here represent all five technological dimensions. Although the teachers experimented invention pedagogy for the first time in practice, they thoroughly covered the process-oriented nature of working from design to engineering and crafting, and documenting, but the dimension of programming was still challenging to them.

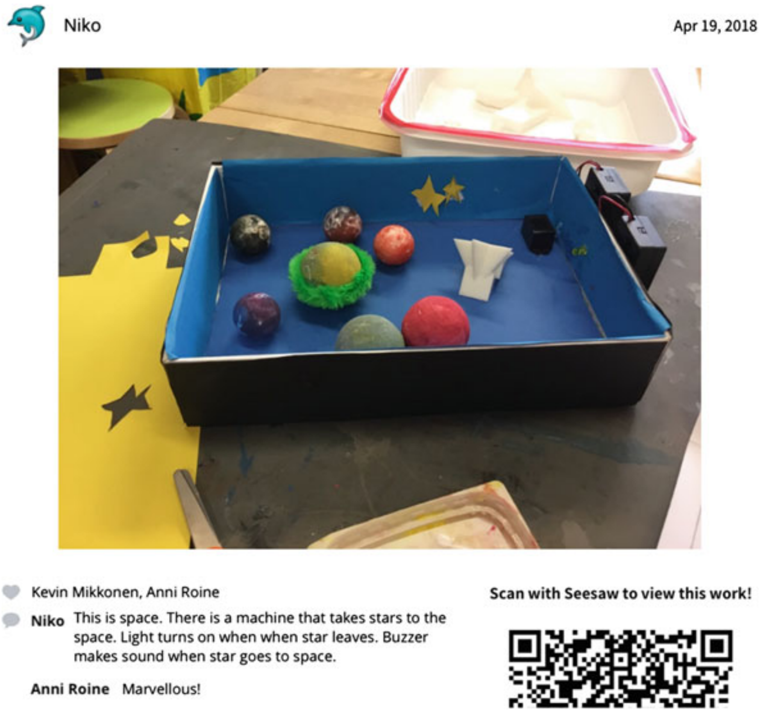

Fig. 9.4 Child-centered documentation and sharing of the final artefact in SeeSaw application in the *Two worlds* project (note: all names are pseudonyms, and the texts are translated from Finnish). (Photo: Arto Vaahtokari)

9.6 Three Orientations in Young Students' STEAM Education

We were also interested in how the creative technological activities were related to the learning areas implemented in the projects (i.e., the interdisciplinary core entities, individual school subjects, and transversal competence themes). We conducted a co-occurrence network analysis to detect and reveal the underlying connections between the learning areas and the technological activities, which resulted in three clusters illustrating varying orientations: (1) The maker orientation, (2) the competence orientation, and (3) the digital orientation. The orientations and the connections are visualized in Fig. 9.6, where the red network represents the maker orientation, green the competence orientation, and blue the digital orientation. The bigger the dot and the more prominent the text, the more frequent the term was in the data. The thickness of the lines refers to the strength of the links between the keywords. In the network, some keywords have been shortened for the clarity of the illustration; the full keywords are presented in Table 9.4. Thus, in the following we interpret the figure and the table together.

Fig. 9.5 The child is programming a Kubo robot in the *My neighborhood* project. The task was to program the robot back to the pre-school on a map of the preschool's surroundings (Photo: Kindergarten Myllynratas)

Maker orientation The maker orientation had the strongest emphasis in the projects. In Fig. 9.6, the red network includes many of the most relevant keywords (indicated with prominent text) and very strong links (indicated with thick lines) within the orientation and to other orientations as well. It included versatile technological activities and learning areas that represent various aspects of STEAM education. The maker orientation was the most interdisciplinary in nature, including the learning entities *Diverse forms of expression*, *Rich world of the language*, and *Exploring and interacting with my environment* as well as the school subject mathematics. Materiality and hands-on making were highlighted within the maker orientation, the technological activity *manual crafting* is in the center of the entire network and has many strong links all over the network. Significantly, one strong link connects manual crafting to *digital producing*, indicating that these two activities were implemented together many times. Naturally, manual crafting was also connected to design and engineering activities, such as *sketching and drawing* and *structure building*. However, the orientation did not include any documentation or sharing activities, suggesting that the evaluative and reflective phase of the process was not underlined alongside design and making. Neither did the orientation include any transversal competence themes. In sum, the focus of maker orientation was on interdisciplinary learning through a wide variety of hands-on design, engineering and crafting activities.

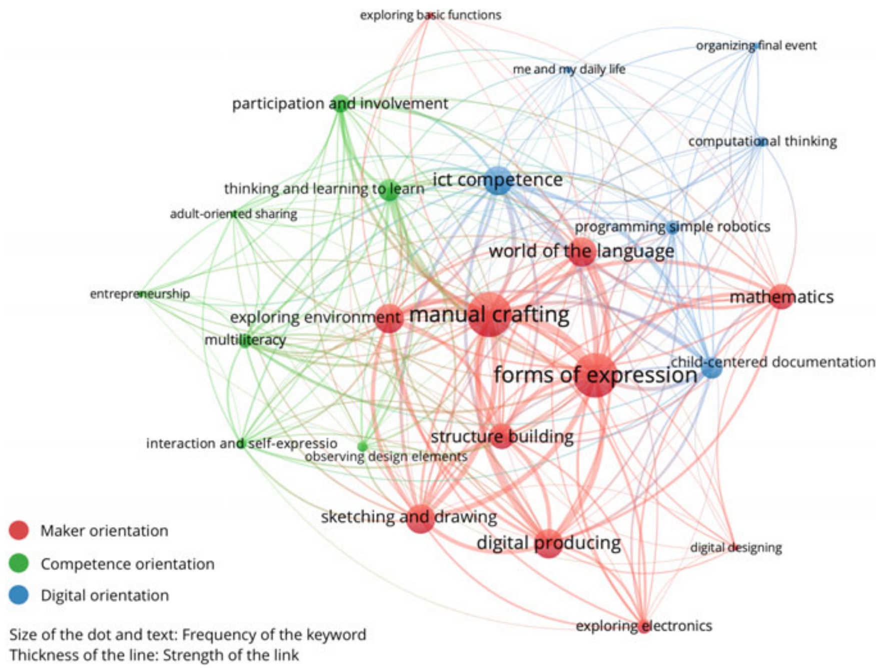

Fig. 9.6 The three orientations network, based on the occurrences and the link strength of the learning areas and the technological activities of the projects

Competence orientation The competence orientation (green network) focused heavily on transversal competence themes; five of the seven themes were included in this orientation. The primary focal theme was *Thinking and learning to learn*, which is also connected to many other competence themes. Surprisingly, *Participation and involvement* is in the outskirts of the network, although this competence theme is underlined in many definitions of future-oriented learning, referring to co-agency with peers, teachers, parents, and communities (e.g., OECD, 2019). *Multiliteracy* is even less prominent in the network, albeit the projects included activities touching upon a variety of literacies (i.e., spoken and written language, numbers, digital data, and material artifacts). The technological activities implemented most within the competence orientation, *observing design elements* and *adult-oriented sharing*, were more cognitive in nature than in the maker orientation. In brief, the competence orientation emphasized the learning of general skills, and these are linked to "minds-on," rather than hands-on, activities.

Digital orientation The digital orientation (blue network) appeared to be the most narrowly focused of the three orientations, particularly in regard to the learning areas. This emphasizes *ICT competence*, which is one of the transversal competence themes. Only one other learning area, *Taking care of self and managing daily life* (cf. me and my daily life in Fig. 9.6), was included in this orientation. This

Table 9.4 The three orientations, the included learning areas, and technological dimensions and activities

Orientation	Learning areas	Technological dimensions and activities
Maker orientation	**Interdisciplinary core entities** Diverse forms of expression Exploring and interacting with my environment Rich world of the language **School subject** Mathematics	**Designing** Sketching and drawing Digital designing **Engineering** Structure building Exploring electronics Exploring basic functions **Crafting** Manual crafting Digital producing
Competence orientation	**Transversal competence themes** Thinking and learning to learn Participation and involvement Multiliteracy Cultural competence, interaction, and expression Working life competence and entrepreneurship	**Designing** Observing design elements **Documentation and sharing** Adult-oriented sharing
Digital orientation	**Transversal competence themes** ICT competence Taking care of self and managing daily life (Note. me and my daily life in Fig. 9.6)	**Programming** Programming simple robotics Computational thinking **Documentation and sharing** Child-centered documentation Organizing final event

learning area is quite peripheral in the network, indicating that ICT competence was seldom connected to children's everyday experiences, although digital technology is an important part in children's daily lives. These two competence themes were approached with programming activities, *programming simple robotics* and *computational thinking*, although these activities were used in less than half of the projects. Interestingly, the most prominent technological activity within the orientation was *child-centered documentation*. The children often used digital tools for documentation, so perhaps it was natural for the teachers to reflect that this activity was related to learning areas focusing on digital competence. Thus, the digital orientation emphasized the development of students' digital competence, but in a rather narrowly focused way.

The three orientations illustrate varying emphases on young students' STEAM education implemented through invention projects. In addition, they exemplify how introducing a new pedagogy is first linked to common practices and contexts and the more unfamiliar areas and activities are positioned in the outskirts of the orientation network, while also suggesting new directions for developing STEAM education further.

9.7 Discussion and Conclusion

The integrative STEAM approach has been argued to be useful for teaching and learning the twenty-first century competencies, but it has received little research interest, particularly in early education. Although some recent studies exist, the emphasis has mostly been on digital technology, providing a quite narrow perspective on technology education (e.g., Li et al., 2020). In the present chapter, we aimed to broaden this perspective by examining what kind of creative technological activities, both digital and analog, were used in pre-and primary school STEAM-oriented invention projects and how these activities were related to the learning areas pursued in the projects.

The projects included many technological activities, which represented all the five technological dimensions defined in our previous studies (Korhonen et al., 2020). Many of the activities were, in fact, common activities in young students' education, for example, building, manual crafting, and drawing. Nevertheless, analyzing them in relation to the technological dimensions revealed that simple and common activities can be used to support several aspects of students' technological competence (i.e., using, exploring, and creating technological solutions and tools) (cf. Fox-Turnbull, 2019; OECD, 2019). In addition to crafting and engineering activities, it was notable that design was a well-represented dimension. Previous research has found contradictory results regarding young students' designing, from children not being aware that they are following a plan (MacDonald et al., 2007) to a strong correlation between children's design intentions and their final products (Fleer, 2000). Therefore, children should be taught how to design, including the role and usefulness of drawing in developing design ideas (cf. Hope, 2005; Yliverronen, 2014). Design as a focal dimension in the invention process and pedagogy was underlined in our workshops for teachers, and the present results indicate that this dimension was further explored with the children. On the contrary, the programming dimension was not implemented as much as the other dimensions, although many programming tools were introduced in our workshops. This dimension is a new area to be covered in young students' education, and there are still challenges related to teachers' abilities to teach this area, to the lack of suitable learning materials, and also the possibilities of educational institutions to invest in age-appropriate programming tools (e.g., Kewalramani et al., 2020). In real classroom settings, the dimensions are naturally overlapping and entangled; for example, building structures with art and craft supplies represents both the engineering and the crafting dimension. However, acknowledging all the dimensions might help teachers to perceive the diversity and variety of technologies that can be used for creative learning activities, and they can also be used to map out children's existing, evolving, or desired technological competencies.

When analyzing the underlying connection between the technological activities and the learning areas pursued in the projects, three orientations emerged, each emphasizing varying elements of young students' STEAM education implemented through invention projects. The most prominent was the maker orientation, which was also the most interdisciplinary in nature and included more technological activities than the other orientations. As the name suggests, the orientation resembles maker-centered learning, which is generally seen as multidisciplinary, multimaterial, technology-enhanced, and comprehensive in terms of including all stages of creation, i.e. ideation, experimentation, making and reflection (e.g., Riikonen et al., 2020b). In many studies, maker-centered learning has been recognized as a strategic component of future-oriented education (e.g., Lundberg & Rasmussen, 2018); furthermore, it nurtures young students' academic identity (Hachey et al., 2021). The maker orientation also included many common activities for young students', but the less familiar activities were either in the outskirts of the network (digital designing and producing) or not at all included in the orientation (documentation and sharing, and programming dimensions). The maker-oriented approach to STEAM education might benefit from a more focused perspective, where less interdisciplinary and disciplinary learning areas are included, leaving room for transversal competence themes and more versatile technological dimensions.

Quite the opposite, the competence orientation included five transversal competence themes in total, but no interdisciplinary or disciplinary learning areas. The same is true in the digital orientation, with the exception that it included only two transversal competence themes. These two orientations included also documentation and sharing activities, indicating that these were linked with the themes (i.e., the evaluative and reflective dimension of technological activities corresponds to the development of transversal competence). The two orientations, however, included very few other technological activities. In particular, the digital orientation was quite narrowly focused on developing the students' digital competence with activities related to programming and documenting.

Nevertheless, our aim was not to judge the three orientations in terms of one being better than the other, but rather to illustrate the versatile ways of implementing the STEAM approach in pre- and primary students' invention projects. In addition, the orientations portray the broad scope of learning areas pursued in the projects. Our conclusion is that young students' STEAM education might benefit from a more focused, but not too limited, perspective, in which both interdisciplinary and transversal learning areas are included, while still leaving room for versatile technological dimensions including both digital and analog activities.

Like all research, this study has limitations that must be acknowledged. One lies in the nature of the data collected, which emphasizes teacher descriptions, reflections, and visual data. It was beyond the scope of this study to undertake a detailed analysis of the enacted children's and teachers' activities, which would have perhaps provided deeper insights into the nature of technological dimensions and learning areas implemented in the projects. Furthermore, a collective case study usually includes the same data sets from each case to make reliable cross-case generalizations and comparisons (Goddard, 2010). The data sets of the present study varied slightly from case to case due to the different research settings and projects; for example, some cases included teachers' written descriptions and reflections while others included transcribed teacher interviews. However, all the cases had similar contexts and participants, such as the nature of the projects implemented, and the same research objectives guided the analysis of each case. These limitations suggest avenues of future research on young students' STEAM education.

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