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REGULAR ARTICLE

Connecting Plans to Action: The Effects of a Card-Coded Robotics Curriculum and Activities on Korean Kindergartners

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Abstract This study examined the effects of a card-coded robotics curriculum and associated activities on kindergarteners' sequencing and problem-solving skills, which are forms of computational thinking. Kindergarteners participated in card-coded programming using a robot called TurtleBot. A card-coded robot curricular intervention was also designed to enhance their planning behaviors using complementary tools. This study examined an 8-week robotic curricular intervention through assessment of 53 participants ranging in age from 5 to 6, while also evaluating sequencing and mathematical problem-solving in both the treatment and comparison groups. It was found that children in the treatment group who engaged in the card-coded robotic curricular intervention performed better on sequencing and problem-solving tests. This finding indicates that an enhanced planning experience using card-coded robots was beneficial for improving young children's thinking skills. The implications for designing appropriate curricula using robots for kindergarteners are addressed.

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Introduction

Kindergarten children are characterized by curiosity and a desire to learn about the world, particularly via hands-on experiences (Piaget 1953). Recently, kindergarten educators have focused on robotics and computer programming as methods of teaching academic skills to kindergarteners through hands-on experiences with new technologies. In early childhood, new technologies create opportunities to enhance young children's growing, learning, and playing (Bers 2008; Elkin et al. 2016). Research has shown that preschool children can engage in and complete basic programming and robotics tasks (Sullivan and Bers 2016; Sullivan and Kazakoff 2013).

Bers and colleagues (Bers 2008; Bers et al. 2013b) emphasized the potential for robotics and computer programming to be used as the primary tools for teaching technology and engineering to young children in the digital era. Globally, robotics and computer programming for young children have grown in popularity because of support from governments and private initiatives (Elkin et al. 2016). The Korean National Curriculum for early education emphasizes the importance of increasing children's thinking skills through science, technology, engineering, art, and math (STEAM). Compared with trends in Western early education, the technology and engineering STEAM subjects have barely been emphasized in the national curriculum and kindergarten instructional practices (Barron et al. 2011). Programming using robotics or visual tools for young children has been shown to facilitate social development (Bers et al. 2013a), and to facilitate the transformation of abstract concepts of science, engineering, and technology into concrete real-world understanding (Bers et al. 2013a, b); scientific process understanding (Williams et al. 2007); mathematical skills improvements and achievements (Highfield 2010); and cognitive and fine motor skills.

Based on the demonstrated potential of robotics and computer programming in early-childhood education, the key to using robotics and programming to build curricula and instruction lies in reducing the cognitive load as well as teaching in developmentally appropriate ways. In this study, we focused on the role of card-coded robotic curriculum in enhancing planning behaviors using complementary tools to compensate for developmental weaknesses in young children's computational thinking, including sequencing and mathematical problem-solving.

Literature Review

Educational Robotic Programming for Kindergartners

The use of robotics and computer programming to teach is also known as "educational robotics," which imparts knowledge regarding robot programming or the design, creation, and assembly of robots to enhance learning (Di Lieto et al. 2017). As a thinking tool, educational robotics programming can influence kindergartners' cognitive abilities, particularly in STEAM skills, such as scientific processing, mathematical concepts, the transformation of abstract concepts into concretes, and metacognitive skills (Benitti 2012; la Paglia et al. 2011). Also, Bers et al. (2014) reported on the potential benefits of robotic activities in early education and assessed kindergartners' problem-solving and sequencing skills to assess the children's computational thinking (Kazakoff et al. 2013). Robotic programming is a developmentally appropriate strategy for kindergarten classrooms.

Development of Children's Planning Behavior and Robotic Programming

Early-childhood researchers focus on planning behavior development to encourage computational thinking in young children. Planning ability is a complex executive skill that develops on a timetable similar to that of the theory of mind, to which it might well be related (Atance and O'Neill 2001). By 2 years of age, children's ability to talk about future events begins to increase and continues to increase during the preschool years (Hudson et al. 1995). However, children's ability to sequence future events is not well developed until 4 years of age (Friedman 1990). As a form of self-regulation, planning includes sequencing as a fundamental component and involves organizing objects or actions in the correct order (Zelazo et al. 1997).

To develop a successful program using robotics, children must use sequential thinking as a type of computational thinking and plan their programs in a sequence regarding what happens *next*, *before*, or *until* another action. Sequencing is an important skill in early childhood, and it is fundamental to understanding and creating computer programs (Kazakoff et al. 2013). Sequencing is also a crucial ability for understanding the world mathematically (Sarama and Clements 2004; Zelazo et al. 1997), and it is a typical instructional strategy used to teach mathematics and literacy in the kindergarten classroom (Kazakoff et al. 2013). Sequencing tends to call upon children's algorithmic thinking (Angeli et al. 2016). To instruct a robot to move, children need to use procedural thinking and the logic of instruction (Kazakoff et al. 2013). Computer programming is a type of story sequencing (Kazakoff et al. 2013), and Kazakoff et al. (2013) asserted that robotics and programming in kindergarten classrooms could be integrated into various early-childhood curricular areas that require sequential thinking.

Development of Problem-Solving Skills Through Educational Robotic Programming

When children try to learn how to solve a problem using robot programming in properly designed educational environments, they can engage in computer programming experiences to articulate thoughts, observe the outcomes, clarify their thought processes, and receive feedback from teachers (Clements and Nastasi 1999). For young children, learning robot programming through an age-appropriate approach can facilitate the development of higher cognitive processes, such as problem-solving, creative design, creativity, and collaboration, via active participation with, consideration of, and control of the robot (Fessakis et al. 2013). Also, children can participate in active, iterative, and retrospective thinking as problem-solving skills through appropriate failure experiences via learning opportunities experienced while building and programming a robot to complete certain tasks (Flannery and Bers 2013).

Complementary Actions and Tools Used in Young Children

Complementary actions in children's learning are physical actions that may act alone or involve artifacts to reduce cognitive load and improve task performance. External memory devices include technological tools and worksheets (Antle 2013b). Complementary actions and tools are important to aid in developmental improvement and to reduce the cognitive load of young children during difficult tasks (Antle 2013b).

Children use their hands to think (Antle 2013a), and these physical interactions with the world are a key component of cognitive development in childhood. In the embodiment approach to child–computer interactions, the environments around children can support the development of cognitive abilities by allowing for the manipulation and operation of artifacts and external representations (Antle 2013b). Regarding cognitive development, children may successfully learn and complete difficult tasks by focusing on cognitive resources and key aspects of performing an activity using their environment (Manches and Claire 2012). A curriculum for young children needs to include the cognitive structuring of physical and mental actions through hands-on approaches to promote learning that includes the manipulation of physical materials, and this technique was emphasized by Montessori (1966). The use of manipulation in educational materials is designed to help students consider the aspects of physical form and represent abstract concepts (Antle 2013a). Recently, the manipulation of the physical materials approach has been extended to the computational domain for young children. Hands-on actions involving physical computational tasks make abstract concepts more accessible to children (Antle 2013a; Resnick 2006). For children, the theory of complementary actions supports the notion that physical actions in computational tasks make difficult mental tasks easier to perform and are thus beneficial to children's learning.

When children are provided with complementary support, including robots and worksheets, they can learn computer programming as a problem-solving or thinking skill. Using robots for complementary actions can be concrete through the following robotic activities: collaborative planning, representing tasks, practicing their strategies, and applying their plan in the real world. Also, worksheets represent a complementary tool for children to monitor their progress during the process of problem-solving (Merriënboer 1997) as well as a hard support scaffold that can be developed based on learner difficulties prior to an assigned task as a paper-based cognitive tool (Saye and Brush 2002).

Research Questions

The main goal of this study was to examine how kindergarteners respond to coding with a card-coded robot called TurtleBot by using an instructional model and curriculum to develop children's sequencing and problem-solving skills. The instructional model and curriculum were designed for children to perform complementary planning and interactions with a card-coded robot via the adoption of worksheets and tasks with the teachers' scaffolding support. Previous studies (Elkin et al. 2016; Flannery and Bers 2013; Kazakoff et al. 2013) revealed that robotic programming by young children in the classroom influences cognitive and social abilities. However, few previous studies investigated the role of planning activities in an instructional model of robotic programming using complementary tools. Also, previous studies did not evaluate the effects of instructional models and curricula that emphasize planning behaviors and actions using complementary tools in kindergarten classrooms. This study explored the following research questions:

1. What is the instructional model that emphasizes planning and action behaviors in card-coded robotics?
2. Does a card-coded robotic curriculum based on an instructional model that promotes planning affect sequencing and mathematical problem-solving skills?

Method

Participants

The study sample consisted of 53 children from 2 classes at an urban private kindergarten in the Republic of Korea. The final sample consisted of 53 children because one child did not participate in the pre-tests. At the time of the experiment, the children ranged in age from 5 to 6 years. There were 21 girls and 32 boys. The groups consisted of 25 children (girls = 10, boys = 15) in the treatment group and 28 children (girls = 11, boys = 17) from one class in the comparison group. The studies in both classes were administered by their teachers, who had seven years of teaching experience and a researcher was present in each class. Both classes utilize the national curriculum for kindergarten.

Study Design

A quasi-experimental design was adopted with pre-test and post-test samples, which were conducted with an untreated comparison group (Shadish et al. 2002). Two kindergarten classes were separately designated to be a treatment group and a comparison group. This study included pre-tests and post-tests in both groups. In both the treatment and comparison groups, the children were tested to determine their sequencing (Baron-Cohen et al. 1986) and problem-solving performance in mathematics (Ward 1993). Each kindergartner spent 25 min on the pre-tests and post-tests. The robotics curriculum was performed 12 times over eight weeks in 2017, and a post-test was administered to each kindergartner (Figs. 1, 2).

The Foundational Phase

During the robotics curriculum implemented after the pre-test, the kindergarteners were engaged in two stages of foundational activities and applications that consisted of four and eight activities, respectively (see Table 1). In the foundational phase, four or five kindergartners comprised one group and shared ideas on how to operate the TurtleBot. For example, kindergartners were educated on topics that included turning on the TurtleBot, scanning the colored cards to make commands, and running the scanned commands to move the robot.

The Application Phase

The researcher administered the application phase in small groups within the treatment group. Each activity in the phase took 10 to 15 min. At the beginning of the phase, a researcher introduced that day's activity to the whole class and allowed them to practice with a problem. Subsequently, two or three kindergartners were assigned to a group, and a personal worksheet was provided to each student. The group operated a TurtleBot and collaborated to solve the problem. The eight activities in the application phase began with working on the worksheet. Before operating the TurtleBot, the kindergarteners practiced their strategy in advance using the worksheet. They used the pens and stickers whose colors corresponded to the command cards to draw arrows on the worksheet and then scanned the same-colored cards to operate the robot. If the kindergarteners wanted to retry the activity after a failed attempt at problem-solving, they were allowed to do so. Additionally, the teachers helped to modify their paths on the board when kindergarteners demonstrated incorrect paths on the worksheet through questions, such as "Do you know where the mistake is to solve this problem?," "Are there any other ways to solve this problem?," or "Can you fix the incorrect part in the worksheet?." In the treatment group, the curriculum illustrated in Table 1 was used. The kindergarteners in the comparison group performed sequencing and problem-solving activities based on the national curriculum (i.e., Nuri-courses) for eight weeks instead of the TurtleBot program. They worked with mathematical aids that included a number-board game for number manipulation, objects for counting, and puzzles in free, hands-on activities.

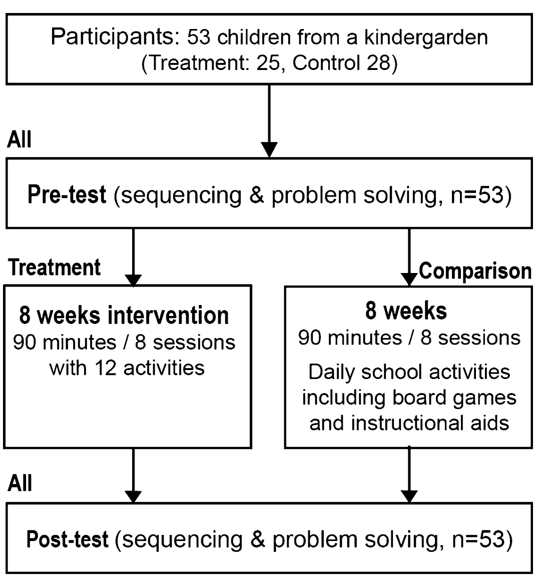

Fig. 1 Research procedure

Intervention: TurtleBot for Kindergartners

The materials used in this study included the TurtleBot, which is a card-coded robot. Four types of colored cards represent a block of code and were adopted in the present study (Table 2). The green card is the *forward* command, the red card is the *backward* command, the blue card is used to make the robot *turn right*, and the yellow card is used to make the robot *turn left*. The children can create a program for the robot to follow by sequentially scanning the cards. The cards make the TurtleBot move 5 cm forward, move 5 cm backward, or turn 90 degrees left or right. A board with a 4 × 4 grid was provided to execute the robot commands based on the coding sequence and solve the given problems.

In this study, we developed an instructional model for enhancing computational thinking in kindergarteners using a programmable toy called the TurtleBot. Figure 3 illustrates a way that this model can support the selections of individual kindergarteners, particularly during free play,

Fig. 2 Card-coded robot, TurtleBot (**a**, **b**), and entry into a coding sequence (**c**)

(a) **(b)** **(c)**

Table 1 Eight weeks of robotics curriculum in the experimental group

Phase	Number	Activity content	Work sheet	Component(s) of computational thinking
1st phase Foundational phase	Activity 1	Mastering basic functionalities (begin, forward)	No	N/A
	Activity 2	Mastering basic functionalities (begin, forward, backward)	No	N/A
	Activity 3	Mastering basic functionalities (forward, backward, turn right)	No	N/A
	Activity 4	Mastering basic functionalities (forward, backward, turn right, and left)	No	N/A
2nd phase Application phase	Activity 5	Returning a baby bird to the nest	Yes	Procedural thinking
	Activity 6	Going to meet Bong Bong	Yes	Algorithmic thinking
	Activity 7	Finding a doughnut	Yes	Efficient thinking
	Activity 8	Riding a bus	Yes	Efficient thinking
	Activity 9	Making a sandwich	Yes	Procedural and efficient thinking
	Activity 10	Taking a trip to China	Yes	Patterns
	Activity 11	Finding letters	Yes	Efficient thinking, algorithmic thinking
	Activity 12	Traveling to see dances around the world	Yes	Efficient thinking, algorithmic thinking, and disassembling

Table 2 Descriptions of each TurtleBot color card

Card	Action
Green card	Move forward: the robot moves 5 cm forward
Red card	Move backward: the robot moves 5 cm backward
Blue card	Turn right: the robot turns 90 degrees right
Yellow card	Turn left: the robot turns 90 degrees left

regardless of the instruction period and size of the group. This model assumes that the programmable toy can be applied in classrooms according to the developmental level of kindergartners and provide opportunities for engagement to every kindergartener in the classroom. The model consists of problem identification, idea generation, solution planning using worksheets, coding with cards, and robot

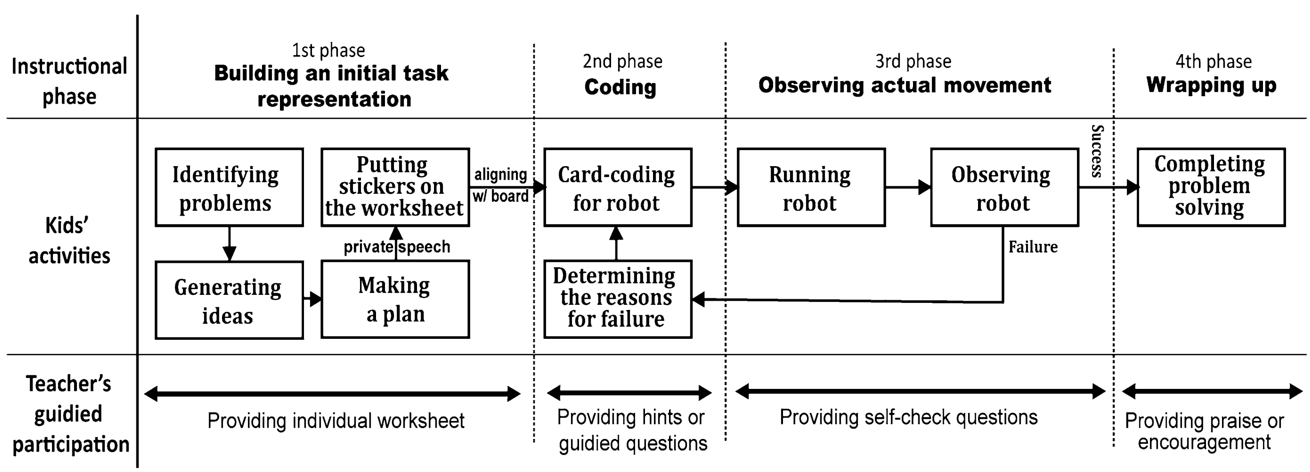

Fig. 3 Intervention for kindergarteners to enhance robot programming planning

movement observations. One of the important phases in the model is to have the kindergartners plan their solution on the worksheets to create a solution representation using visual components before conducting their coding activity. When the kindergartners failed to solve a problem, they may repeat the reasoning, coding, and observation processes.

1st Phase: Building an Initial Task Representation

In the first phase, an initial task representation was built collaboratively, and then the kindergartners identified the problem, generated ideas regarding how to solve the problem, and made a plan to solve the problem. After planning how to solve the given problems together, the children worked individually using a worksheet as a complementary tool before moving on to card-coding the TurtleBot. As an aid, individual worksheets to represent their solutions were provided. After exploring the ways to solve the problem, the students applied stickers to the worksheet. The stickers were small in size, and the same design was used for the robot-coding cards. During the exercise, a worksheet with a 4 × 4 grid, which represents a minimized 4 × 4 grid board, provided an important complementary tool for students as they constructed their strategy (Fig. 4). The worksheet mimics the board on which the robot moves before performing tasks, which helped them to plan a solution to the problem and understand the problem and relevant content while working on the task. The teachers could identify the level or zone of proximal development through the process of generating various ideas and planning. Additionally, the kindergartners used private speech during the planning section of the worksheet for self-guidance and self-direction (Lidstone et al. 2011). During the preschool years, private speech, which represents communication with the self, emerges at times of difficulty and supports learning when the child is working on a task (Lidstone et al. 2011; Winsler et al. 1997). When using the worksheet for idea generation, the children tended to speak aloud and think through their ideas. Through this process, they could explore new knowledge, such as right and left directions, and attempt to represent a solution.

2nd Phase: Coding

In the second phase, card-coding with planning was performed, and the children inserted the cards into the robot based on their planned path to solve the problem on the worksheet. The children created a program using colored cards as a complementary tool by scanning them sequentially. The children inserted the cards into the robot according to their plan on the worksheet. The children had to practice aligning the work between the worksheet and the board. This practice was important for translating the children's cognitive executive connection between a small-scale plan and implementation. The teacher's role was to facilitate the connection between planning on the worksheet and the performance on the board.

3rd Phase: Observing Movement

In the third phase, the robot's movements were observed, in which the children observed the robot's movement based on their card-coding activity and identified the correct or incorrect coding. When the children failed to solve the problem of moving the robot, they thought through the reason for failure, identified unsuccessful strategies, and modified their plan. This step was also called the debugging or troubleshooting process, which refers to the cyclical or iterative process used to understand why something is not working or behaving as expected (Bers et al. 2014; Weintrop et al. 2016). In the process, children could use their own strategies to become engaged, such as putting

Fig. 4 Activities using 4 × 4 worksheets and grid boards

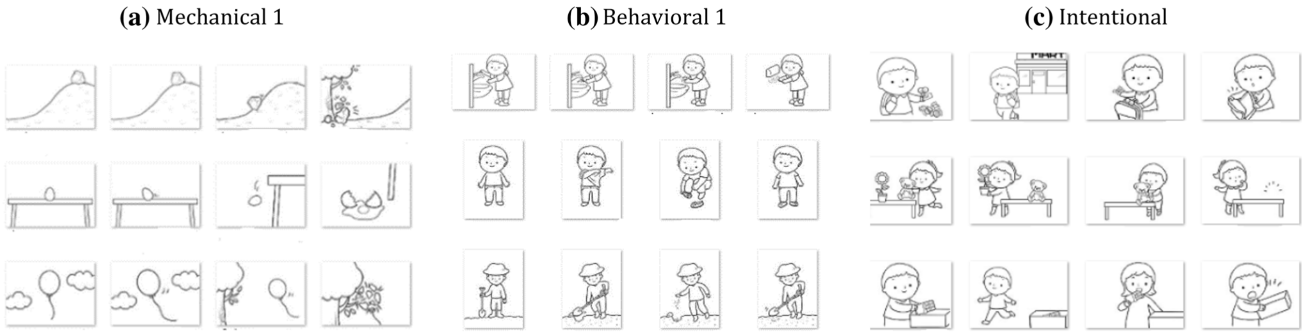

Fig. 5 Sequencing examples of **a** mechanical, **b** behavioral, and **c** intentional stories

stickers on the worksheet and the board or using their body to understand the direction of the robot. When the children wanted to elicit help from their teachers or friends, the teacher needed to encourage them by asking questions to help them reach the solution.

4th Phase: Wrapping Up

In the fourth phase, the children completed the problem-solving task with the robot. The teacher provided praise or encouragement to the kindergartners based on their results.

The teacher's main role was to facilitate the process of computational thinking using TurtleBot by providing the necessary scaffolding to engage the kindergarteners properly. Scaffolding, based on Vygotsky's concept, is the process by which a more knowledgeable peer or teacher enables the solving of tasks that would be hard for learners to complete independently (Wood et al. 1976). Based on this concept, in this study, scaffolding involved the teachers controlling any elements of the task that were initially beyond the students' capacity. The teacher facilitated the students' development of various ideas through appropriate scaffolding for each individual child, so they can develop their plans on their worksheet. This process allowed the children to plan prior to beginning a coding project and use real-world thinking to solve problems.

Instruments

Sequencing

To measure young children's computational thinking, we assessed their ability to arrange pictures into a predetermined sequence (Baron-Cohen et al. 1986). We examined whether a child understood the story depicted in the sequence. Baron-Cohen et al. (1986) used five types of stories, including Mechanical 1 (objects interacting causally with each other), Mechanical 2 (people and objects acting causally on each other), Behavioral 1 (a single person acting in everyday routines not requiring attribution of mental states), Behavioral 2 (people acting in social routines, involving more than one person, but not requiring attribution of mental states), and Intentional (people acting in everyday activities requiring attribution of mental states). We developed the stories for each condition on white cards with simple black lines (Fig. 5). In line with Baron-Cohen et al. (1986), we conducted a pilot study to examine the appropriateness of the program for younger children in a kindergarten class, modified the original cards based on the children's responses, and adapted the program for the present study.

Problem-Solving Performance Instrument

To measure the children's problem-solving performance, we adapted the Korean version (Ryu 2003) of Ward's (1993) original problem-solving performance instrument. This instrument measures young children's problem-solving performance across various questions. We adapted this instrument to examine the effect of children's math activities using robotics on their math problem-solving performance. After a review by two early-childhood experts to confirm the instrument's developmental appropriateness and validity, some tasks were modified slightly to enhance clarity and efficiency. The instrument consisted of 20 items including four items on categorization, three items on patterns, three items on numbering, two items on measuring, five items on diagramming, and three on statistics (Table 3). The items in the instrument are representative of the content covered under the Korean National Curriculum for kindergartens. Thus, the number of items in the instrument was increased from the original number in the instrument developed by Ward (1993). To statistically assess inter-rater reliability, the intraclass correlation coefficient was calculated, and the results demonstrated a highly reliable coefficient between 0.91 and 0.96 for the pre- and post-tests.

Table 3 Summary of items in the problem-solving performance instrument

	Type	Number	Items	Range	Total score
Problem-solving for kindergartners	Categorization	1–4	4	0–7	45
	Patterns	5–7	3	0–8	
	Numbers	8–10	3	0–6	
	Measurement	11–12	2	0–8	
	Diagramming	13–17	5	0–9	
	Statistics	18–20	3	0–7	
	Total	1–20	20	0–45	

Table 4 Means, standard deviations, and mean differences among the pre- and post-test scores in sequencing and problem-solving

	Group	*N*	Pre-test		Post-test		Mean gain (M_g)
			M	SD	M	SD	
Sequencing	Treatment	25	21.60	4.25	26.64	1.96	5.04 (– 2.29)
	Comparison	28	21.29	3.26	24.18	3.50	2.89 (0.24)
Problem-solving	Treatment	25	25.72	6.29	37.16	3.88	11.44 (– 2.41)
	Comparison	28	26.79	5.07	29.75	6.33	2.96 (1.26)

Table 5 Summary of the comparisons of sequencing and problem-solving between the treatment and comparison groups

	Group	*N*	Pre-test		Post-test		F	Effect size
			M	SD	M	SD		Eta-squared
Sequencing	Treatment	25	21.60	4.25	26.64	1.96	8.33**	0.15
	Comparison	28	21.29	3.26	24.18	3.50		
Problem-solving	Treatment	25	25.72	6.29	37.16	3.88	10.08**	0.17
	Comparison	28	26.79	5.07	29.75	6.33		

Note Significant at the $p < 0.01$ level

Results

In this study, the data from the pre- and post-tests were analyzed using descriptive statistics and an analysis of covariance (ANCOVA) using a significance level of 0.05. A one-way ANCOVA was employed to evaluate the children's sequencing and problem-solving performance in the treatment and comparison groups.

Sequencing

The data presented in Table 4 illustrate that the treatment group's mean sequencing score (M_g = 5.04, SD_g = – 2.29, n = 25) was higher than the comparison group's mean score (M_g = 2.89, SD_g = 0.24, n = 28). In addition, an ANCOVA was performed to examine the differences between the groups to determine whether the pre-tested groups could be correctly considered as equivalent by removing score differences among the pre-test values across groups and by removing the between-group source variation. Table 5 illustrates that the F value for the treatment and comparison groups in the sequencing was significant ($F(1,49) = 8.33$, $p < 0.01$). Thus, significant differences occurred between the mean sequencing scores of the treatment and comparison groups. The effect size of the sequencing results demonstrated that the eta-squared value was 0.15, which indicated that the effect was large (Cohen 1988).

Problem-Solving Performance

The data presented in Table 3 indicate that the treatment group's mean problem-solving scores (M_g = 11.44, SD_g = -2.41, n = 25) were higher than the comparison group's mean problem-solving scores (M_g = 2.96, SD_g = 1.26, n = 28). Table 4 indicates that the F value for the treatment and comparison groups' problem-solving was also significant ($F(1,49) = 10.08$, $p < 0.01$). Thus, significant differences occurred between the mean problem-solving scores of the treatment and comparison groups. The effect size of the result for problem-solving demonstrated that eta-squared value was 0.171, which indicated that this effect was also large (Cohen 1988).

Discussion and Conclusion

The goal of this study was to examine the effects of a card-coded robotics curriculum on children's computational thinking through sequencing and problem-solving tasks during 8 weeks of activities enhanced with complementary action. The results demonstrate that use of the card-coded robotics curriculum yielded significant differences in sequencing and problem-solving between the treatment and comparison groups. Previous studies indicated that robotics activities are effective as a tool to help make abstract ideas more concrete through the programming of robot commands and demonstration of the resultant actions (Bers 2008). When young children in pre-kindergarten and kindergarten classrooms engage in robotics and programming curriculum, they show significant increases in their sequencing (Kazakoff and Bers 2014; Kazakoff et al. 2013) and mathematical problem-solving skills (Brosterman 1997). The results of this study also demonstrate that children who experienced the instruction model and curriculum using the card-coded robot were more proficient in arranging pictures into a predetermined sequence (sequencing) and solving mathematical problems (problem-solving). Therefore, engaging in card-coded programming seems to benefit children because it allows them to elaborate on their experiences and to create and execute plans to solve problems.

The children enjoyed learning how to use the card-coded robots, likely because the activities that involved the robots and worksheet complemented the students' cognitive load. In early childhood, children need to use their working memory span to remember instructions, manipulate programming sequences, and connect their plan to tasks (Elkin et al. 2016). According to Richmond et al. (2011), children can increase their working memory, attention span, and ability to plan with respect to various factors. Thus, the curriculum planning of card-coded robotic programming accounted for cognitive and social developmental aspects involved in mastering concepts and instructions. The card-coded robotic activities, which included worksheets as a complementary tool and hands-on activities involving physical computational objects, can make abstract concepts or symbolic representations more accessible to children (Antle 2013a; Resnick 2006) by supporting the demonstration of physical actions on computational objects, thereby facilitating problem-solving at the children's current level of cognitive capacity.

The findings from the present study suggest that kindergarteners can enhance their problem-solving and planning abilities through a robotics curriculum. From a practical perspective, educators should try to provide opportunities to engage and use robotics tools, and educational robots and materials in considering children's development. In addition, the role of teachers as a facilitator is an important part of encouraging and providing scaffolds to engage kindergartners in robotics activities properly. Thus, teachers should develop their professional competencies in integrating robotics with instructions to improve the thinking skills of kindergarten children.

This study presented certain limitations. First, the study groups as a quasi-experimental design were divided by classrooms within a kindergarten setting into treatment and comparison groups. The comparison group received an alternative intervention instead of no intervention in a quasi-experimental study (Shadish et al. 2002). This was because this study was conducted in a kindergarten context, and it was difficult to set up a true control, particularly as kindergarteners in Korea should participate in the national curriculum and instructions based on the law. Second, this study used sequencing and problem-solving in mathematics to examine only the children's computational thinking. Thus, the children's logical thinking or algorithmic thinking as an age-appropriate behavior must be examined via investigations into the components of computational thinking in young children.

In conclusion, we find that kindergartners who engage in the card-coded robotics curriculum are better at sequencing and problem-solving, and an enhanced planning experience using card-coded robots is beneficial for improving kindergartners' thinking skills. This study increases our understanding of how an instructional model and curriculum designed to enhance children's computational thinking can be implemented in kindergarten classrooms.

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