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Supporting Preschool Children's STEM Learning with Parent-Involved Early Engineering Education

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Abstract

This study examines the development of a STEM-based (Science, Technology, Engineering, and Mathematics) and parent-involved engineering design curriculum for early childhood education and investigates its design principles and contributions to children's STEM-related learning. This research utilized a design-based research methodology broken into three main phases (preliminary research, prototyping, and assessment). The data were gathered over a 2-year span, and the curriculum was designed and revised during the prototyping phase's three iterative cycles. This paper presents the findings of a field test that involved two early childhood education teachers, five preschool children, and five parents. Findings validated eight key design principles of the curriculum and revealed that the curriculum contributes to the knowledge, skills, feelings, and dispositions children have towards STEM. The findings suggest that the developed curriculum can be used as a novel way of integrating STEM into early childhood education, with a particular focus on engineering, while encouraging parental involvement.

Keywords Design-based research · Early childhood education · Early engineering education · Parental involvement · STEM

Introduction

STEM education is important in fostering and sustaining young children's natural interest in the topics and career fields within its scope and building their competence in problem-solving and critical and logical thinking while developing their habits of mind (e.g., curiosity, creativity, persistence, collaboration, and communication; Isabelle and Valle 2016; Lange et al. 2019; Moore et al. 2018). Hence, over the past decade, policy makers, researchers, educators, and parents have focused on including STEM in early childhood education (ECE) and on supporting children's STEM-related knowledge and skills through various learning opportunities inside and outside school (Dubosarsky et al. 2018; Haden et al. 2014). Because of its nature requiring knowledge of math and science to develop technologies and solve engineering problems, engineering serves as a natural binding factor in the integration of STEM disciplines into educational environments and provides children of all ages with realistic learning experiences in an engaging way (Moore et al. 2018; Pantoya et al. 2015). Therefore, in recent years, engineering has taken a central place in early childhood STEM education (English 2018; Moore et al. 2014a, b). It is also a discipline worth discovering on its own because it has a creative and highly materialistic side that can address learning in multisensory ways (Bagiati and Evangelou 2015). However, little is known about how a developmentally appropriate engineering education can be provided in early childhood, how STEM can be integrated into ECE environments using engineering as a forerunner to other subjects, and how parents can be involved in their children's engineering education (Cunningham et al. 2018; English 2018; McClure et al. 2017). This study, which proposes an engineering curriculum for preschool children and investigates the contributions of this curriculum in children's

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learning, aims to make strides toward addressing the above-mentioned gap in both the literature and practice (Bagiati and Evangelou 2015; Dubosarsky et al. 2018; McClure et al. 2017).

Engineering Education in Early Childhood

Pre-college engineering education aims to have students engage in solving problems with practical or societal importance by employing the engineering design process (EDP; National Academies of Science, Engineering, and Medicine 2017). Early engineering education (EEE) also aims to improve children's awareness about the technologies produced by engineers from different fields and used in daily life. Hence, EEE aims to encourage children's appreciation of the significance of science and engineering and the roles they play in improving people's quality of life (Smetana et al. 2012).

Since 2000, engineering education at the primary and secondary levels has attracted international interest (Purzer and Douglas 2018), and various standards, frameworks, and curricula have been developed for K-12 engineering education (Cunningham 2009; Moore et al. 2014a, b; National Academy of Engineering and National Research Council [NRC] 2009; Next Generation Science Standards 2013). However, until recently, EEE and its potential contributions to children had gone unnoticed in ECE and children have had limited opportunities to engage engineering-related content (Bagiati 2011; English 2018; Moore et al. 2018). In parallel with STEM's rising in early childhood education, over the past 10 years, researchers have focused their attention on integrating engineering into preschool classes (Bagiati 2011; Blank and Lynch 2018; Cunningham et al. 2018; Lippard et al. 2018; Van Meeteren and Zan 2010). These studies revealed that early childhood is the ideal time to begin introducing children to engineering and STEM concepts because children are instinctively inclined to discover the world around them (Bagiati 2011; Davis et al. 2017; Elkin et al. 2018).

EEE improves preschool children's knowledge and skills in STEM disciplines and enables them to understand the human-made world (Cunningham 2009) and experience abstract scientific concepts in realistic and engaging contexts (Moore et al. 2018). Within the context of EEE, some science concepts, (e.g., density, energy, gravity, friction, volume, balance, and the properties of materials; Cunningham et al. 2018; Hoisington and Winokur 2015; Moomaw 2013; Park et al. 2018; Raven et al. 2018), math concepts (e.g., one-to-one correspondence, measurements, and numbers; Moomaw 2013), crosscutting concepts (patterns, cause and effect, scale, proportion and quantity, structure and function, and stability and change; NRC, 2012), and engineering concepts (e.g., "engineer," "engineering," "design," "engineering design process," "sketch," "plan," "function," "model," and "test"; Bagiati and Evangelou 2018) can be experienced by young children in meaningful and realistic ways. Moreover, EEE provides children with an opportunity to experience the EDP in a developmentally appropriate manner, thereby demonstrating and developing engineering skills while seeking solutions to problems through the application of engineering principles (e.g., identification of the problem and its constraints; development of a solution and representation of it in a plan, sketch, and/or model; solution testing; solution improvement based on test results; Cunningham et al. 2018). Engaging in EEE also helps children develop the thinking skills (e.g., curiosity, persistence, flexibility, reflectiveness, and the ability to think in collaboration with others) that are essential to the success of learning STEM and in real-life engineering practices (Stone-MacDonald et al. 2015). Therefore, exposing children to EEE in their early years creates opportunities to keep their curiosity alive, thereby constructing the foundations of their learning in STEM disciplines, and it present science to children as both interesting and relevant (NRC 2012).

Theoretical Framework

This study is theoretically based on both the sociocultural theory of Vygotsky (1978) and the ecological system theory of Bronfenbrenner (1979). According to sociocultural theory, the interactions between children and the people in their environment mediate children's learning and development (Haden et al. 2014; Vygotsky 1978). From this point of view, the guidance of an adult or more specialized person is crucial so that children can learn a skill and practice it independently (Berk and Winsler 1995). Ecological systems theory goes one step further and states that the various factors in children's social environments are of varying importance to their education and development. From this perspective, parents—the adults who take part in children's microsystems and are the most constant people in their immediate surroundings except for teachers—have a critical role in their children's education and development (Bronfenbrenner 1979; Ihmeideh and Oliemat 2015; McClure et al. 2017). In this study, parents were viewed through the lens of ecological systems theory and were seen as highly effective in terms of their children's engineering education. Additionally, the curriculum activities were designed at a difficulty level that saw children accomplish them under the guidance of their parents, which is in keeping with sociocultural theory.

The Role of Parents in EEE

Parents can bolster children as they build the foundations of engineering education by identifying manifestations of engineering concepts both inside and outside school, and they can encourage their children's interest in engineering (Dorie et al. 2014a; Haden et al. 2014; Smetana et al. 2012). Therefore, when parents clearly conceptualize their role in science and engineering education, they can help with their children's development of related knowledge and skills (Dorie and Cardella 2014; Gunning et al. 2016). For example, a conversation about the bridge a parent and child are crossing might be an opportunity for the child to discover new concepts in engineering and science. By presenting the bridge as an engineering product that makes our lives easier and discussing how bridges support enormous weights without collapsing, parents can identify the importance of engineering in daily life (Dorie and Cardella 2014). Similarly, children who have difficulty seeing the other side because of the fences in the schoolyard can find solutions to this problem by constructing a treehouse with their parents. Meanwhile, skills can develop related to generating ideas, testing them, conducting research, creating a design, improving it, and solving problems (Weatherly et al. 2017). All these reasons convey the importance of establishing a partnership between parents and schools that centers the education process and engineering education initiatives directed at preschool children (Bagiati and Evangelou 2015; Dorie and Cardella 2014; Peterson 2017; Smetana et al. 2012).

In the literature, authors highlight educational events, such as STEM career nights and family engineering days (Peterson 2017; Smetana et al. 2012), and some studies have sought to bring parents and children together through activities related to robotics and engineering (Dorie et al. 2014b; Gunning et al. 2016; Haden et al. 2014). All such efforts are valuable in terms of improving general awareness of the importance of engineering and allow for parents and children to not only feel motivated but also to learn, explore, and create together. However, in ECE programs, engineering is novel educational content, and both parents and teachers may perceive it as less attainable and more intimidating than other STEM disciplines (National Academy of Engineering & NRC 2009; Stone-MacDonald et al. 2015). Research has suggested that this might be because many questions remain unanswered, such as how engineering can be taught in early childhood through formal and informal learning opportunities and which types of materials and curriculums could be used; the lack of answers is due to the limited number of resources available to guide both parents and educators in the process of providing an engineering education to preschool children (Bagiati and Evangelou 2015; Blank and Lynch 2018; Dubosarsky et al. 2018). As the literature has suggested, to support children's learning, parents and preschool teachers need to know what engineering is, what engineers do, the steps they follow during the design process, and engineering-related precursor behaviors and ways of thinking that preschool children might present. They also need to know which STEM-related concepts and skills can be developed in children through engineering education, what roles teachers and parents play in children's engineering education, and how children's learning in STEM can be assessed (Dorie et al. 2014a; Moomaw and Davis 2010; Smetana et al. 2012; Stone-MacDonald et al. 2015).

At the same time, the literature contains a limited number of curricula that can guide practices in ECE by proposing a clear teaching philosophy, developmentally appropriate learning objectives (Copple and Bredekamp 2009), and assessment tools (Bagiati and Evangelou 2018; Dubosarsky et al. 2018). However, well-planned and developmentally appropriate engineering activities that include parents can be an excellent opportunity for parents, teachers, and children to learn and experience STEM together (Smetana et al. 2012). In order to answer unanswered questions about the theory and practice of integrating STEM and ECE, there is a need for research-based curricula developed for ECE that involves parents in their children's STEM education (McClure et al. 2017).

This study focuses on developing an EEE curriculum and exploring its design principles (main characteristics) and effectiveness. In line with these aims, the following research questions will be explored: What are the design principles of an effective and parent-involved engineering design curriculum for preschool children? What are the possible contributions of such a curriculum to preschool children's STEM-related learning?

Methods

A high-quality curriculum can be created with an iterative approach that includes the development, testing, revision, and retesting of each unit (Clements and Sarama 2007; Thijs and van den Akker 2009). Therefore, in this study, a design-based research (DBR) methodology was utilized to emphasize an iterative process aimed at evaluating an innovative intervention while systematically strengthening innovation (Plomp 2013). In such iterative processes, educational researchers design and develop usable and efficient interventions that address real-world problems and produce a theory to guide the design (Easterday et al. 2014). In educational settings, DBR has the potential to contribute to bridging the gap between theory and practice in the classroom (van den Akker 2013). This study overlaps with the aim of DBR in terms of developing a useful and theory-oriented educational product (Collins et al. 2004).

Study Phases

This study was carried out in three main phases over the course of 2 years. In the preliminary research phase, researchers conducted a need and context analysis to generate background information about STEM education in ECE (Thijs and van den Akker 2009). The literature has shown that ECE teachers need STEM-related teaching resources and collaboration with experts in order to bring STEM into their classrooms (Bagiati and Evangelou 2015; Brenneman et al. 2019; Park et al. 2017) and that engineering can be an effective way of integrating STEM disciplines both with each other and with ECE classroom practices. Moreover, the literature review revealed that the role of parents in their children's education and the partnership between parents and schools are vital to the implementation of STEM learning in ECE (Bagiati and Evangelou 2015; Dorie and Cardella 2014; Smetana et al. 2012).

The literature review also provided researchers with the opportunity to explore current curricula, frameworks, and standards in EEE (Bagiati and Evangelou 2018; Cunningham 2009; Lottero-Perdue et al. 2016; Next Generation Science Standards 2013; NRC 2012; Stone-MacDonald et al. 2015). These resources served as a framework during the development of the curriculum's design and then had a role in shaping the initial curricular content. First, the curriculum's initial learning objectives, draft design principles, and determined learning objectives were presented for evaluation to two experts carrying out studies in the field of EEE. After the researchers redesigned the learning objectives in order to reflect the experts' recommendations, they served as the basis for the design of learning activities and a child observation form. Thus, the first prototype of the curriculum was designed to be developed throughout the cycles of the prototyping phase.

In the prototyping phase, different prototypes of the curriculum and its design principles were revised by means of formative evaluations. Nieveen and Folmer's (2013) research methodologies guided researchers in determining the iterations of the prototyping process and the steps followed (see Fig. 1). Thereby, a total of three iterations were carried out during the study. First, four experts from the fields of science, mathematics, engineering, and ECE were consulted to evaluate the first prototype. After the required modifications were made by integrating their suggestions, the second and third prototypes of the curriculum were tested for a total of 8 weeks during workshops held on weekends through two different iterations (micro-evaluation and field test). The workshops were called Parent-Child Engineering Education Workshops. The second prototype was designed and tested using a micro-evaluation study with a sample composed of the curriculum's target users in order to explore its practicality and effectiveness. In response to the micro-evaluation findings, the third prototype was created and tested on another group, which was composed of target users in a typical user setting in the form of a field test). Since DBR is a comprehensive process and provides a detailed data source, the data used to answer this study's research questions were obtained from this final implementation of the curriculum (the field test).

In the assessment phase, the focus was on evaluating the effectiveness of the curriculum's third prototype. More specifically, researchers focused on determining to what extent the curriculum brought met its intended objectives

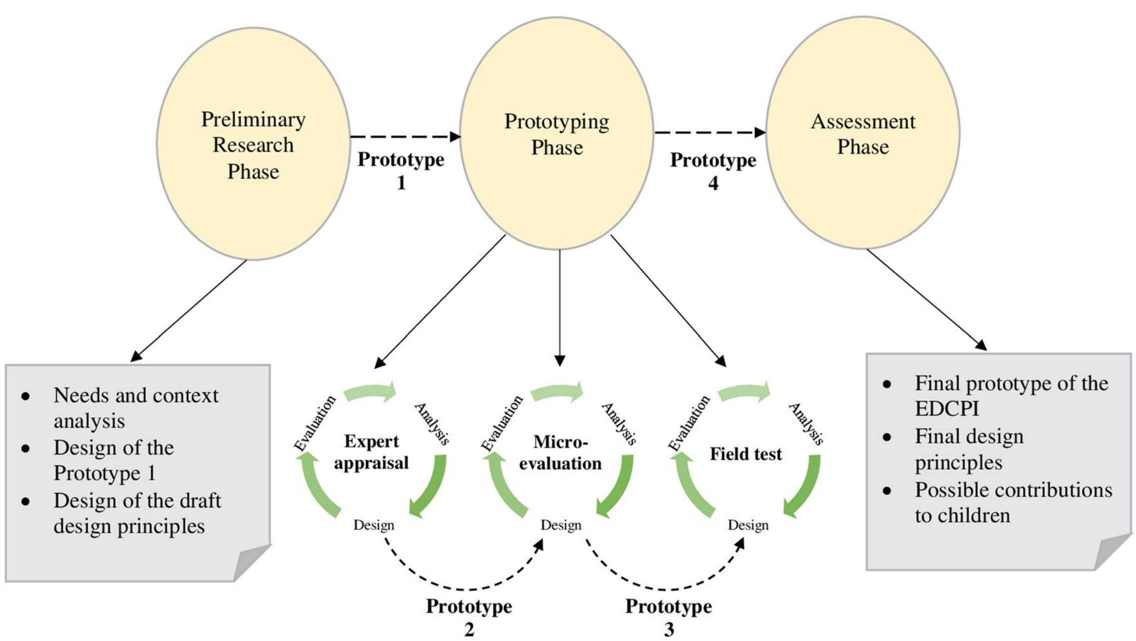

Fig. 1 Main and micro-phases of the study

and on reaching the final prototype and design principles (Thijs and van den Akker 2009; see Fig. 1).

Implementation

The micro-evaluation and the field test's workshops both lasted for 4 weeks (8 weeks in total), and both were performed over five sessions; in each, a different learning activity was implemented (10 sessions in total). In the field test, each session lasted about 3 h, and all were carried out by gathering parents and children who wanted to participate in the study from two different classes into a single class.

Fig. 2 The setting where the field test was conducted

Figure 2 shows the learning environment in which the field test was conducted.

The necessary approvals were obtained from the Directorate for National Education in the city where the study was conducted from the university's Human Subjects before it was conducted. Participants were selected by sending parents a consent form that included explanations about the study's aims and procedures. Parents gave their consent to participate by signing the form and sending it back to the researchers.

Before the curriculum was implemented, both parents and teachers were given 1 h of training during which this study's R1 (first author) introduced STEM and EEE. Figure 3 summarizes the steps followed during the implementation of the micro-evaluation and field test, and it also presents some of the content of the parent and teacher training. During those processes, R1 met with participating teachers every week to discuss that week's activity. In these meetings, activities were evaluated from the teachers' perspectives, and teachers were actively involved in the curriculum's design process, R1 and R2 (second author) considered their reflections, evaluations, and ideas for improvement.

Participants

The field test was carried out with two ECE teachers (T2 and T3), five children (C9–C13), and five parents (P9–P13). The participating children were three boys and two girls between 61 and 73 months old ($M = 68.6$, $SD = 5.31$). Three of the

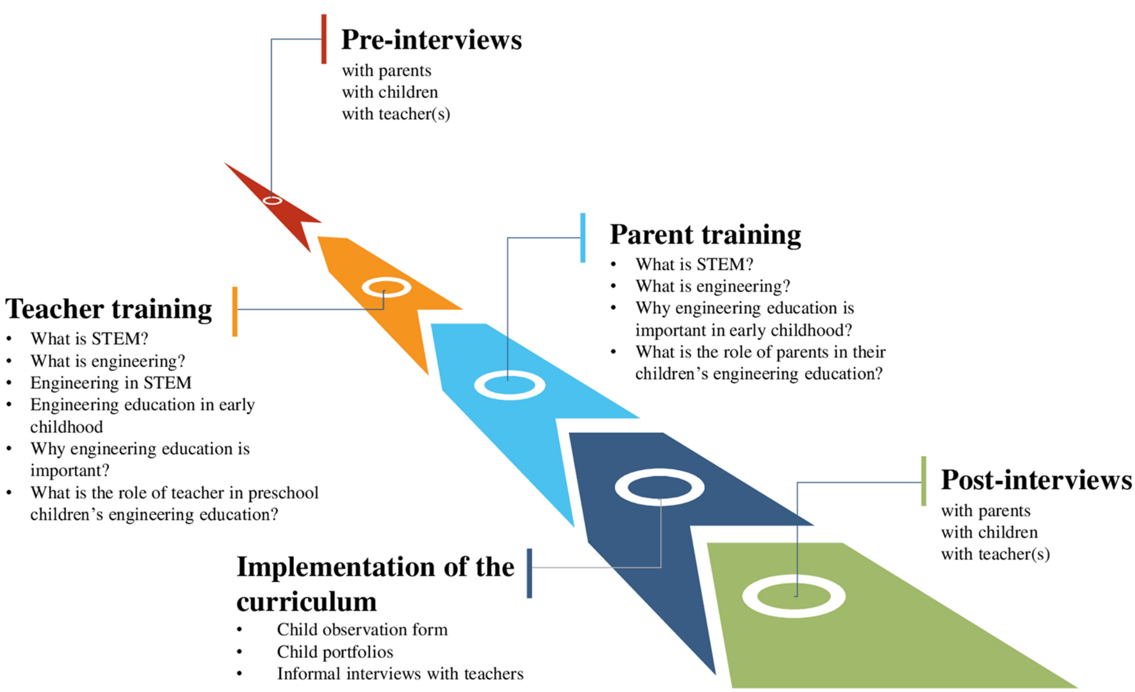

Fig. 3 Implementation procedure and the content of the parent and teacher training (modified from First Author, 2019, p. 150)

children (C9, C10, and C12) had engineers for parents, but only one of those parents attended (P10) a workshop. T2 implemented three of the activities, and T3 implemented two. However, both teachers read the activity templates for each activity and attended meetings with the R1 each week to give feedback. Both teachers had a bachelor's degree from an early childhood teacher education program, and neither had previously received STEM education. Throughout the implementation of the activities, R1 was in the education environment and assumed the role of participant observer, conducting observations without interfering in the learning process (Creswell 2014).

A STEM-Based and Parent-Involved Engineering Design Curriculum

This study's curriculum is grounded in a learner-centered curricular ideology that defends curriculum integration and focuses on providing children with hands-on learning experiences to holistically educate children (McLachlan et al. 2010). The curriculum is also grounded in the idea that teachers and parents should facilitate the process of structuring knowledge and that activities should be shaped according to children's needs and interests. The pragmatic paradigm was adopted as the curriculum development model (Visscher-Voerman and Gustafson 2004). According to this model, educational products are revealed at the end of the rapid design, testing, and revision of several prototypes. The prototyping cycles proposed by this model helped the researchers explore the design principles underlying the curriculum and, with each iteration, achieve results that were increasingly close to what was intended. Learning objectives were determined as the first step of the curriculum design process. Activities were then designed to reach these objectives and to use the curriculum in ECE, which is an activity-based education process.

Learning Objectives

The curriculum's content was constructed around its learning objectives, which were derived from the literature (e.g., Bagiati and Evangelou 2018; Cunningham 2009; Next Generation Science Standards 2013; NRC 2012; Stone-MacDonald et al. 2015), and they were grouped under four main dimensions of learning: knowledge, skills, feelings, and dispositions (Bagiati 2011; Katz 1999).

The curriculum's knowledge-related learning objectives mostly focus on understanding what engineering is, what engineers do, examples of technologies produced by engineers and used in everyday life, explorations of different engineering fields, and understanding the role of engineering in improving and facilitating our lives. Skills are defined as small actions that can be developed in a short period of time and are easily observable (Katz 1999). The main skills-related learning objectives are identifying a problem, producing and representing possible solutions in a plan and/or model, constructing a design and improving it after a number of tests, understanding the critical role of materials in the design process, and applying math and science knowledge to design problems.

As Helm and Katz (2001) emphasized, an appropriate curriculum should also provide children with opportunities to discover and strengthen their dispositions. In this study, dispositions were defined as "habits of mind or tendencies to respond to certain situations in certain ways" (Katz 1994, p. 24) and were represented in five different thinking skills: curiosity, persistence, flexibility, reflectiveness, and the ability to think collaboratively (Stone-MacDonald et al. 2015). Finally, feelings were defined as how the children felt about a learning activity (Katz 1994). The curriculum includes some feelings-related learning objectives, such as feeling happy while pretending to work as an engineer, being satisfied with helping the characters in the stories, working with a parent, and utilizing open-ended materials.

Learning Activities

The curriculum consists of five learning activities, each of which addresses STEM-related concepts and practices, and it focuses on one of five different thinking skills (curiosity, persistence, flexibility, reflectiveness, and the ability to think collaboratively). In each activity, parent-child groups are presented with design problems that exemplify different fields of engineering in age-appropriate ways (see Table 1 in the appendix for the design problems presented in each activity as well as the concepts, fields, and thinking skills).

In the first four activities, each child works only with their own parent. Since the fifth activity aims to promote collaborative thinking, it is based on collaboration among parent-child groups. Thus, while the fifth activity is conducted, all participants are divided into two groups. Two children and their parents are in the first group, and three children and their parents are in the second group; everyone works within their own groups.

All the activities are structured around the four main steps of the EDP: think about it, try it, fix it, share it (Stone-MacDonald et al. 2015; see Fig. 4). Activities start with an introduction during which the teacher informs the groups about engineering and the work of engineers; the teacher provides examples of technologies produced by engineers from various fields. Then, each week, the groups are presented with a different problem through the use of a story and two gender-neutral puppets (a parrot and a turtle).

After the problem is introduced, each group creates a plan reflecting their own idea(s) for a solution and explains their plan to the teacher. Subsequently, the groups create

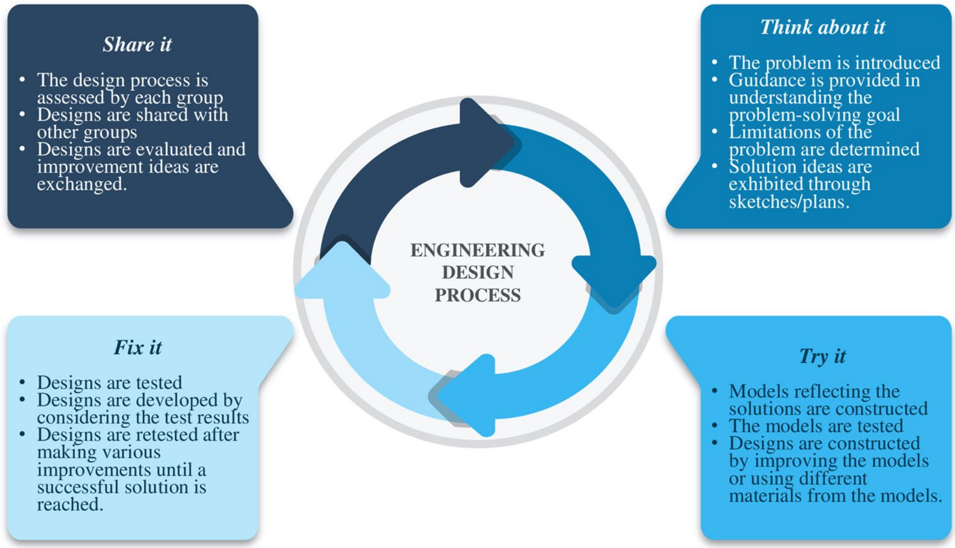

Fig. 4 EDP steps followed in the learning activities (modified from Stone-MacDonald et al. (2015, p. 12)

a model that represents their solution in three dimensions with the open-ended materials, after which they test their models within the constraints of the problem. The groups then produce and implement ideas to improve their models based on the results of the tests. Finally, they share their own design with other groups, and the learning process is reviewed under the guidance of the teacher.

Data Collection

Interviews with Teachers and Parents

Formal and informal interviews were conducted with teachers during and after the workshop process. While the interviews carried out during the teacher-researcher meetings were informal, those conducted after the study were formal and semi-structured. During the weekly informal interviews, the researcher and teachers evaluated the activity conducted the previous weekend (the following is a sample of the questions asked: "Did you have any difficulty implementing the activity?"; "Can you suggest any changes to this activity to make it more effective for children?") and the activity that would be conducted the following weekend (the following is a sample of the questions asked: "When you consider the individual differences of students and parents in your class, do you have any suggestions to make this activity more inclusive?"; "Would you make any changes to this activity if it were implemented in your class?"; "Is there anything in the activity template that is not clear and/or you would like me to explain further?"). After the workshop, the semi-structured post-interviews were conducted with teachers to evaluate the curriculum from their perspective in terms of its design principles and the curriculum's design, development, and implementation process. Similarly, semi-structured post-interviews were carried out with the parents. In this way, data regarding teachers' and parents' evaluations of the curriculum and experiences during the workshop were obtained (the following is a sample of the questions asked: "Do you have any suggestions on how to make the engineering design activities from the workshops more effective for children?"; "Were there any factors preventing/facilitating the education process in this workshop?")

Before implementation, expert opinions were obtained to shape the interview questions and ensure that the content was valid and that the required revisions were made in accordance with the experts' suggestions. The interviews were recorded with a voice recorder. At the end of each interview, the data were summarized, and the accuracy of the data as well as the researcher's interpretation of them were checked by consulting with interviewees (Creswell and Poth 2018).

Child Observation Form

An observation form was designed according to the experts' suggestions to report observations related to the learning objectives. The form consisted of three parts which include indicators of learning objectives concerned with the curriculum's three dimensions (skills, dispositions, and feelings). The form included a checklist of observed indicators and an explanation section that allowed observers to reflect on their observations associated with each indicator.

For the activity held in each session of the workshop, a video recording was carried out. In addition, the interactions of each parent-child group during the activities were recorded with voice recorders placed under their desks. R1 and the teacher independently filled out observation forms for each child after the activity in line with their own observations during the activity and with the video and audio records. To calculate the inter-rater reliability between the observations of the researcher and those of the teacher, the number of agreements was divided by the sum of agreements and disagreements (Miles and Huberman 1994). The inter-rater reliability was 77%, which indicates substantial agreement (Landis and Koch 1997).

The skills dimension was scored on the observation forms. This dimension included 30 indicators spread across the seven learning objectives, and each indicator corresponded to one point. Hence, the total score a child could receive from this dimension was 30. Children's acquisition of STEM-related skills was identified by referring to their average scores (children who scored between 0 and 10 were considered to have emerging skills; those who scored between 10 and 20 were proficient; those who scored between 20 and 30 were advanced; Purzer and Douglas 2018). However, for the feelings and dispositions dimensions, frequency calculations were made in order to make a comparison in terms of how frequently the children displayed indicators.

Interviews with Children

Children were interviewed before and after the workshop so the researchers could understand the development of their knowledge of engineering and technology. Post-interviews were also designed to explore children's feelings about their workshop experiences (the following is a sample of the questions asked: "Were there things that you and your parent could not agree on while doing the activities?"; "During which subjects did you and your parent get along well?"; "Did anything upset you while making these designs?"). As with the parent and teacher interviews, experts were consulted. Each child was asked 7 questions in the pre-interview and eight in the post-interview. In addition to semi-structured interview questions, the interview protocols also included three tasks for children, which were considered part of the eight questions. R1 conducted the interviews with each child separately and in an empty classroom and recorded the sessions with an audio recorder.

In addition to semi-structured interview questions, the interview protocols also included some tasks for children. In the pre-interviews, seven cards with images of people from different professions (mechanical engineer, civil engineer, police officer, sanitation worker, cook, doctor, and fire fighter) were shown to the children, and they were asked to guess what the profession of the person was on the card. Further, in both the pre- and post-interviews, children were shown cards that visually displayed various technologies used in daily life (e.g., eyeglasses, a car, a computer, a washing machine, toothpaste) and some natural objects (e.g., a pine cone and a tree branch). They were asked whether the object could be designed by an engineer and whether it was a technology. The same cards were shown in random order to all children. Each interview with a child took about half an hour (including tasks). When the cards were met with short answers, such as "yes" or "no," the researcher encouraged the children to explain their answers (the following is a sample of questions the researcher asked: "Why do you think that an engineer did not design this?"; "Why do you think this is not a technology?").

Portfolios on the Children

The researcher used portfolios to gather evidence of each child's learning (McAfee and Leong 2012). For this purpose, a separate computer folder was created for each parent-child group. Each group's photographs taken during the learning process and the video and the audio recordings recorded throughout each activity were stored in these folders. Additionally, the children's portfolios included each group's engineering notebooks. The notebooks included the plans for the solution and the measurement results and ideas noted during the "think about it" step of the EDP. While all the plans were drawn by the children, the measurement results were sometimes noted by the parents and sometimes by the children.

Data Analysis

R1 analyzed the data using the constant comparative method, which is one of the techniques proposed in the grounded theory for qualitative data analysis (Patton 2015) and is also used in DBR (e.g., Shattuck and Anderson 2013; Wang et al. 2014). In the current study, classifications and interpretations were made regarding both verbal and visual forms of data in order to make the collected data meaningful, explain their explicit and implicit features, and determine the structures of meaning (Flick 2014). In this process, the constant comparative method enabled the researchers to create new codes and categories and to make comparisons among those emerging from various data sets (Glaser and Strauss 2006).

Before the data analysis, all the video and audio records of the interviews and observations were transcribed and the irrelevant data were removed. The raw data were then pooled with the data obtained from the portfolios (including engineering notebooks and photos) and analyzed together to obtain a holistic viewpoint. The indicators were subsequently identified from the raw data, and the categories were obtained by making comparisons among the identified indicators and coding them to the related categories (Creswell 2014).

As Sandelowski et al. (2009) stressed, qualitative data can be transformed into countable or nominally categorizable quantitative forms if the research design requires it and the sampling frame of the study allows for it. In this study, the child observation forms enabled the researcher to obtain countable data to evaluate the development of children in skills dimensions as of the first activity and the frequency with which indicators were displayed in the feelings and dispositions dimension. In this context, the data obtained from the observation form were analyzed not only qualitatively but also quantitatively on a simple scale by conducting frequency calculation.

In this study, the triangulation of observers and researchers was used to remove possible biases that may arise due to the collection and analysis of the data by a single person (Patton 2015). As mentioned before, both the R1 and teachers conducted observations and assessed children using the observation forms. Further, the codes derived from the interview data and the data in their original form were examined by another analyst from the ECE field to increase their reliability (Hastings 2010). Both researchers exchanged ideas for coding, and the specific themes were reached with 89% agreement.

Findings

What are the Design Principles of an Effective and Parent-Involved Engineering Design Curriculum for Preschool Children?

The findings verified the eight main design principles that were identified in the first phase and revised after the micro-evaluation study. They also revealed that the third prototype should be revised to enhance the clarity of the learning objectives, which is a sub-principle of developmental appropriateness (Copple and Bredekamp 2009). Teachers said that due to the similarities of some indicators, they had some trouble evaluating the children using the observation forms. Therefore, in the final prototype, the researcher revised the indicators perceived as similar to each other and clarified them by adding descriptions of behaviors that the children might exhibit during the engineering activities (see Table 2 in the appendix).

What are the Possible Contributions of Such a Curriculum to Preschool Children's STEM-Related Learning?

Contributions to Children's Knowledge

The findings indicate that the curriculum contributed to children's knowledge of engineering and technology and their understanding of the importance of engineering to human life and the development of society. During pre-interviews, most of the children reported that they did not know what engineers do, while the initial knowledge of children whose parents were engineers was limited to the work of their parents. Moreover, most children recognized all the professions on the cards except that of engineering, and they reported that the person on the engineering card could be a construction worker, a professor, or a repair person who fixed robots. As with engineering, the children's initial knowledge about technology was limited. Four of the five children stressed that they had not heard of a given technology before, and they had difficulty giving examples of technological tools in the classroom (see Table 3 in the appendix).

In the post-interviews, although all children provided correct examples of technology used in daily life after the implementation of the curriculum, most of them still had difficulty defining what technology is. Therefore, the relevant indicator ("can define technology") was modified to "Gives examples of the technologies around them." The findings also showed that some children ($n = 2$) had problems recognizing some of the technologies on the cards (e.g., toothpaste, medicine) because they thought that technology was only related to the working systems and movement functions of objects (see Table 3 in the appendix).

The findings revealed that the curriculum also contributed to children's knowledge of different fields of engineering and the effects of engineering on various areas of human life. After the implementation of the curriculum, although none of the children could remember the name of various fields of engineering, some ($n = 2$) gave correct examples of the technologies produced by engineers working in these fields. Moreover, statements from all the children reflected that they were aware of the effect of engineering in various areas of human life and its role in the improvement of society. According to the findings, the curriculum gave some children an understanding that everyone can be an engineer or think like one. In fact, during the pre-interviews, two children reported that girls could not be engineers; after they completed the curriculum, all children reported that both girls and boys could be engineers. Most of them also gave examples of situations they believed required the work of an engineer (see Table 4 in the appendix).

Contributions to Children's Skills

The curriculum also aimed to contribute to the development of the children's skills in engineering and other STEM areas. For that reason, they were observed each week to track the development of their skills using the observation forms (Fig. 5). The findings indicate that the activities taught the children to identify a design problem or need, brainstorm ideas for a solution, explore available materials, and present their solution by drawing a plan and constructing a model (see Table 5 in the appendix). For example, in the

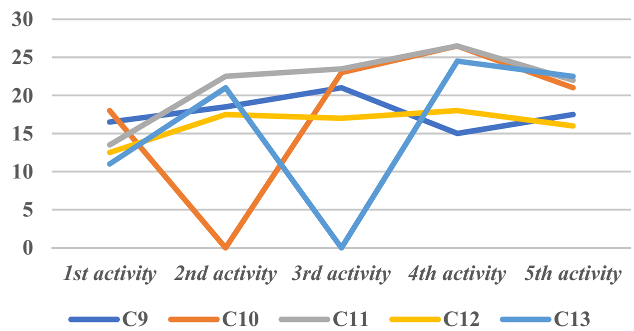

Fig. 5 The scores obtained for each activity by children from the skills dimension. *Note* C10 did not attend to the second activity and C13 did not attend the third activity

third activity, a group designed an elevator to carry three marbles to the parrot's nest at the top of the tree. According to the findings, all the children performed at the proficient level during the first activity, and the majority reached the advanced level as they gained experience in the EDP by way of participating in the activities.

The findings also revealed that the children were skilled in following their plans, choosing the appropriate materials to meet the limitations of the problem, actively experimenting with their models under their parents' guidance, and generating ideas to improve their designs. For example, in the fourth activity, parent-child groups were expected to design a filter to clear a river of waste. They had to consider how to meet certain requirements and circumvent some limitations. The designed filters were meant to collect both big and small waste, and the children had to be able to collect the waste without touching the water (see Table 6 in the appendix).

According to the findings, the curriculum also allowed children to benefit from their existing math-related knowledge and skills and to develop them further with the guidance of their parents. The findings revealed that the activities provided children with abstract experiences in object counting, comparison (e.g., less/more, heavier/lighter, taller/shorter), subtraction, addition, geometry, and fractions (e.g., half and full). Moreover, during the determination of the limitations of the problems, the children gathered some data by making measurements with standardized and non-standardized tools and considered these data while constructing their designs (see Table 7 in the appendix). Similarly, the curriculum enabled the children to exhibit and develop their spatial thinking skills. As they drew up plans displaying their ideas for a solution in each activity, they envisioned the problem and its solution and illustrated them on paper. Moreover, the children added more details about the problem and the solution to their plans as they gained experience in engineering. For example, in the first activity, while all the children drew a triangle in their plans to depict their roof design, in the third week, most of them added the parrot, the parrot's house, and the pulley. Figure 6 illustrates how the children used their spatial thinking skills in the fifth activity.

The children also demonstrated the ability to apply their existing scientific knowledge to their design process, and they had concrete experiences with abstract scientific concepts (e.g., speed, force, incline, pulley systems). Moreover, the learning process provided the children with the opportunity to review their science-related knowledge and test their hypotheses (see Table 8 in the appendix).

Contributions to the Children's Dispositions

The findings of the first activity revealed that the most frequently observed indicators of curious thinking were related to learning new knowledge, gaining new experiences, and asking questions about observation and observable situations. The findings of the second activity indicated that conducting many trials until reaching a successful design, designing a plan in the problem-solving process, following the plan, and pursuing the goal until a successful result is obtained were the most frequently exhibited indicators of persistent thinking. For flexible thinking, the findings of the third activity revealed that proposing various ways to solve a problem and verbally expressing how the design would work before presenting their ideas about solutions with a draft and/or model were the most commonly observed indicators. The findings of the fourth activity revealed that the documenting of experiences and ideas related to the design process was an indicator of the reflective thinking exhibited

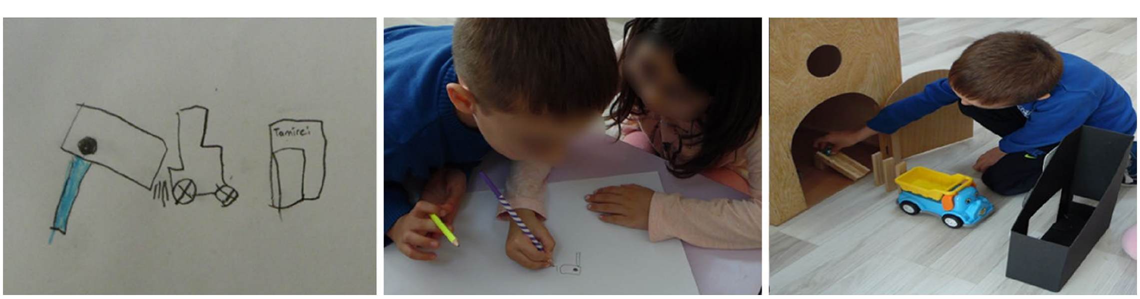

Fig. 6 The plan and design of C10 and C12 to transport the car to the repair shop with the force of a marble

by all the children. Finally, the findings of the fifth activity indicated that the most frequently observed indicators of collaborative thinking were related to the children realizing that other people's feelings and thoughts about a situation or event may be different than their own and to the children waiting for their turn when working with group members on a task (see Table 9 in the appendix).

Contributions to the Children's Feelings

According to the findings, the curriculum provided the children with mostly positive feelings about engineering. The most frequently observed feeling was the pleasure felt when working with open-ended materials in the design process ($f = 23$ out of 25). The children became very excited while exploring open-ended materials ($f = 20$) and seemed happy to produce designs to solve a variety of problems by using everyday materials in unique ways. Being eager to attend engineering design activities ($f = 19$) and being happy to work collaboratively with parents in the design process ($f = 18$) were the other most frequently observed feelings the children displayed. The following excerpts reflect these findings.

First activity
C11 (after choosing their materials and rushing to her seat): Teacher, can we start?
Second activity
T2: Now, would you like to be an engineer again and make a bridge for the turtle?
C12 (laughing and yelling excitedly): Yes!
Post-interview
C9: I liked what I constructed with my father because it was more beautiful. We collected the garbage in the river.

The children also experienced some negative feelings during the activities. It was observed that some children were bored and distracted from time to time ($f = 8$). As seen in the quotations below, according to parents and teachers, the children's distraction may have been related to environmental stimuli and the fact that the activity was held in a classroom different than their usual one.

Post- interview
P11: My daughter was distracted from time to time. I think the ornamental materials distracted her. They were placed there for different purposes and could be used in ways other than for decoration. However, if those materials had not been available, perhaps she would not have been enthusiastic about the activity.
Post-interview
T3: In the classroom, there was almost no material because you had already collected them.…You know, anything can distract their attention. This was unavoidable and was not related to the curriculum or its implementation. No matter where they are, when in a new environment different from their original classroom, there is much stimuli to catch their attention.

As in the excerpt below, participant teachers reported that the curriculum gave them the flexibility to integrate other types of activities (e.g., play and movement activities) into the learning process. Teachers reported that when children became distracted, teachers were able to help them discharge their energy and continue the activity with more focus by adding play activities between the EDP steps.

Post-interview
T2: This was a parental involvement activity conducted on the weekends, and everyone allocated a certain time to participate. When I apply this curriculum in my classroom, I can extend it over the whole day and add something to it. Here, everything is going step by step. I mean, children are drawing plans, creating the models, determining the limitations, and measuring, but when I apply this curriculum in my own classroom and when children get bored, I can add extra activities between these steps. I think that the curriculum provides the teachers with flexibility in this respect.

As seen in the excerpt below, it was also observed that the children were disappointed if their trials were unsuccessful during the design process ($f = 3$). However, observations regarding disappointment were recorded primarily in the first weeks of activity implementation.

First activity
C13 (the paper towel rolls in his roof design are wet, and he turns to his mother with an upset expression): This is not what I wanted. Water got in it.

According to the findings, as the children realized that they had a chance to develop and retry their designs, although they failed during the trials, they started to focus on what the failures meant for the next step. For example, in the second activity, the bridge constructed by a parent-child group fell into the water during a test (see Fig. 7). After testing, as seen in the excerpt below, the child's responses to the teacher's questions indicated that she was aware that her design did not meet the requirements of the problem due to the material she used (paper towel) and that she had some ideas for improving her design.

Second activity
T2: How do you want to improve your bridge?
C12 (shows plastic covers): I will paste these, and the turtle will cross.
T2: But if you also add them, won't the bridge be a little heavier?

Fig. 7 C12 tests her bridge design

C12: I will remove these ones (shows the paper towel rolls), and I will paste these ones (shows the plastic box covers).

Discussion and Conclusions

This study proposed a STEM-based and parent-involved engineering design curriculum for ECE and explored its main characteristics and possible contributions. As Sargeant and Harcourt (2012) emphasized, including children's perspectives while preparing studies aimed at them is critical. The curriculum proposed in this study was developed in response to the feedback solicited from the participant children and therefore reflects their needs and interests. This study provides evidence that the developed curriculum can provide preschool children with both engineering knowledge and overall STEM knowledge. As in previous studies (Knight and Cunningham 2004; Malone et al. 2018; Pantoya et al. 2015), children participants' initial knowledge about engineering and technology was limited and they tended to define engineers as those involved in repair and construction. The findings showed that the curriculum can provide children with the understanding that engineers work to make life easier and engineering is important for people. After the study, all children were able to compare the living conditions of today to those of the past by focusing on the facilitating role of engineering, although they had a hard time explaining how engineering contributed to society and the world. Similarly, although they could not define what the word "technology" means, they were able to give correct examples of technology in their daily lives. As Sullivan and Bers (2016) stressed, the development of preschool children's knowledge of the human-made world and engineering and technology is crucial for them to understand the world we live in. The findings of this study support the relevant literature, which argues that through a developmentally appropriate curriculum and real-world engineering experiences, preschool children can obtain an understanding of engineering and its importance to living things, the environment, and society (Bagiati and Evangelou 2018; Raven et al. 2018).

This study revealed that before the implementation of the curriculum, some children had a bias that girls could not be engineers. Similarly, Knight and Cunningham (2004) asked students in grade three to 12 to draw an engineer and found that the majority of the students drew men. These findings may be related to common portrayals of engineers as men in engineering-related content (Anderson 2013). However, the findings showed that this bias disappeared after the curriculum was implemented; witnessing that both their female peers and mothers could be very successful in engineering and science may have broken this prejudice in children (Reinking and Martin 2018). Moreover, regardless of their gender, children could give examples from their daily lives of situations in which they or their parents worked like engineers. These findings reflect the fact that the curriculum contributed to the perspective children had regarding their becoming an engineer (English 2018; Raven et al. 2018), their perspective that engineering is part of their daily lives, and their acceptance of the idea that people with different characteristics can think like engineers (Cunningham and Lachapelle 2016).

This study also noted that the children had a proficient level of engineering skills, even during the first activity of the workshop, and that the majority of them reached an advanced level in the subsequent activities. This finding supports the literature's finding that preschool children are emerging engineers (Ashbrook and Nellor 2015; Stone-MacDonald et al. 2015), and when they are challenged with developmentally appropriate engineering problems, similar to professional engineers, preschool children can determine the needs or problems and try to construct their own designs to meet or solve them (Bagiati and Evangelou 2016; Dubosarsky et al. 2018; Hoisington and Winokur 2015; Raven et al. 2018). As Purzer and Douglas (2018) stated, appropriate opportunities and support should be provided in order to unearth and develop this knowledge and these skills. Moreover, as this study's findings show, through EEE, it is possible to reveal and nurture preschool children's engineering-related skills with the help of their parents. In line with previous studies (Bagiati 2011; Lottero-Perdue et al. 2016; Pantoya et al. 2015), this study also shows that EEE is a developmentally appropriate way of helping children build the foundations of interdisciplinary thinking. As suggested in relevant studies (e.g. Cunningham et al. 2018; Hoisington and Winokur 2015; Raven et al. 2018), this study shows that EEE aids in making the majority of STEM-related concepts tangible to preschool children and gives them the opportunity to experience these concepts in a realistic context.

This study also demonstrates that children can develop various thinking skills by engaging in EEE. The children were interested in learning new content and making observations. They tested and developed their designs until they were met with success. They produced alternative ideas, expressed their experiences and thoughts verbally or visually, and realized that others may think differently than they do. Moreover, in parallel with the literature, this study revealed that preschool children were pleased to work with open-ended materials while constructing their designs. They were eager to participate in engineering design activities and glad to work with their parents (Bagiati 2011; Weatherly et al. 2017). As Naukkarinen and Bairoh (2020) mentioned, exploring the creative side of engineering might make the discipline attractive to preschool children who already have creative minds (Fox and Schirrmacher 2014).

However, this study also reflects the findings obtained from the implementation of the third prototype of the curriculum. Based on these findings, final modifications were made to the curriculum, but the final prototype was not tested with the target users in the context of a field study. Therefore, it is possible to mention the contributions of the curriculum to children as expected contributions (van den Akker 2010). In future studies, the final prototype of the curriculum can be applied to children and parents with different characteristics.

Finally, this study's findings support the theory that parents can contribute to their children's STEM learning (Dorie and Cardella 2014; Gunning et al. 2016; McClure et al. 2017). This study revealed that the involvement of parents in their children's EEE is important and that children are satisfied when they can solve engineering problems in collaboration with their parents. Meanwhile, the number of developmentally appropriate educational resources that can guide teaching and parental practices is still limited. The curriculum could be helpful in creating learning opportunities so that children can determine design problems, think about how materials can be redesigned, and think about ways to solve problems using their STEM knowledge and skills. Moreover, the curriculum can be an effective way of engaging parents in the process of preschool children's STEM education by means of hands-on activities and thus serve as a bridge between the school and the family in children's STEM education.

Limitations

As stated in previous sections, the curriculum and its positive effects on children were promising. Nevertheless, this study is limited in terms of reflecting the attitudes of parents during curriculum activities. Some parents may have exhibited an overly intrusive attitude in the activities, and this might have impacted their children's performance. Although the researchers made observations and analyses about this potential, reporting it was beyond the scope of this study. In their next study, the researchers intend to share these data and findings with readers.

Additionally, prior to this study, parents were trained in how to guide their children in the EDP, but the duration of this training was short. In future studies, parents may be provided with longer-term training so that some parents' excessively interventionist attitudes can be addressed. Moreover, parents' excessively intrusive attitudes during activities may have been related to their parenting styles (Baranovich et al. 2019). Therefore, future studies should focus on the behavior of parents with different parenting styles in their engineering activities with their children. Finally, in the current study, although only one parent participated in the workshop process with their child, three of the children had engineers as parents. This study did not find that children whose parents are engineers are more competent in engineering activities. However, the fact that three of five children had an engineer for a parent limits this study's implications regarding non-engineer parents.

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