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Short-term effects of a classroom-based STEAM program using robotic kits on children in South Korea

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Abstract

Background Despite the recent emphasis on technology and engineering in early childhood education, the importance of teaching relevant concepts in early education has been underappreciated in South Korea. This study examined the feasibility and efficacy of a science, technology, engineering, art, and mathematics (STEAM) program integrated into the national curriculum in a Korean early childhood education setting. Children aged 5–6 years (231 girls and 219 boys; treatment group: 334 children; control group: 116 children) were tested on computational thinking, vocabulary, numeracy, self-regulation, and social behavior before and after receiving STEAM curriculum that included robotics activities or an equivalent curriculum.

Results Findings revealed that among the outcome measures, young children in the treatment group exhibited significant increases in computational thinking and expressive vocabulary. Moreover, gender demonstrated a significant interaction effect with the increase in computational thinking as measured by an assessment developed for a specific robotic material as well as in self-regulation and social behavior.

Conclusions This study provides empirical and comprehensive evidence regarding the effectiveness of an integrated STEAM program with developmentally appropriate robotic kits for young children.

Keywords Robotic activities, Computational thinking, Program evaluation, STEAM, Educational robotics, Gender differences

Introduction

In the contemporary world, children are growing up in environments with innovative technologies and smart devices that influence their personal development and the culture in which they are raised (Keeley & Little, 2017; Oh & Park, 2019). In our rapidly changing digital society, jobs that require coding and computer science skills to understand and utilize innovative technologies are burgeoning (Cameron, 2020). Computational thinking (CT) refers to problem-solving skills, attitudes, behaviors, and methods that are commonly employed in the field of computer science but can also be applied to various other domains (Bers et al., 2022). Accordingly, children must learn how to proactively analyze and solve problems using the 4Cs (creativity, critical thinking, communication, and collaboration) and 3Rs (reading,' riting, and' rithmetic) as future competencies (The Partnership for 21st Century Skills, 2016). An increasing number of countries have established educational policies or frameworks of technology and computer programming for children, highlighting integrated science, technology, engineering, and mathematics (STEM) education and practices (Caeli & Bundsgaard, 2020; Cameron, 2020;

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Manches & Plowman, 2017; Next Generation Science Standard Lead States, 2013; STEM Learning, 2018; U.K. Royal Academy of Engineering, 2016).

The Early Childhood STEM Working Group (2017) reported that high-quality STEM education fosters young children's abilities, beliefs, and attitudes, such as active engagement, confidence, curiosity, and understanding, to succeed in STEM fields. However, the increased emphasis on STEM subjects may obscure the value of creative processes, including play, exploration, risk taking, and flexible thinking (Eisner, 2001; Hetland & Winner, 2004). STEAM education and practice, which combines STEM with art (A) and encompasses the diverse range of human activities that involve the creation of visual, auditory, or performative expressions to convey emotions, ideas, or experiences, is highly suitable for young children due to their natural inclination toward art activities. Integrated STEAM education allows teachers to incorporate multiple disciplines and explore ways to encourage children's creativity (Perignat & Katz-Buonincontro, 2019; Watson, 2020). In line with this educational trend, the South Korean government proposed an educational policy that focuses on STEAM to strengthen the interdisciplinary approach to education (Korea Foundation for the Advancement & Creativity, 2019; Korea Ministry of Education [KME], 2015). However, to date, CT and technological literacy have only been introduced in late elementary school classes.

Providing engineering and technology education in the Korean early childhood classroom

In 2013, kindergartens and childcare centers in South Korea, managed by different jurisdictions, began mandating a national-level early childhood common curriculum—the *Nuri* curriculum—to establish equal educational opportunities for children aged 3–5 years by providing free education and a unified curriculum. The *Nuri* curriculum aims to facilitate children's problem-solving skills by emphasizing their interests and experiences and adopting a play-based approach (Korean Ministry of Education, Science, and Technology [KMEST] & Ministry of Health and Welfare [MHW], 2013; KME & MHW, 2019). This curriculum comprises the following five content areas: *physical exercise and health, communication, social relationship, art experience, and natural exploration*. Early childhood teachers create lesson plans that incorporate math, natural science, and art activities and materials related to daily life themes (e.g., tools for our lives, our neighbors, summer, and so on). These plans aim to promote young children's learning to math, science, language, and art subjects while implementing the *Nuri* curriculum and engaging them in the learning process (KMEST & MHW, 2013).

Lee et al. (2014) examined the efficacy of the *Nuri* curriculum to evaluate the performance of 5-year-old children in each content area on the basis of their engagement in related activities. They uncovered a significant improvement in children's knowledge, performance, and attitude in each content area after experiencing the *Nuri* curriculum. However, the *Nuri* curriculum lacks specific content related to the engineering (E) and technology (T) domains (Choi & Lee, 2017; Lee, 2014; Sung et al., 2019). Until recently, a lack of understanding and attention to the importance of teaching concepts related to E and T in early childhood education was observed. Nonetheless, in recent years, several countries, such as the United States (U.S.) and the United Kingdom (U.K.), have introduced innovative learning frameworks for teaching E and T knowledge and skills to young children (National Research Council, 2015; U.K. Department for Education, 2013). They have also provided best-practice examples for STEAM education for young children, as demonstrated by Bers (2018), Kermani and Aldemir (2015), STEM Learning (2018), and Sullivan and Bers (2016a).

STEAM education adapted for children's developmental characteristics offers children opportunities to engage in hands-on experiences and participate in inquiry-based activities (Bers et al., 2014; Elkin et al., 2016; Jung & Won, 2018; Jurado et al., 2020; Sullivan & Bers, 2018; Sung et al., 2019; Turan & Aydoğdu, 2020). Young children who engaged in meaningful hands-on STEM experiences exhibited a positive attitude and belief toward learning subjects in these fields (Bagiati et al., 2010; Dejarnette, 2016, 2018). STEAM education for young children can convey the requisite information and expertise of E and T, such as actual programming, without depending on computers or electronic devices and tools in the classroom (Bers, 2018). Integrated activities of arts and crafts, literacy, music, physical play, and other activities using tangible technology tools allow the formation of abstract CT concepts and principles while simultaneously making the inquiry process more visible and concrete (Bell & Vahrenhold, 2018; Horn et al., 2012).

Although some studies have explored the effects of programs developed to teach only E and T skills, few have examined the effectiveness of STEAM education among children in the context of the national early childhood curriculum at the class level. This study applied STEAM activities using robotic programming kits integrated into the Korean *Nuri* curriculum. The effects of a classroom-based STEAM program that was designed to provide basic knowledge, thinking skills, and positive and playful experiences of programming were also examined and compared with the effects of a typical learning approach from the *Nuri* curriculum.

Theoretical background: constructionism and positive technology development

The theoretical approach to robotic activities comes from Papert's constructionism (1980), which is rooted in Piaget's (1954) constructivism and emphasizes children's active construction of knowledge through hands-on experience. In addition to explaining how knowledge is internally constructed, Papert (1980) expanded Piaget's theory by exploring how computers and robotics can support this process. Specifically, Papert explored how learners interact with artificial objects and how the interaction promotes self-directed learning, leading to the construction of new knowledge (Ackermann, 2001). Papert (1980) also noted that well-designed constructionist activities are embedded in "powerful ideas," which are central concepts and skills within a domain that is personally useful and epistemologically interconnected with other disciplines. The robotics activities in this study incorporated powerful ideas from computer science and engineering, such as *algorithms*, *modularity*, *control structures*, *representation*, *hardware/software*, *design process*, and *debugging*.

Positive Technology Development (PTD), a pedagogical approach introduced by Bers (2012), facilitates positive and developmentally appropriate experiences using technology in early childhood education. The PTD framework encompasses six positive behaviors, including content creation, creativity, communication, collaboration, community building, and choice of conduct. Incorporating the PTD pedagogical framework into a robotic kit-mediated learning environment helps children engage in playful computer science learning experiences while improving their socioemotional development (Bers & Horn, 2010; McClure et al., 2017; Sarama et al., 2018). Thus, the current study applied the PTD framework to design a STEAM program in conjunction with the *Nuri* curriculum.

Effects of a STEAM program using robotics activities on children's CT

When a tangible robotic program using a LEGO robot was implemented in a kindergarten classroom, children demonstrated higher sequencing and programming scores in the final part of the project than in the first introductory activity (Bers et al., 2014). As measured by a rubric, study of problem-solving tasks using the Bee-Bot showed significant gains between the initial and final CT (Angeli & Valanides, 2020). Significant effects of the robotic curriculum have been observed in young children's CT using the Colby mouse (Khoo, 2020; Roussou & Rangoussi, 2020), TurtleBot (Nam et al., 2019), KIBO robotics kit (Bers et al., 2019; Sullivan et al., 2017), Bee-Bot (Georgiou & Angeli, 2019; Saxena et al., 2020), and KIWI (a prototype of KIBO; Sullivan & Bers, 2016b).

Although numerous studies have examined the concept of CT, debate continues over its general, educational, and operational definitions (Relkin et al., 2020). Although the definition of CT for young children is still being debated, the measurements used to assess it differ in terms of constructs and method For example, Bers (2018) defined CT in early childhood education as the ability to abstract, formulate, and solve problems. In addition, on the basis of Papert's (1980) definition of "powerful ideas," Bers proposed "seven powerful ideas." Relkin (2018) developed the TACTIC–KIBO instrument to evaluate those seven powerful ideas. However, the TACTIC–KIBO is limited, because it can only measure CT in children after they have experienced a specific robotic platform, such as KIBO robotics kits. Contrastingly, Bebras cards—a classroom card game for children aged 7–11 years provided by the U.K. Bebras Challenge (www.bebras.uk) —can measure young children's CT without requiring a specific programming platform (Dagiene et al., 2017).

Bebras cards include different levels of tasks that evaluate CT concepts, such as patterns, algorithms, logic, and abstraction. It has been validated for young Korean children, and the constructs of young children's CT at the easy level measured by Bebras cards are *pattern recognition* and *algorithms* (Sung, 2022). This study aimed to reveal whether a classroom-based STEAM program using robotics activities integrated into the *Nuri* curriculum can improve children's CT. Considering the effectiveness of unplugged robots in promoting CT in children, we hypothesized that the treatment group (TG) of children engaged in robotic activities would exhibit higher CT capabilities than the control group (CG). However, among the two measurements reviewed above, TACTIC–KIBO, which is measured using a specific platform, could not be applied to CG children who have not experienced KIBO robotics. Therefore, the two groups' CT abilities were compared before and after using only Bebras cards.

Interdisciplinary learning association as an effect of STEAM program using robotics activities

Research that directly examines how robotics programs impact numeracy, language, and social abilities remains scant. Nonetheless, the PTD pedagogical framework suggested that the STEAM program enhances children's interest and knowledge in various areas. High-quality STEAM experiences provide a foundation for learning about these disciplines and bring STEM disciplines into greater balance with other developmental areas, such as language, literacy, arts, physical movement, social interaction with peers and teachers, and mindsets that facilitate curiosity, communication, and collaboration (Bers & Horn, 2010; McClure et al., 2017; Sarama et al., 2018). For instance, programming using Logo's "Turtle" has demonstrated how children develop greater awareness of the properties of shapes and their measurement (Clements & Nastasi, 1993). This approach provides a context for young children's exploration of mathematical ideas (Clements et al., 2001). Well-designed playful learning activities using robotic kits can also support math and science learning, deepen children's understanding of relevant concepts, promote problem-solving skills, and motivate them to apply their knowledge to play.

In addition, a study of the Building Blocks math curriculum found that children demonstrated higher scores in oral language and literacy owing to their ability to recall keywords, express their ideas, and understand spoken language during block activities (Sarama et al., 2012). Conversely, a longitudinal study of children aged 6–9 years found that language ability was associated with high academic performance in geometry, data analysis, and probability 3 years later but not in arithmetic or algebra (Vukovic & Lesaux, 2013). Kindergarten makerspace activities were found to result in an overall high PTD in children (Bers et al., 2018; Strawhacker & Bers, 2018, 2018). In addition, a study involving unstructured robotics classes showed that children engaged in significantly more collaborations (Lee et al., 2013).

Various activities that use or do not use robotic kits allow children to engage in engineering the design of play, such as by building structures, moving objects, counting and measuring, sorting and comparing, and analyzing causalities (Kermani & Aldemir, 2015; Lavigne et al., 2020). In this study, the robotic activities were integrated into the *Nuri* curriculum and connected with various areas of pretend play, block play, music, and reading. The use of the PTD pedagogy framework in the STEAM program allowed children in CG and TG classes to acquire knowledge and thinking skills in multiple disciplinary areas over time. Nonetheless, it was hypothesized that the class that implemented the STEAM program using robots would provide new educational materials to strengthen technology- and engineering-related content and become a new stimulus for activities connected to other disciplines. This treatment should encourage children to participate and interact more actively in activities and play to support their CT and other learning areas than would be the case in a typical curriculum setting.

Gender differences in the effects of the STEAM program using robotics activities

Although numerous studies have focused on how female and male students at the post-secondary school level perceive STEM subjects, this topic has only recently been examined in elementary schools and early education settings. Robotics and engineering courses for high school students have demonstrated that women are less confident in their abilities and struggle more with programming than men (Milto et al., 2002; Nourbakhsh et al., 2004). In kindergarten through second grade, boys perform significantly better than girls on advanced programming tasks involving KIWI robotic kits, such as using repeat loops with sensor parameters (Sullivan & Bers, 2016b). Research conducted in Singapore and the U.S. indicates that girls internalize the stereotype that they are poor at math as early as their preschool years (Cvencek et al., 2015; Gunderson et al., 2012). The results of the Tangible K Program, which comprised six robotics and programming lessons for kindergarteners, showed that boys scored significantly higher than girls in two areas: correctly attaching robotic materials and selecting the right instructions when programming (Sullivan & Bers, 2013).

Present research questions and hypotheses

The present study investigates whether integrating unplugged robotic kits into the *Nuri* curriculum results in higher cognitive and social abilities in children compared to a group of children who experienced the same curriculum without robotics activities. Furthermore, the study explores potential gender differences after the treatment. Specifically, the study aims to answer the following three research questions (RQ) and hypotheses (H).

RQ1: Is there a difference in CT scores between TG children who experienced a STEAM approach using robotics activities integrated into the *Nuri* curriculum and CG children who experienced the conventional learning activities approach of the *Nuri* curriculum?

H1: On the basis of previous research on the effectiveness of unplugged robots and the missing E and T contents in the *Nuri* curriculum, we predicted that CT post-test scores would be higher than pre-test scores and that TG children's CT scores would show greater improvement compared to CG children.

To address RQ1, we used Bebras cards to assess children's CT without a specific platform and examined the treatment effects on CT. Furthermore, we utilized TACTIC–KIBO, a measurement tool that uses a specific platform, to evaluate the improvement in CT-related concepts of young children who programmed robots for 5 weeks. However, given that CG children are inexperienced with programming robots, TACTIC–KIBO measurements using a robot were not meaningful for them. Therefore, we only evaluated the treatment effect using TACTIC–KIBO on TG children.

RQ2: Does the treatment improve children's math, language, and social development, including sociability, prosocial behavior, self-regulation and reduce behavioral problems? Does TG result in a greater increase in children's math, language, and social development compared to CG?

H2: We hypothesized that the STEAM program's development using the PTD framework would lead to transfer effects into cognitive and non-cognitive domains, resulting in higher post-test scores in math, language, and social development than pre-test scores. In addition, we expected that TG would lead to a greater increase in math, language, and social and emotional growth and a reduction in challenging behaviors compared to CG.

RQ3: Is there a gender-based difference in the effects of TG on children's CT, math, language, and social development?

H3: Given that gender-based stereotypes regarding STEM may develop as early as kindergarten (Makarova et al., 2019), we hypothesized that the gender of the children would interact with the effects of TG.

Methods

Participants

The participants were 450 5- and 6-year-old children (mean age = 73 months; boys $n = 219$, girls $n = 231$) from 34 classes of 30 different kindergartens and childcare centers in the cities of Seoul and Busan and in Gyeonggi Province, South Korea. The TG comprises 334 children (mean age = 73 months; boys $n = 154$, girls $n = 180$) who participated in a STEAM education program using robotic kits integrated into the *Nuri* curriculum for a 5-week period. The CG comprised 116 children (mean age = 73 months; boys $n = 65$, girls $n = 51$) who attended a regular early childhood institution that employed the *Nuri* curriculum with the same topic, "Tools for our lives." Although a quasi-experimental setting using non-random sampling for the TG and CG was employed in this study, equivalent groups from institutions that follow the *Nuri* curriculum faithfully were selected.

Kindergartens and childcare centers were recruited by research and program personnel, and 30 institutions agreed to participate. Each early childhood institution signed a memorandum of understanding in which they agreed to accept random assignments to either the TG or CG and cooperate with data collection. Teachers from institutions assigned to the TG participated in a training and then implemented the STEAM program using robotic kits in each classroom in line with the student's interests and play. If an institution was assigned to the CG but wished to join the TG, it was treated as a TG. If an institution was assigned to the CG, the same STEAM program was implemented after data collection as compensation. Parents who consented to their children's participation in the study received information about the children's tests, and only children whose parents consented to their participation in the test undertook the assessment tasks necessary for this study. The participants' backgrounds are listed in Table 1. The teachers from institutions assigned to the TG provided consent for participation in the research involving the 5-week program using robotic kits.

Pre- and post-test procedures

All participants were informed of the procedures, which were approved by the Institutional Review Board, and written informed consent was obtained. Teachers were asked to use the Child Self-Regulation and Behavior Questionnaire (CSBQ) to assess the children who agreed to participate in the study before the workshop on the STEAM program and after implementing the STEAM program. Pre- and post-tests were administered to the children who participated in the Bebras card game, TACTIC–KIBO, Vocab Task, and early numeracy task to examine the effect of the integrated STEAM education using programming robotic kits, whereas the TACTIC–KIBO assessments were administered to TG children using KIBO robotics. Although TACTIC–KIBO was developed to measure CT skills and knowledge, it focuses on a specific programming platform (KIBO Robotics); thus, a comparison between the TG and CG was unnecessary.

Research assistants were trained to establish rapport with the children and consistently administer the assessments. A team comprising three or four graduate and undergraduate research assistants visited the early childhood institutions before the start of the program and after the end of the program to examine the children's CT, vocabulary, and math abilities. They conducted a series of one-on-one tests with young children during free playtime in an independently prepared examination space or room separated from the classroom. The centers provided free play in the morning and afternoon; however, the majority of tasks were administered in the morning, taking into account children's tendency to return home early and the best time for them to concentrate. Before each test, each child verbally assented to the assessment by responding affirmatively to the following: "I am today's teacher. I will show you something new and fun and I want to see how you work with it. Shall we do it together?" Each child participated in three sequential tasks. If the child was bored or unable to concentrate on the examination, the research assistant paused and asked, "Shall we keep going?" and either continued or stopped and sent the child back to the classroom, depending on the child's response. Furthermore, to prevent the

Table 1 Socio-demographic features of children and their families

Variables	Categories	Treatment Group *N* (%)	Control Group *N* (%)	Total
Children		334	116	450
Gender	Boy	154 (46.1)	65 (56.0)	219 (48.7)
	Girl	180 (53.9)	51 (44.0)	231 (51.3)
Experience with robotics or programming	Yes	44 (13.2)	20 (17.2)	64 (14.2)
	No	212 (63.5)	95 (81.9)	305 (67.8)
	No response	78 (23.4)	1 (0.9)	79 (24.4)
Father's educational level	High school	23 (6.9)	2 (1.7)	25 (5.6)
	College	45 (13.5)	1 (0.9)	46 (10.2)
	University	109 (32.6)	1 (0.9)	110 (24.4)
	Graduate school	30 (9.0)	–	30 (6.7)
	No response	171 (40.6)	112(96.6)	239 (53.1)
Mother's educational level	High school	30 (9.0)	2 (1.7)	32 (7.1)
	College	55 (16.5)	1 (0.9)	56 (12.4)
	University	95 (28.4)	1 (0.9)	96 (21.3)
	Graduate school	27 (8.1)	–	27 (6.0)
	No response	127 (38.0)	172 (40.9)	239 (53.1)
Institution	Childcare center	265 (79.3)	25 (78.1)	381 (84.7)
	Kindergarten	69 (20.7)	7 (21.9)	69 (15.3)

children from feeling exhausted, each research assistant was in charge of one task, and they allowed the children to engage in free playtime again after each task, so that the tasks were not performed consecutively. The average duration of each task was approximately 15 min.

Treatment and control classrooms

The treatment program was developed to improve young children's CT, mathematical and scientific concepts, skills, and attitudes using unplugged robots, such as KIBO, as a medium. The play activities in the STEAM program focused on the "Tools for our life" theme, which is part of the *Nuri* curriculum. The educational contents comprised basic concepts and skills of early CT called the "powerful ideas" (Bers, 2018). On the basis of the PTD framework, play activities were developed for children to select tools and materials freely, explore them (i.e., choices of conduct), and create new artifacts (i.e., content creation and construction combined with other materials). The play activities were designed to cultivate the children's creativity, communication, and collaboration, with the ultimate goal of community building by the final week of the KIBO project. The program included 62 STEAM play activities using robotic kits, which were introduced as free play or small- or large-group activities. As the project progressed, the STEAM elements and powerful ideas were expanded in each play activity, allowing the activities to be intensified. However, the control classrooms freely administered the theme of "Tools for our life" of the *Nuri* curriculum without the programming robot for 5 weeks.

Each treatment classroom was provided with two sets of KIBO 21 kits and two sets of KIBO 18 kits developed by the DevTech Research Group at Tufts University. The programming block commands and the conditional statements of the parameter cards were all translated into Korean and attached to English notations to make it easier for children to recognize the symbols and commands. In addition, activity journals entitled "My KIBO Workbook" were provided for young children along with their play activities and KIBO kits. A program manual was developed, and the necessary class materials for the activities were provided to the teachers.

After receiving the consent form and questionnaire packages from the teachers who agreed to participate, a half-day workshop was held to introduce them to the STEAM program. Teachers were taught how to proceed with the play activities of the 5-week program, learned robotics and programming to enable them to operate the KIBO, and practiced robotics work onsite. Before implementing the program, a researcher and research assistants trained the teachers in the half-day workshop on easy operation and then shifted to complex programming on the spot. The teachers were observed and received help developing their programming skills to enable them to implement the STEAM program using unplugged robot kits independently. After the workshop, research assistants occasionally assisted teachers with robotic concepts or program-related questions to ensure that they were confident in implementing the program.

Over a 5-week treatment period, the STEAM program was implemented by 31 classroom teachers, who integrated it into their daily routine on the basis of their education plans and the children's level of interest (Fig. 1). The program included 62 STEAM activities that can be used independently, expanded upon, or connected with play in various areas, such as the spiral scope, and the sequence of the classroom project progressed (Sung et al., 2020). The seven powerful ideas, including basic concepts and skills of early CT, were introduced at the level of exploring the robotic parts of KIBO, such as motors and sensor modules. In the first and second weeks of the program, children learned to recognize the coding symbols in the command blocks. In the third and fourth weeks, they learned the principles of operation and commands, such as repetition and motion conditions of the KIBO robot. During the final week, children were encouraged to create and express themselves freely by programming the KIBO platform and blocks. The research procedure is summarized in Fig. 2.

Child measures

Computational thinking

To assess the impact of the STEAM program on children's CT abilities using unplugged robotic kits, the Bebras cards and TACTIC–KIBO were used. The Bebras cards evaluate CT skills independent of a specific programming platform (Sentence, 2018; www.bebras.uk), whereas TACTIC–KIBO examines CT concepts and programming proficiency using a specific platform, such as the KIBO (Relkin, 2018). Both tasks were translated into Korean and reviewed by professors and field experts in early childhood education and child studies. Each Bebras card includes a task that measures CT concepts, such as *patterns, algorithms, logic,* and *abstraction*. The difficulty of the task on each card was divided into an easy, medium, or hard level. The easy-level task cards comprised 17 tasks covering patterns, algorithms, and logic. Only easy-level task cards were used in this study—even though they did not include abstraction tasks—because tasks above the medium level were overly difficult for 6 years to perform during the pilot examination. A maximum of 3 min was assigned for each task, and the test

Fig. 1 Examples of the STEAM program using robotic kits integrated into the Nuri curriculum. **A** Examples of KIBO plays. **B** Examples of each class project in the final week

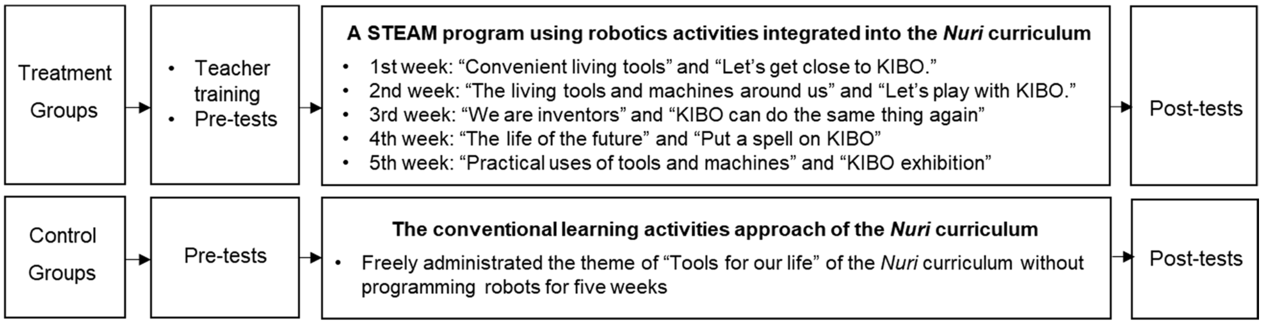

Fig. 2 Research procedures of treatment group and control group

was discontinued if the answers to the five consecutive tasks were incorrect or could not be given. In the results of the construct validity of the Bebras cards (Sung, 2022), some items exhibited extremely low loadings for each construct. After deleting items with a factor loading lower than 0.30 among the theoretical constructs, the *patterns* construct and *logic* construct, for which only two items remained, were combined into the *pattern recognition* construct. Therefore, the Bebras cards have eight items in the two constructs, namely, *pattern recognition* and *algorithms*.

The TACTIC–KIBO was developed and validated by Relkin (2018) to assess programming-platform-specific CT in children aged 4–7 years. It comprises four levels of activity using the KIBO kit, each of which contains questions and tasks associated with the seven powerful ideas (Bers, 2018)—specifically, *control structure*, *hardware*, *software*, *representation*, *algorithms/modularity*, *debugging*, and *design process*. The test was only administered to TG children. Each response to a question or task was scored as 1 for satisfactory and 0 for unsatisfactory. If the total numerical score at each level was higher than 3, the assessment was continued to the subsequent level of questions and tasks. Total and subscale scores for both tasks were calculated and used for subsequent analyses.

Expressive vocabulary

To examine the impact of the STEAM program on children's object identification and labeling skills, the researchers employed the Vocab Task from the Early Years Toolbox (EYT) was employed. The EYT is an iPad-based battery of tests that assesses various aspects of young children's cognitive abilities, such as executive function, self-regulation, language, and numeracy. Developed by Howard and Melhuish (2015) and validated by Chung et al. (2018) in Korea, the Vocab Task involves 55 items that require children to verbally produce the correct label for each stimulus depicted on an iPad screen. The children's responses are recorded using an application, and if a child produces an incorrect label initially, the research assistant prompts them with the question, "What else might this be called?" The subsequent analyses used the total number of correct item scores.

Early numeracy

To evaluate the STEAM program's impact on early math ability, researchers employed the early numeracy task from the EYT battery. This task assesses the following 12 different early numeracy abilities: spatial thinking and measurement, number concepts, cardinality, identifying numbers, matching numbers and digits, counting subsets, number order, conceptual subitizing, ordinality, word problems, patterning, and equations. Before starting the tasks, each child was provided dynamic visual and auditory feedback from the instructional and practice trials. This assessment, which comprises 85 tasks, is in a format that helps participants solve problems. Scores were calculated as the number of correct items; if the child responded incorrectly to five consecutive tasks, the assessment was stopped. The total and subscale scores were used for subsequent analyses.

Child self-regulation and social behavior

The CSBQ (Howard & Melhuish, 2015) was administered to evaluate the effects of the STEAM program on the children's self-regulation and social behavior. This 34-item educator-report questionnaire includes subscales for sociability, externalizing problems, internalizing problems, prosocial behavior, cognitive self-regulation, behavioral self-regulation, and emotional self-regulation. Each item asks respondents to evaluate the frequency of target behaviors on a scale of 1 (not true) to 5 (certainly true). Some items load onto more than one subscale, and the average total and subscale ratings were used for subsequent analyses. A higher score indicates that the child exhibits better self-regulation, higher social development, and lower rates of externalizing and internalizing problems. The internal consistencies of the pre- and post-tests were satisfactory at α = 0.75 and α = 0.77, respectively.

Data analyses

Data were analyzed using SPSS 26.0 Statistics software. First, a descriptive statistical analysis was conducted on children's background, CT, language, mathematics, self-regulation, and social behaviors. Correlation analysis was conducted to examine associations between previous experiences with robots or programming education and children's outcomes and between children's outcome variables from the pre-test and post-test. Subsequently, separate one-way analyses of covariance (ANCOVAs) with pre-test scores as covariates were conducted to investigate the significant effect of the STEAM program integrated into the *Nuri* curriculum on pre- and post-test scores for CT measured by Bebras cards, vocabulary, mathematics, and self-regulation and social behaviors in TG and CG children. In addition, a repeated-measures analysis of variance (ANOVA) was conducted to examine the significant improvement in children's CT concepts related to programming using TACTIC–KIBO through the integration of the STEAM program into the *Nuri* curriculum. The assumptions of the variance tests were checked, including the homogeneity of variance of each group, as this study had non-equivalent group sizes due to its quasi-experimental design. Last, a two-way repeated-measures analysis of variance (ANOVA) was performed to examine whether the STEAM program's effects were statistically significant concerning children's gender, with treatment (pre-test and post-test) and gender (boys and girls) as the two factors.

Results

Preliminary analysis

The intercorrelations for the children's variables are presented in Table 2. The variables of previous programming experiences, such as coding blocks and robotics, were not controlled for in the subsequent analyses, because they were not correlated with children's CT, numeracy, self-regulation, or social behavior, with the exception of vocabulary. In addition, the rate of non-response to items related to previous experiences was almost 25%.

Children's CT abilities measured by the Bebras cards and TACTIC–KIBO were positively correlated in the pre-test ($r = 0.18$, $p < 0.001$) and post-test ($r = 0.28$, $p < 0.001$). Children's expressive vocabulary was positively correlated with CT abilities, as measured by the Bebras ($r = 0.27$, $p < 0.001$) and TACTIC–KIBO ($r = 0.45$, $p < 0.001$) in the pre-test. It was also related to their CT abilities, as measured by the Bebras ($r = 0.42$, $p < 0.001$) and TACTIC–KIBO ($r = 0.46$, $p < 0.001$) in the post-test. Children's math ability was positively correlated with their CT abilities as measured by Bebras ($r = 0.34$, $p < 0.001$) and TACTIC–KIBO ($r = 0.36$, $p < 0.001$) in the pre-test as well as with their CT abilities, as assessed by Bebras ($r = 0.37$, $p < 0.001$) and TACTIC–KIBO ($r = 0.48$, $p < 0.001$) in the post-test. Children's self-regulation and behavior were associated with their CT abilities, as measured by the Bebras ($r = 0.17$, $p < 0.001$) and TACTIC–KIBO ($r = 0.22$, $p < 0.001$) in the pre-test and by the Bebras ($r = 0.14$, $p < 0.05$) and TACTIC–KIBO ($r = 0.14$, $p < 0.01$) in the post-test.

Table 2 Correlations between previous experience in programming and child outcome variables

	1	2	3	4	5	6	7	8	9	10
1. Bebras[a]_pre	1									
2. KIBO[b]_pre	0.18***	1								
3. Voca_pre	0.27***	0.45***	1							
4. Math_pre	0.34***	0.36***	0.46***	1						
5. SR_pre	0.21***	0.22***	0.22**	0.26***	1					
6. Bebras[a]_post	0.45***	0.29***	0.35***	0.35***	0.17**	1				
7. KIBO[b]_post	0.19***	0.52***	0.45***	0.46***	0.12**	0.28***	1			
8. Voca_post	0.32***	0.44***	0.71***	0.51***	0.20***	0.42***	0.46***	1		
9. Math_post	0.24***	0.39***	0.39***	0.69***	0.27***	0.37***	0.48***	0.51***	1	
10. SR_post	0.17***	0.22***	0.22**	0.29***	0.78***	0.14*	0.14**	0.14***	0.29***	1
11. Pre-ex	0.10	0.06	0.12*	− 0.01	− 0.01	0.05	− 0.01	0.15**	0.06	− 0.01

a = Children's CT ability without using a specific platform. b = Children's CT ability while using a specific platform. Voca = Expressive vocabulary. Math = Numeracy. SR = Self-regulation and social behavior. Pre-ex = Previous programming experience; 1 = experience; 0 = no experience. Pre = Pre-test. Post = Post-test; *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

Effects of the STEAM program using unplugged robotic kits with children

The homogeneity of variance across groups was confirmed through a homogeneity test (Levene's test, F [1, 447] = 1.31, $p = 0.253$). Table 3 compares the pre- and post-test scores for children's CT, vocabulary, mathematics, self-regulation, and social behavior using the mean scores and standard deviations after implementing the STEAM program and the regular *Nuri* curriculum for the TG and CG, respectively. The Bebras pre- and post-test average scores for the TG were 3.11 and 3.94, respectively, indicating a 0.83 increase, whereas the Bebras pre- and post-test average scores for the CG were 2.10 and 2.76, respectively, demonstrating a 0.66 increase. An ANCOVA between groups (TG and CG) found significant effects of the STEAM program on TG children's CT measured using the Bebras, F (1, 446) = 13.32, $p < 0.001$, partial $\eta^2 = 0.03$, compared to the CG children's CT.

In addition, the TACTIC–KIBO pre- and post-test average scores of TG were 9.55 and 18.47, respectively, revealing an 8.92 increase. Repeated-measures ANOVA indicated a significant STEAM program effect of the TG children's CT measured by the TACTIC–KIBO, Wilks's $\Lambda = 0.25$, F (1, 326) = 992.85, $p < 0.001$, partial $\eta^2 = 0.75$.

Table 4 exhibits the means, standard deviations, and ANCOVA results for children's expressive vocabulary, numeracy, self-regulation, and social behavior in the pre- and post-tests. In terms of children's expressive vocabulary, the pre-test average scores of the TG and CG were 38.12 and 36.84, respectively, and the post-test average scores were 39.79 and 38.04, with increases of 1.67 and 1.2 points, respectively. The assumption of homogeneity of variance across the groups was satisfactory (Levene's test, F [1, 440] = 0.40, $p = 0.527$). This group difference was significant, F (1, 439) = 3.89, $p = 0.049$, partial $\eta^2 = 0.01$.

The pre-test average scores of children's numeracy were 64.42 and 61.97 for the TG and the CG, respectively, and the post-test average scores were 66.72 and 65.83 for the TG and the CG, respectively. However, the assumption of homogeneity of variance across groups in children's numeracy was violated, indicating Levene's test is significant. The variance ratios were double checked to determine if variances were sufficiently unequal to cause issues (Field, 2004). The variance of TG post-test scores was divided by the variance of CG post-test scores: 99.20 (TG)/57.76 (CG) = 1.72. The variance ratio of pre-test scores was 113.21 (TG)/92.35 (CG) = 1.23. If the resulting values are from 1.5 to 1.8, F tests were robust for all the considered conditions (Blanca et al., 2018). The ANCOVA results indicated no significant difference between the TG and the CG. In Welch's test and Brown–Forsythe's test for unequal variance, no group difference was found, $F = 0.98$, $p = 0.32$, and $F = 0.98$, $p = 0.32$, respectively.

Finally, the pre-test average scores of children's self-regulation and behavior were 3.39 and 3.34 for TG and CG, respectively, and the post-test average scores were 3.44 and 3.35 for TG and CG, respectively. Although the assumption of homogeneity of group variance was satisfactory, the ANCOVA results indicated no

Table 3 Results of pre- and post-tests for children's CT

Variables	Treatment Group		Control Group		ANCOVA		
	Pre-test M (SD)	Post-test M (SD)	Pre-test M (SD)	Post-test M (SD)	F (df)	Partial η^2	Levene's test F
	$n = 334$	$n = 333$	$n = 116$	$n = 116$			
Bebras cards	3.11 (2.05)	3.94 (2.11)	2.10 (2.06)	2.76 (1.97)	13.32 (1446)	0.03	1.31 (1447)
Pattern recognition	1.57 (1.15)	1.94 (1.23)	1.03 (1.25)	1.41 (1.27)	$p = 0.000$		$p = 0.253$
Algorithm	1.68 (1.21)	2.11 (1.18)	1.08 (1.06)	1.36 (0.98)			
	$n = 332$	$n = 329$			Repeated-measured ANOVA		
TACTIK–KIBO	9.55 (5.28)	18.47 (5.12)	–	–	992.85 (1326)	0.75	
Control structure	1.95 (1.13)	3.08 (0.84)	–	–	$p = 0.000$		
Hardware	1.29 (0.70)	2.36 (0.79)	–	–			
Software	1.88 (1.01)	2.86 (0.86)	–	–			
Representation	1.61 (1.20)	2.78 (0.97)	–	–			
Algorithms	0.90 (1.08)	2.58 (1.06)	–	–			
Debugging	0.94 (0.99)	2.73 (1.12)	–	–			
Design process	0.98 (0.63)	2.07 (1.07)	–	–			

ANCOVA analysis of covariance, *ANOVA* analysis of variance

Table 4 Results of pre- and post-tests for children's learning outcomes

Variables	Treatment Group		Control Group		ANCOVA		
	Pre-test	Post-test	Pre-test	Post-test	F (df)	Partial η^2	Levene's test F
	M (SD)	M (SD)	M (SD)	M (SD)			
	$n=331$	$n=326$	$n=116$	$n=116$			
Vocabulary	38.12 (6.77)	39.79 (6.47)	36.84 (6.16)	38.04 (5.71)	3.89 (1439)	0.01	0.40 (1440)
	$n=330$	$n=327$	$n=116$	$n=116$	$p=0.049$		$p=0.53$
Early numeracy	64.42 (10.64)	66.72 (9.96)	61.97 (9.61)	65.83 (7.60)	0.65 (1437)	0.00	4.39 (1438)
	$n=334$	$n=324$	$n=116$	$n=116$	$p=0.42$		$p=0.04$
Self-regulation and social behavior	3.39 (0.50)	3.44 (0.46)	3.34 (0.55)	3.35 (0.61)	2.33 (1440) $p=0.13$	0.01	2.72 (1441) $p=0.10$
Sociability	3.54 (0.63)	3.59 (0.59)	3.56 (0.60)	3.52 (0.63)			
Prosocial	3.59 (0.60)	3.63 (0.57)	3.52 (0.68)	3.52 (0.77)			
Behavior SR	3.63 (0.74)	3.67 (0.68)	3.63 (0.82)	3.60 (0.84)			
Cognitive SR	3.43 (0.72)	3.56 (0.70)	3.42 (0.68)	3.41 (0.69)			
Emotional SR	3.47 (0.52)	3.48 (0.53)	3.33 (0.59)	3.43 (0.59)			
Externalizing_R	2.91 (0.70)	2.93 (0.65)	2.82 (0.75)	2.86 (0.74)			
Internalizing_R	3.12 (0.66)	3.22 (0.61)	3.09 (0.70)	3.11 (0.77)			

SR self-regulation, *R* reversed scores, *ANCOVA* analysis of covariance

significant difference in the change in children's self-regulation and social behavior between the TG and CG.

Gender effects

Table 5 describes the means and standard deviations of the pre- and post-tests of the children's CT abilities, expressive vocabulary, numeracy, self-regulation, and social behaviors before and after implementing the STEAM program using robotic activities integrated into the *Nuri* curriculum. A series of 2 (gender: boys and girls) × 2 (treatment: pre-test and post-test) repeated-measures ANOVAs was performed to detect whether the effect of the STEAM program was statistically and significantly different by gender (Table 6). The children's abilities in all areas improved significantly after implementing the STEAM program using robotic activities. All main effects of the program treatment were statistically significant, indicating significant effects higher than 0.07 in CT abilities, expressive vocabulary, and numeracy, with the exceptions of self-regulation and social behavior, which exhibited a minimal effect at 0.03.

Differences in the main effect by gender were evaluated on the basis of the interaction effects found in the ANOVAs. Although no significant difference was observed between boys and girls in children's CT as measured by the Bebras cards, a significant difference was found between boys and girls in children's CT as measured by the TACTIC–KIBO. That is, the TACTIC–KIBO test's results revealed a small but significant interaction effect between gender and the program's effects, F (1, 325) = 8.57, $p < 0.01$, partial $\eta^2 = 0.03$. In the TACTIC–KIBO test, boys' scores on the pre- and post-tests were higher than girls' scores, and boys exhibited greater improvement in CT after implementing the STEAM program than girls (Fig. 3A). No significant differences were found in the effect of gender on children's expressive

Table 5 Gender differences of the STEAM program for child outcomes in the treatment group

Variables	Pre-test				Post-test			
	Boys		Girls		Boys		Girls	
	N	*M* (*SD*)	*N*	*M* (*SD*)	*N*	*M* (*SD*)	*N*	*M* (*SD*)
Bebras cards	154	2.86 (1.96)	180	3.32 (2.12)	154	3.79 (1.96)	179	4.07 (2.22)
TACTIC–KIBO	153	9.93 (5.30)	179	9.20 (5.24)	152	19.73 (4.68)	177	17.36 (5.24)
Vocabulary	153	38.42 (6.63)	178	37.71 (6.88)	150	40.00 (6.26)	179	39.62 (6.66)
Mathematics	152	65.46 (9.88)	178	63.51 (11.23)	150	67.96 (9.18)	177	65.70 (10.53)
Self-regulation and social behavior	154	3.26 (0.50)	180	3.50 (0.48)	154	3.37 (0.49)	177	3.50 (0.43)

Table 6 Repeated-measures ANOVAs of gender differences in the effects of the STEAM program

Predictors	SS	MS	df	*F*	*p*	Partial η^2
	Differences in CT measured by the Bebras cards					
Program treatment	116.43	116.43	1	45.56	0.000	0.12
Program treatment × Gender[a]	1.34	1.34	1	0.53	0.469	0.00
Error	845.95	2.56	331			
	Differences in CT measured by the TACTIC–KIBO					
Program treatment	13,090.29	13,090.29	1	1024.22	0.000	0.76
Program treatment × Gender	109.47	109.47	1	8.57	0.004	0.03
Error	4153.75	12.78	325			
	Differences in vocabulary					
Program treatment	493.67	493.67	1	39.97	0.000	0.11
Program treatment × Gender	4.29	4.29	1	0.35	0.556	0.00
Error	4001.38	12.35	324			
	Differences in mathematics					
Program treatment	883.30	883.30	1	24.49	0.000	0.07
Program treatment × Gender	3.82	3.82	1	0.11	0.745	0.00
Error	11,612.01	11,612.01	322			
	Differences in self-regulation and social behaviors					
Program treatment	0.57	0.57	1	9.77	0.002	0.03
Program treatment × Gender	0.46	0.46	1	7.93	0.005	0.02
Error	19.19	0.06	329			

ANOVA analysis of variance, *SS* sum of squares, *MS* mean squares, *CT* computational thinking. [a]Boy = 1, girl = 2

Fig. 3 Effects on the STEAM program using robotic kits by gender. **A** Interaction effects between gender and CT measured using the TACTIC–KIBO. **B** Interaction effects between gender and self-regulation and social behavior

vocabulary and early numeracy as a result of the program. Contrastingly, a small but statistically significant interaction effect was observed between gender and the program's effect on self-regulation and behavior, F (1, 329) = 7.93, $p < 0.01$, partial $\eta^2 = 0.02$ (Fig. 3B). Girls' self-regulation and social behavior scores were higher than those of boys in the pre- and post-tests, and the increase in boys' scores was greater than that in girls. Boys' self-regulation and behaviors were significantly enhanced, t (153) = −4.12, $p < 0.001$, whereas girls' scores exhibited no significant increase, t (176) = −0.22, $p = 0.82$.

Discussion

Computational thinking in children

A significant increase in CT scores was observed after employing Bebras and TACTIC–KIBO. The use of robotics activities in the STEAM program effectively improved children's knowledge and understanding of CT concepts, such as pattern recognition, algorithms, logic, control structure, hardware/software, representation, debugging, and design processes. These findings are consistent with previous studies exploring the effects of STEM programs that use robotic kits to enhance CT in young children (Bers et al., 2019; Georgiou & Angeli, 2019; Khoo, 2020; Nam et al., 2019; Roussou & Rangoussi, 2020; Saxena et al., 2020; Sullivan et al., 2017; Sullivan & Bers, 2016a).

The robotic activities integrated into the *Nuri* curriculum significantly improved children's general CT, such as problem solving, as measured by the Bebras card, compared to the conventional *Nuri* curriculum. Although the *Nuri* curriculum enhances children's knowledge, performance, and attitude in the Natural Exploration content area (Lee et al., 2014), the relatively low emphasis on Technology and Engineering in the curriculum may have contributed to a minimal increase in CT for CG children compared to TG children.

Based on the domain-general perspective of the CT definition (Wing, 2006), robotic activities improved children's problem-solving skills, recursive thinking, and evaluation of solutions. Moreover, the correlation results support the PTD perspective that children's CT is associated with various cognitive domains, self-regulation, and social development, indicating positive and significant associations between all outcome variables (Bers & Horn, 2010; Flannery & Bers, 2013; McClure et al., 2017; Sarama et al., 2018).

The increase in CT scores measured using the TACTIC–KIBO was larger than that assessed using the Bebras cards. This difference in scores can be attributed to the fact that the TACTIC–KIBO measures CT-related elements on the basis of the KIBO Robotic Kit. During the 5-week program, the children explored and applied the KIBO kit in various ways, such as operating programming commands as they wished, completing more complex activities, and engaging in independent play. Consequently, the CT scores measured using the KIBO kits were more distinct in determining which subdomain of CT knowledge was acquired after the program was implemented. Children who had been proactively immersed in the activities demonstrated a higher level of familiarity when handling the KIBO robot kits, which correspond to the tasks of the TACTIC–KIBO measurement, than before the program. The findings suggest that the STEAM program, utilizing robotics activities, offers more diverse teaching materials for young children to learn engineering and technology than typical programs that do not use materials for robotics. By combining these topics with various types of play, the program enriches children's experiences and expands their understanding, thereby strengthening their CT abilities.

Vocabulary, numeracy, self-regulation, and social behavior in children

The STEAM program using robotics activities, integrated into the *Nuri* curriculum, expanded children's vocabulary. As aforementioned, a high-quality STEAM program with robotics activities provides learning opportunities to connect children's knowledge and skills in the linguistic domain. Children's engagement in robotic play using new and interesting materials, such as KIBO kits, can provide them opportunities to express their ideas and learn new vocabulary, which can increase their use of diverse vocabulary. Our findings partially support previous results showing that children develop critical thinking, executive functioning, and problem-solving abilities that demand cognitive skills across domains in STEM play (McClure et al., 2017; Sarama et al., 2018).

Although the improvement was not statistically significant when compared to the CG, children who participated in integrated robotics activities exhibited greater improvements in mathematics, self-regulation, sociability, and prosocial behaviors as well as fewer internal and external behavioral problems than CG children. As the *Nuri* curriculum itself improved children's holistic development, including cognitive, social, and behavioral development (Lee et al., 2014), the TG's effects did not reach a significant level compared to the CG.

However, the TG children exhibited significant improvements in all areas in the within-subject results. In the process of play and activities using the new robotic kits, children mathematize their play, collaborate with peers, and use prosocial skills, including self-regulation, to solve problems that arise during play. This supports previous PTD findings that STEAM education fosters children's cooperation (Bers et al., 2018; Lee et al., 2013). In addition, these outcomes align with Strawhacker and Bers (2018) findings that tools and materials in robotic kit-mediated learning environments inspire children to build, program, and create. As teachers support children's choices of conduct and community building, such activities can promote children's PTD. Experiences in STEM activities help children gain confidence, curiosity, interest, and positive attitudes within and outside STEM subjects (McClure et al., 2017; Sarama et al., 2018). Considering that CT involves general competence in skills, processes, and approaches to problem solving (Selby & Woollard, 2013; Wing, 2011), elevated CT ability may be extended to other domains, such as children's vocabulary, numeracy, sociability, and self-regulation, or vice versa.

Gender effects

The interaction effect between the children's genders and program effects was significant for CT as measured by TACTIC–KIBO as well as for self-regulation and social behaviors. This finding is partially consistent with the results demonstrating that boys who applied the programming curriculum demonstrated more advanced programming skills than girls (Sullivan & Bers, 2013, 2016b) and may reflect the effects of stereotypes of STEM-related practices. The interaction effect of gender was found only on CT as measured by TACTIC–KIBO using specific robotic kits. During the program's free play with robotic kits, the girls exhibited an interest in decorating the robot, whereas the boys were more interested in programming and operating it. This observation of children's play is similar to the findings of children's exploration of behaviors associated with the introduction of technology to free play in Swedish preschools (Elvstrand et al., 2012).

Most children aged 5–16 years and adults consider a mechanical robot, with or without a face, to be male (Beran et al., 2011; Cameron et al., 2016; Walters et al., 2008). Although the KIBO robot used in the present study is a faceless, neutral-colored, gender-neutral toy, boys tend to approach it in a friendlier manner than girls due to its similarities with a wheeled car. Considering that young children prefer robots of the same gender (Sandygulova & O'Hare, 2018), it may be possible to increase their participation and interest by considering their preferred play type or play materials in STEAM programs using robotic kits or technology education.

Bian et al. (2017) reported that from the age of six, girls begin believing that they are not smart enough to perform math-related activities. Mawson (2010) examined the responses of seven children to questions about their views on technology and found some slight gender differences. The girls were slightly more likely to select household items in the pictures of technology, and they were also more likely to indicate that they could not decide or did not know in their responses to some statements about technology. However, all children agreed on some statements, such as the belief that there are chances to design and plan new things in technology and that anyone, not just experts, can use technological items. The study also found that girls may have a more socially contextualized view of technology than boys. These passive beliefs or attitudes about STEM in girls may lead them to engage less in STEAM activities and eventually result in less learning, such as CT, about certain programming platforms, KIBO, math, and self-regulation and social behaviors. To encourage young girls to increase their interest in and self-belief about STEAM from an early age, gender-neutral STEAM programs or STEAM education using materials that are attractive to girls must be provided. As children exposed to programming curricula or STEAM programs hold fewer gender stereotypes regarding STEM professions (Metz, 2007; Sullivan & Bers, 2016a, 2016b), parents and teachers should be more sensitive to gender biases during conversations with children when preparing educational play and materials and constructing educational environments and materials. Beliefs, attitudes, and expectations of teachers and parents can influence girls' behavior and guide them in STEM activities (Tenenbaum & Leaper, 2003; Thomson et al., 2017).

Limitations and future research directions

Although the size of CG was smaller than that of the TG, this study demonstrated the impact of a 5-week STEAM program that incorporated robotic activities on children's outcomes using a quasi-experimental design. However, a limitation of this study is that the 5-week program was a relatively short period to expect significant developmental changes in young children, which may explain the small but significant effect sizes of the TG and CG comparisons. Nevertheless, the intraindividual comparison of the experimental groups revealed a medium to large effect size of the treatment program. Future studies should examine changes in young children using a wider range of play materials and extend the program beyond 5 weeks.

Furthermore, although we inquired about the children's prior exposure or education in robotics or programming, we did not have information on the contents, methods, or duration of such experiences or education. We simply asked them to confirm the existence of the experience. Therefore, future research should control for STEM-related activities using other materials or prior experience in the child's home or institution before the STEAM program implementation to examine the program's effects. In addition, this study did not examine other variables that could have influenced the program's effect size. Subsequent studies should investigate how teachers' teaching efficacy, attitudes, and pedagogical knowledge influence their implementation of the program and children's learning outcomes. Whether children's general cognitive and social abilities impact their development of CT should also be explored.

Although not systematically observed, we found that girls exhibited an interest in decorating the KIBO, whereas boys demonstrated an interest in programming and operating it. These behaviors can be reinforced or reduced depending on how teachers react. Thus, further research should examine whether teachers' gender biases affect children's roles in their activities or interests in STEM play.

Finally, the present study provided teacher training for the STEAM program and guided teachers to link the method of robotic activities to the *Nuri* curriculum. However, measuring the actual operation of the program or the quality of the play or project was not possible, because the teachers were allowed to freely adapt the program to follow the class's interests and the institution's schedule. In future research, the program's quality must be assessed, and whether differences among the programs influence their effects must be determined.

Conclusion

This study provides empirical and comprehensive evidence of the effectiveness of a STEAM program among young children in the Korean early childhood education and care field. On the basis of pre- and post-results for a larger sample size than previous research, this study identifies various outcomes of child participants and their CT. Furthermore, it not only highlights the use of robotic kits in STEM education but also demonstrates their value in a classroom-based curriculum that aligns with the national *Nuri* curriculum.

Although the lifelong benefits of early STEM education cannot be assumed solely on the basis of the effect of a STEAM curriculum on early development, it has been demonstrated as a predictor of future academic success. For example, early math ability is the most consistent predictor of later academic success (Jordan et al., 2009; Nguyen et al., 2016; Rabiner et al., 2016), and positive approaches to learning in early childhood predict students' reading and math achievements (Razza et al., 2015; Sung & Wickrama, 2018). However, a lack of alignment between preschool and elementary STEM curricula and limited opportunities for early STEM education have caused some children to fall behind during a crucial learning and development period. While following the play-based approach of the mandated *Nuri* curriculum, practitioners of the 2019 revised *Nuri* curriculum must consider improving children's CT skills by utilizing materials, such as KIBO, that are suitable for children's developmental stages and preparing an environment for children to experience technology and engineering content.

In addition, adequate training must be provided to early childhood educators in teaching STEM concepts and to promote changes in teachers' and parents' understanding of high-quality STEM education. Therefore, education administrators and professionals in leadership positions must implement a public educational policy for early STEAM education and address-related challenges, including the development of new STEAM programs and resources, research and advisory councils to promote early STEAM curricula, and professional development training and incentives for STEM education.

Abbreviations

ANOVA	Analysis of variance
ANCOVA	One-way analysis of covariance
CG	Control group
CSBQ	Child Self-Regulation and Behavior Questionnaire
CT	Computational thinking
EYT	Early years toolbox
PTD	Positive technology development
STEM	Science, technology, engineering, and mathematics
STEAM	Science, technology, engineering, art, and mathematics
TG	Treatment group

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Author contributions

The first and third authors acquired funding and supervised the research team. The first author contributed to the study design and conducted the data analysis. The first draft of the manuscript was written primarily by the first author, with the assistance of the second author. The second author performed the data collection and coding with the preparation of the materials. All the authors commented on the previous version of the manuscript and approved the final manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The data sets are available from the corresponding author upon reasonable request.

Declarations

Competing interests

The authors declare no competing interests.

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