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Technology and geometry: Fostering young children's geometrical concepts through a research-based robotic coding program

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Abstract
Geometric concepts are fundamental to early geometry education, and developmentally appropriate practices are crucial for teaching them to young children. Robotic coding is an effective tool in many areas of early mathematics and has significant potential in teaching geometric concepts. This study aimed to test the impact of a research-based robotic coding program on young children's understanding of geometric concepts. A quasi-experimental design was used with two intervention groups. The study involved 52 5-year-old children from a public kindergarten. The intervention-1 group (n = 18) received a research-based robotic coding program, while the intervention-2 group (n = 16) received a research-based no-coding program. The non-intervention group (n = 18) attended their regular program. Data on participants' understanding of geometrical concepts was collected through individual interviews using a geometric shapes classification test. Hierarchical linear modeling (HLM) was utilized to assess the effectiveness of two interventions. The results showed that both interventions had a significant effect with the robotic program being more effective. Additionally, follow-up tests indicated that both interventions had a lasting effect on the children's understanding of geometrical concepts. The study highlighted the potential of incorporating robotic coding and relevant research in fostering young children's geometrical development.

Keywords Early childhood · Technology · Geometry · Robotic coding · Learning trajectories · Research-based robotic coding program

1 Introduction

Integrating innovative tools into early childhood education has become increasingly crucial, particularly in math, because a strong foundation unlocks future academic success (Ritchie and Bates, 2013). Geometry is one of the curriculum focal points in young children's math education (National Council of Teachers of Mathemetics

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[NCTM], 2006). Therefore, it is important to teach young children geometrical concepts to provide a strong mathematical foundation (Clements et al., 2018). Technology offers interactive, game-based learning experiences (Alaswad & Nadolny, 2015) that cater to young children's natural curiosity and love for play. For instance, to comprehend spatial relationships, children can engage with digital applications that allow them to manipulate virtual shapes (Gecu-Parmaksiz & Delialioglu, 2019) or program a robot to navigate geometric mazes. These playful activities not only enhance motivation but also reinforce comprehension enjoyably and memorably by providing concrete experiences. Building on its potential, technology can further support children in connecting abstract mathematical concepts to practical applications. Although technology has the potential to make mathematical learning more engaging, concrete, and visually stimulating, it is important to consider its use within a theoretical framework for young children's learning (Steffe et al., 2013). Thus, we consider contemporary theories and practices on young children's geometry learning to provide a developmentally appropriate program. More specifically, we investigated the effect of a research-based robotic coding program on young children's geometrical concepts.

1.1 Theoretical and conceptual background

1.1.1 Geometry in early childhood

Geometry is one of the core skills of the cognitive domain and serves as a unifying theme across the entire mathematics curriculum. Therefore, it has a rich content to make many mathematical concepts understandable (Sherard, 1981). Furthermore, geometry emphasizes concrete objects and shapes making it an essential component of early mathematical education (Alisinanoğlu et al., 2013). Geometric shapes form the basis of early geometry teaching (Aslan et al., 2012) and play an important role in distinguishing objects in space (Leushina, 1991). Teaching geometric shapes helps children understand, identify, and describe objects in their environment (Ridwan & Hidayat, 2020). Moreover, a significant number of secondary and high school students struggle with comprehending geometry subjects. Therefore, it is essential to teach geometric concepts to children using developmentally appropriate methods from an early age (Demir, 2022). To achieve this, it is crucial to understand how geometric thinking is formed and developed in children.

Studies on young children's geometrical thinking date back to the beginning of the second half of the twentieth century. In his classic work entitled "The Child's Concepts of Space" published in 1967, Piaget emphasizes that children's first concepts about space are topological, therefore teaching geometry should start with topological concepts before Euclidean geometry (Piaget & Inhelder, 1967). In other words, before Euclidean relations such as the size of the angle and the number of sides and corners, topological relations such as border, enclosure, and form should be emphasized (Kellough et al., 1996).

Another theory in this field is the van Hiele theory. It has been commonly accepted for many years. Van Hiele theory argues that geometric thinking has a developmental course consisting of five stages. They follow a certain order and depend on the acquisitions in the previous stage, just like the developmental stages in Piaget's cognitive development theory (van Hiele, 1985). The first two stages of van Hiele theory cover the preschool and primary school years. In the first stage, visualization, children make judgments about shapes by looking at their appearance. These judgments are based on perception, not reasoning. At this stage, children can recognize a circle, square, triangle, or rectangle but this recognition is not based on the mathematical characteristics of the shapes such as sides and corners (Mason, 1998; Troutman & Lichtenberg, 1995). In the next stage, Analysis, children begin to consider and classify shapes according to their mathematical properties such as sides and corners. This period corresponds to the 3rd-4th grade of primary school (Aslan & Aktas Arnas, 2007).

Van Hiele theory has been the basis for studies on geometric thinking for many years and has been widely accepted all over the world. However, studies carried out by Clements and his colleagues in recent decades reveal some findings that van Hiele theory is unsatisfactory in explaining geometric thinking in young children (e.g. Clements & Battista, 1992; Clements et al., 1999). According to Clements and his colleagues (Clements et al., 1999), some young children cannot reliably distinguish shapes at a certain point in time. For example, while children are successful in recognizing a typical triangle example, they fail to identify examples of triangles in different dimensions and orientations. For this reason, the explanations of van Hiele theory that these children can recognize shapes visually and therefore should be considered to be at the visual level are inadequate. Instead, Clements and his colleagues state that children at this stage should be considered to be at the pre-recognition level (Clements et al., 1999). Subsequent studies focusing on the claims of Clements and his colleagues have reached similar results in different cultures such as Türkiye (Aktas Arnas and Aslan 2010; Aslan & Aktas Arnas, 2007) and Singapore (Yin, 2003). The findings also suggest that the failure of young children at this pre-recognition level to classify shapes is because they are often presented with typical examples in shape teaching, atypical examples are neglected (examples with different dimensions and orientation), and defining features of the shape (such as edges and corners) are not emphasized (Aslan, 2004, Aslan & Aktas Arnas, 2004, 2007; Hannibal, 1999; Hannibal & Clements, 2000).

The studies, conducted in recent decades on geometrical thinking in children, have also pioneered intervention programs on teaching geometry at an early age. These programs include game-based activities with concrete materials (e.g., Ardianti et al., 2023; Çelik, 2020; Fisher, 2010; Fisher et al., 2013; Madlool Abbas, 2021; Masran & Abidin, 2018; Orçan Kacan, 2023; Sari et al., 2018) as well as interventions that include various technological applications. The results of technology-based intervention studies have shown that computer-assisted method (Khotimah et al., 2020; Putri, 2020; Zaranis & Synodi, 2017), educational software (Demir, 2022; Furner & Marinas, 2007; Özçakir et al., 2019; Valdivia et al., 2021), web-based applications (Bazargani et al., 2022; Borissova et al., 2022; Fesakis et al., 2011), digital games (Ridwan and Hidayat, 2020) and augmented reality applications (Gecu-Parmaksiz and Delialioglu, 2019; Thamrongrat & Law, 2019; Zainuddin, 2013) are effective in supporting children's geometrical concepts. In addition to all these technological applications, robotic coding has also recently begun to be used in various areas of early childhood mathematics. Past research findings have revealed the significant impact of robotic coding practices on mathematical reasoning (Somuncu & Aslan, 2022), problem-solving (Çakır et al., 2021), number and operation (Emen-Parlatan et al., 2023), and mathematical measurement (Ceylan & Aslan, 2023) of young children. However, there is a significant gap regarding robotic coding interventions in early geometry teaching. We have very limited findings on the effectiveness of robotic coding in teaching geometric concepts in the early years.

1.1.2 Robotic coding

Robotic coding is a kind of coding that brings together the field of coding and mechanics, where children can produce their own codes (Çaka, 2022). Robotic coding is also an important educational instrument that supports children's ability to produce solutions to real-life problems and creativity. Through robotic coding, children have the opportunity to experience programming with physical tools (Arslan and Kayali, 2023).

Nowadays, there has been an increasing interest in robotic coding in early childhood education. The burgeoning trend of integrating robotics and coding into preschool education offers a promising avenue for nurturing crucial developmental skills in young learners (Bati, 2022). This integration transcends mere technological exposure, instead acting as a catalyst for playful exploration and the cultivation of foundational competencies. Early childhood education coding activities typically favor engaging interfaces like block-based platforms or visual drag-and-drop systems (Lee, 2020). These interfaces cater to young children's developmental needs without complex syntax and empower children to construct rudimentary command sequences and see their robots move, emit lights, or generate sounds. Like building blocks, but with the added thrill of code animating their creations (Yu & Roque, 2019).

Research has shed light on the impacts of robotic coding on computational thinking, problem-solving, and various mathematical concepts of children. A STEAM program that used robotic kits increased the computational thinking abilities of young children such as recognition of patterns, logic, algorithms, representation, control structure, debugging, and design processes (Sung et al., 2023). Yang et al. (2022) compared the impacts of using programming versus playing with blocks on some cognitive abilities. They reported that children in the robot programming group performed better in sequencing ability which is one of the basic constituents of computational thinking. Bati (2022) investigated the role of coding in computational thinking and argued that both coding environments (plugged/unplugged) support the computational thinking of young children however robotic toys are one step ahead because they ensure clearer and more concrete feedback than digital tools. Çiftçi and Bildiren (2020) employed a coding education program without robotics. They stated that there was not a significant effect on preschoolers' non-verbal cognitive abilities, whereas, Çakır et al. (2021) found that robotics had remarkable impacts on the problem-solving skills of children compared to traditional activities. Misirli and Komis (2023) emphasized the importance of tangible learning experiences in young children's learning. Robots also help develop scientific processes (Turan & Aydoğdu, 2020), executive functions (Di Lieto et al., 2017), spatial reasoning (Berson et al., 2023), and cognitive development (Liu et al., 2023).

Robotics and coding have innovative potential, making learning engaging, hands-on, and interactive by bringing abstract mathematical concepts to life with concrete actions. Robotic coding encourages deeper understanding (Pozdniakov & Freiman, 2021; Roschelle et al., 2017). Additionally, English (2018) states that the coding process is in natural collaboration with mathematics. For these reasons, many studies have examined the effectiveness of coding interventions on various mathematical concepts of children. For instance, Miller (2019) has found that robotic coding instruction led to higher levels of students' mathematical thinking such as patterns and structures that can lead to generalization. Ceylan and Aslan (2023) determined that robotic coding activities significantly improved the mathematical measurement skills of preschool children. Somuncu and Aslan (2022) found that robotic coding activities had significant effects on the mathematical reasoning of children. In another study, Emen-Parlatan et al. (2023) examined the impact of a robotic program on preschoolers' formal and informal mathematics abilities such as numbers, informal calculations, and decimal concepts. They found that the robotics program significantly improved preschoolers' early mathematical abilities. In conclusion, these studies reveal the positive impact of robotic coding on a variety of early mathematical concepts. However, the efficacy of robotic coding on the improvement of geometrical concepts in young children is still unclear.

On the other hand, some studies investigated the impacts of using technological instruments on young children's geometrical skills. For instance, Bazargani et al. (Bazargani et al., 2022) applied an IoT-Based (Internet of Things) method to support children's basic geometric concepts. They found a remarkable improvement in learning outcomes and highlighted a more enjoyable learning environment compared to traditional approaches. Gecu-Parmaksiz and Delialioglu (2019) compared the impacts of manipulatives (virtual versus physical) on preschoolers' geometry skills. They presented virtual manipulatives on tablet computers using Augmented Reality Technologies (ART). They found that an improvement occurred in both groups, while the group that used ART outperformed the group that used physical manipulatives. Similarly, Özçakir et al. (2019) investigated using digital learning activities to young children basic geometric shapes knowledge, and they found that digital-based activities helped children develop a higher level of geometric understanding.

A few studies used robotic toys to improve geometry skills, but not with preschoolers. For instance, Kim et al. (2021) used the robot Sphero to teach fourth and fifth-graders geometry concepts, namely, complementary and supplementary angles. They argued that the robotic instructions provide a playful and informal way to teach geometry concepts in a thoughtful and challenging manner. In a study conducted with younger children, Bartolini and Baccaglini-Frank (2015) realized a long-term intervention by using robotic toys in a first-grade classroom to develop square and rectangle concepts in young children. They used Bee-Bot, and the path of Bee-Bot's movements to produce squares and rectangles, and they analyzed how children conceptualized the definition of these shapes. They especially emphasized that Bee-Bot provides a rich context and contributes to young children creating new definitions of square and rectangle.

There is no doubt regarding the meaningful impacts of robotic coding interventions on preschoolers' geometry-related abilities such as spatial relationships, cognitive abilities, problem-solving skills, scientific processes, general mathematical abilities, and some mathematical concepts. Furthermore, studies also revealed the impacts of technological tools on preschoolers' geometrical abilities and the contribution of robotic toys on older children's geometrical concepts yet, the impact of robotic coding activities on young children's geometrical abilities has not been clarified.

1.2 Research problem

The present study was conducted to test the impact of a research-based robotic coding program on young children's understanding of geometric concepts. The study aimed to have a better understanding of the effect of robotic coding on young children's geometric concepts by comparing control and research-based no-coding programs. To guide the study, the following questions were formulated:

RQ1—What is the effect of intervention programs (research-based programs with and without coding) on young children's geometric concepts compared to the non-intervention group? If so, is this effect permanent?

RQ2—What is the effect of the research-based robotic coding program on young children's geometrical concepts compared to the research-based no-coding program?

In the first question, we want to explore the effects of both intervention programs compared to the control (non-intervention) program. In the second question, we want to explore the effect of the research-based robotic coding program compared to the research-based no-coding program. Therefore we aimed to shed light on adding robotic instructions to relevant research regarding young children's geometric concepts.

2 Method

2.1 Design

A quasi-experimental design was utilized to test the impact of a research-based robotic coding intervention on the geometrical concepts of young children. To answer research questions, the intervention-1 group, in which the research-based robotic coding program was applied; the intervention-2 group, in which the research-based no-coding program was applied, and the non-intervention group, which continued their regular programs, were used. Participants' geometrical concepts were measured by applying the Geometric Shapes Classification Test (GSCT) before (pretest), immediately after (posttest), and one month later (follow-up test) from the intervention.

2.2 Participants

Participants were randomly recruited from a kindergarten in the city of Mardin in southern Türkiye. There were four classes in the kindergarten. Two of these classes were assigned as the intervention group and one as the non-intervention group. Thus, the research sample consisted of 52 children in the five-year age group, with 18 in the intervention-1 group (mean age: 66 months, range: 62–72 months; 9 girls and 9 boys), 16 in the intervention-2 group (mean age: 66 months, range: 62–71 months; 8 girls and 8 boys), and 18 in non-intervention group (mean age: 66 months, range: 62–72 months; 8 girls and 10 boys). All of the children were attending early childhood education for the first time and had not received any coding training before. They were from low-income families. Most of their fathers were secondary school graduates, while most of their mothers were illiterate.

2.3 Intervention

To support children's geometrical concepts, a research-based robotic coding program was applied to the intervention-1 group, and a research-based no-coding program was implemented in the intervention-2 group. While preparing the intervention programs, developmental goals were determined by taking into account the research findings on geometrical thinking. More specifically, learning trajectories (Clements & Sarama, 2014) were at the heart of the research-based programs. Recent studies regarding learning trajectories suggest presenting young children with their developmental level and higher instructions is more effective (Baroody et al., 2022; Clements et al., 2019). Further, studies indicated that the defining properties of shapes are often neglected in early childhood geometry education because educators often present typical examples of geometric shapes to young children (Aslan, 2004). Therefore, we aimed to present both typical and atypical examples while emphasizing defining properties. Activities were planned to achieve these goals and presented to field experts and teachers for their feedback. The activities were organized in line with the feedback and piloted on a group not included in the sample. After the pilot implementation, the programs were finalized. The programs were implemented by one of the researchers during five weeks. Information regarding research-based robotic coding program is presented in Table 1.

The research-based robotic coding program consists of 15 activities (See Table 1). The first five activities include coding training, and the other 10 involve teaching geometric concepts through robotic coding. Coding training activities aim to introduce children to coding and provide them with basic skills. It includes unplugged and plugged coding activities. These activities include recognizing the direction arrows and coding mat, creating purpose-oriented codes by bringing the direction arrows together, applying the codes, and debugging. The other 10 activities were prepared based on past research about geometrical thinking (e.g., Aslan, 2004; Clements et al., 1999, 2018) and include finding shapes with open/closed, curved/straight edges, with/without corners; recognizing typical and atypical examples of

Table 1 Research-based robotic coding program

	Activity name	Goals	Materials
Coding introduction activities	Introducing direction arrows	• Recognizing direction arrows (right, left, forward, backward)	Direction cards
	Which arrow should I use to go where?	• Recognizing direction arrows (right, left, forward, backward)	Direction cards
	Code and do it!	• Coding with concrete materials	Direction cards, mat, teddy bear
	Jump, frog jump!	• Coding with concrete materials	Cardboard frog and leaves
	Complete the Mat	• Coding with concrete materials	Leftover materials
Geometric shapes activities with coding	Find sides and corners	• Coding with concrete materials • Understanding the concepts of side and corner	Direction cards, mat
	Beware of rectangles and squares pits!	• Coding with concrete materials • Focusing on the defining characteristics of rectangle and square, recognizing their typical and atypical examples, and distinguishing them from non-examples	Direction cards, mat, examples of rectangle and square, and distractors
	Code first and move later	• Coding with concrete materials • Focusing on the defining characteristics of a circle and a triangle, recognizing their typical and atypical examples, and distinguishing them from non-examples	Direction cards, mat, toy trucks, examples of circle and triangle, and distractors
	I meet coding robots	• Getting to know coding robots and doing robotic coding	Cubetto and Bee-Bot coding robots, mat
	Cubetto, my transportation robot	• Coding with robots • Focusing on the defining characteristics of circle, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Cubetto coding robot, mat, toy ship,examples of circle and distractors
	My playmate Cubetto	• Coding with robots • Focusing on the defining characteristics of square, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Cubetto coding robot, mat, examples of square and distractors
	Cubetto shapes to the rescue	• Coding with robots • Focusing on the defining characteristics of rectangle, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Cubetto coding robot, mat, examples of rectangle and distractors
	Cubetto the collecting robot	• Coding with robots • Focusing on the defining characteristics of triangle, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Cubetto coding robot, mat, examples of triangle and distractors
	Bee-Bot works like a real bee	• Coding with robots • Focusing on the defining characteristics of geometric shapes, recognizing their typical and atypical examples, and distinguishing them from non-examples	Bee-Bot coding robot, mat, box, examples of geometric shapes and distractors
	Bee-Bot's geometric hive	• Coding with robots • Focusing on the defining characteristics of geometric shapes, recognizing their typical and atypical examples, and distinguishing them from non-examples	Bee-Bot coding robot, mat, cardboard hive, examples of geometric shapes and distractors

shapes (those with different orientation, size, skewness, and aspect ratio than the typical example) and distinguishing them from non-examples through robotic coding. We used two coding tools in robotic coding activities: Cubetto and Bee-Bot. Cubetto is a programmable educational robot. It is designed for children over three and includes a coding board, coding blocks, and a fabric mat. It gives children the opportunity to code without a screen. Bee-Bot is a robot designed in the shape of a bee for preschool children to code. Unlike Cubetto, Bee-Bot does not have a separate coding panel. Commands are given through the buttons on the Bee-Bot. Figure 1 shows the activity examples which used Bee-Bot and Cumetto.

The research-based no-coding program consists of 10 activities (see Table 2). These activities have the same content as the 10 activities related to teaching

Fig. 1 Activity examples from research-based robotic coding program (Intervention-1 group)

Table 2 Research-based no-coding program

Activity name	Goals	Materials
Where is the side and where is the corner?	• Understanding the concepts of side and corner	Items in the classroom
My name is circle	• Focusing on the defining characteristics of circle, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Examples of circle and distractors, and a worksheet about circle
Square tree	• Focusing on the defining characteristics of square, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Examples of square and distractors, scissors and glue
Complete the track and place the shape	• Focusing on the defining characteristics of rectangle, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Examples of rectangle and distractors, toy barriers
Colorful triangles	• Focusing on the defining characteristics of triangle, recognizing it's typical and atypical examples, and distinguishing them from non-examples	Examples of triangle and distractors, paints and play dough
Find the lost shape	• Focusing on the defining characteristics of shapes, recognizing their typical and atypical examples, and distinguishing them from non-examples	Examples of geometric shapes and distractors
There are many shapes	• Focusing on the defining characteristics of shapes, recognizing their typical and atypical examples, and distinguishing them from non-examples	Examples of geometric shapes and distractors
I drew, colored and completed the shapes	• Focusing on the defining characteristics of shapes, recognizing their typical and atypical examples, and distinguishing them from non-examples	Examples of geometric shapes and distractors, and paints
Guess which shape	• Focusing on the defining characteristics of shapes, recognizing their typical and atypical examples, and distinguishing them from non-examples	Examples of geometric shapes and distractors, and cardboard
Look, touch, and place	• Focusing on the defining characteristics of shapes, recognizing their typical and atypical examples, and distinguishing them from non-examples	Examples of geometric shapes and distractors

geometric shapes applied to the intervention-1 group (understanding the defining features of shapes, recognizing atypical examples, eliminating non-examples, etc.). Unlike the geometrical activities in intervention-1 group, these activities involved paper/pencil work and the use of concrete materials rather than coding (see Fig. 2).

During the intervention period, the non-intervention group continued their regular program prepared by the Turkish Ministry of National Education (MEB, 2013). The program involves a target related to geometrical concepts. The target includes saying the names and properties of geometric shapes and showing objects that resemble them. Therefore, unlike the research-based programs in intervention-1 and intervention-2 groups, the regular program does not include features such as emphasizing the defining characteristics of shapes and presenting atypical examples as well as typical examples.

2.4 Data collection tool and procedure

The Geometric Shapes Classification Test (GSCT) designed by Aslan and Aktas Arnas (2007) was utilized as a data collection tool. The measurement tool, which is an achievement test, was designed to determine the basic geometric shapes

Fig. 2 Activity examples from research-based no-robotic coding program (intervention-2 group)

recognition levels of children between the ages of 3–6. It consists of four subtests: Circle, square, rectangle, and triangle classification test, each consisting of 12 items. Thus, there are 48 items in total in the test. The minimum score that can be obtained from the test is 0 and the maximum score is 48. In each subtest, typical and atypical samples (samples of different orientations, sizes, aspect ratios, and skewness) and non-sample shapes are included. To test the reliability of the GSCT, the difficulty and discrimination index of each item in the test were calculated. It was assigned that there were no items with an item discrimination index below 0.15, and item difficulties varied between 0.32 and 0.99. Additionally, KR 20 alpha values were measured to specify the reliability of the GSCT. The KR 20 alpha value was calculated as 0.82 for the GSCT (Aslan and Aktas Arnas, 2007).

Application permissions were obtained before starting the data collection process. An information meeting was held with the administration and teachers. After the sample was determined, written permission was obtained from the parents for their children's participation in the research. Afterward, the Geometric Shapes Classification Test (GSCT) was applied to the children in the sample as a pretest. The GSCT was administered to each child individually. Each application took approximately 15 min. After the pretest was completed, intervention programs were implemented for intervention-1 and intervention-2 groups. The non-intervention group continued the regular program. After the intervention programs, the measuring tool was applied to the children as a posttest. Finally, four weeks after the posttest, the test was implemented for the participants as a follow-up test.

2.5 Data analysis

2.5.1 Descriptive statistics

Initially, descriptive statistics were calculated for pre-intervention, post-intervention, and follow-up GSCT scores. This included measures of central tendency (means) and variability (standard deviations) for each time point and group. This step provided an initial overview of the data distribution and potential differences between groups.

2.5.2 Hierarchical linear modeling (HLM)

To statistically evaluate the change in children's GSCT scores across the three time points (pre-intervention, post-intervention, and follow-up) and compare the change between and within groups, an HLM was conducted.

2.5.3 Rationale for HLM

HLM was chosen because it is well-suited for analyzing data with a nested structure, such as in this study where repeated measures are nested within individual children (Woltman et al., 2012). This nesting violates the assumption of independence in traditional linear regression methods. HLM allows for the proper estimation of variances at both the observations (Level 1) and children (Level 2) levels, providing a more accurate picture of the underlying relationships between variables (Stevens, 2007). The specific HLM model employed in this study was a two-level longitudinal model. Level 1 consisted of children's GSCT scores at each of the three-time points (before, after, and follow-up interventions). Level 2 represented individual children, capturing potential differences in baseline scores and response to the interventions.

2.5.4 Software and analysis

The HLM analysis was conducted using the HLM 8.0 student version software. The analysis focused on estimating the fixed and random effects within the model, allowing for the examination of both mean changes in GSCT scores across time and individual differences in these changes. Three Hierarchical Linear Models were estimated to progressively examine the factors affecting children's GSCT scores:

1. *Unconditional Model*: The initial model included no predictors at either level (Level 1: children's scores in different times; Level 2: groups). This "empty" model served as a baseline and provided the intraclass correlation coefficient (ICC), which indicates the proportion of variance in GSCT scores attributable to individual differences between children (as opposed to within-child variance over time).
2. *Level-1 Time Model:* This model incorporated time as a predictor at Level 1, differentiating between pre-post and follow-up scores. This allowed us to assess whether children's GSCT scores significantly changed across the intervention and follow-up period.
3. *3.Level-2 Group Model:* Building upon the Level-1 model, this final model added group (intervention-1, intervention-2, or non-intervention) as a predictor at Level 2. This permitted us to evaluate the intervention's efficacy by comparing the change in GSCT scores between groups and estimating the differential effects of each intervention relative to the non-intervention group. Additionally, a further comparison between intervention groups 1 and 2 was incorporated within this model.

2.6 Ethical considerations

Ethical principles were taken into account throughout the research process. First, permission was obtained from the institution where the research would be conducted and from the children's families. Teachers of the classes that will be included in the sample were interviewed and informed about the research, and their voluntary participation was ensured. The data was collected in a way that would not disrupt the children's education process as soon as they were ready. In cases where children were reluctant to participate in the test, the test was administered later. To ensure equal opportunities, the program and materials applied in the intervention groups were shared with the teachers of other classes after the data collection process was completed.

3 Findings

To evaluate the intervention's immediate and long-term effects, the GSCT was administered three times: before the intervention (pre-test), immediately after (post-test), and four weeks later (follow-up test). The results for each administration, including mean scores, standard deviations, range, skewness, and kurtosis, are detailed in Table 3.

Children's performance on the GSCT significantly improved from pre-test to post-test across all groups. To examine the statistical significance of these changes and compare the intervention's effectiveness between groups while accounting for individual differences, HLM was conducted. Table 4 presents the specific parameters estimated by the HLM models, including coefficient values, standard errors, and *t* and *p*-values, which shed light on the magnitude and significance of the observed GSCT score improvements and enable us to draw further conclusions about the intervention's efficacy.

Table 4 reveals that the pre-intervention GSCT score coefficient was significant at 34.33 ($t(50) = 31.06$, $p < 0.05$), indicating a strong association between baseline scores and post-test performance. Notably, the pre-test group coefficient (-0.63, $t(50) = -0.46$, $p > 0.05$) was not statistically significant, suggesting no initial difference in GSCT scores between the intervention (int. 1 and int. 2 combined) and non-intervention groups. Focusing on post-test scores adjusted for pre-test levels, both the overall mean coefficient (2.83, $t(50) = 2.14$, $p < 0.05$) and the intervention group coefficient (5.52, $t(50) = 3.41$, $p < 0.05$) were significant. This means that all children, regardless of group, experienced a statistically significant average increase of 2.83 units in their post-test scores within a 95% confidence interval of 1.50 to 4.16 units. More importantly, the intervention groups (int. 1 and int. 2 combined) demonstrated an additional average increase of 5.52 units (95% CI: 3.90—7.14) compared to the non-intervention group, confirming the effectiveness of the intervention.

Table 4 reveals a significant difference in pre-test scores between the two intervention groups. The intercept for intervention-2 was higher, indicating children in that group started with an average of 4.09 points ($t(32) = 2.76$, $p < 0.05$) more than those in intervention-1. Both intervention groups experienced statistically significant increases

Table 3 Descriptive statistics of GSCT

GSCT	Groups	N	X	S.d	Range	Skewness (S.E.)	Kurtosis (S.E.)
Pre-Test	Intervention- 1	18	31.78	4.09	14	-0.74 (0.53)	-0.2 (1.03)
	Intervention- 2	16	35.88	4.76	20	-0.51 (0.56)	1.72 (1.09)
	Non-intervention	18	34.33	4.83	17	-0.75 (0.53)	-0.27 (1.04)
Post-Test	Intervention- 1	18	43.05	4.80	21	-2.51 (0.53)	7.38 (1.03)
	Intervention- 2	16	40.94	2.11	8	-0.63 (0.56)	0.30 (1.09)
	Non-intervention	18	37.17	4.40	16	-0.23 (0.54)	-0.40 (1.04)
Follow-Up Test	Intervention- 1	18	42.22	3.60	11	-0.23 (0.54)	-0.69 (1.04)
	Intervention- 2	16	40.25	3.82	13	-0.57 (0.56)	-0.10 (1,09)
	Non-intervention	18	38.61	4.20	15	-0.05 (0.54)	-0.73 (1.04)

Table 4 HLM results

Fixed Effects	Coefficient	S.E	*t* value	*p*
For Intercept (π_0)				
Overall mean intercept adjusted for GSCT pretest scores, (β_{00})	34.33	1.05	31.06	0.001
Group $_{\text{(interventions and the non-intervention)}}$, ($\beta_{01}$)	-0.63	1.37	-0.46	0.65
For Intercept (π_{10})				
Overall mean intercept adjusted for GSCT pretest scores,(β_{20})	35.87	0.94	33.88	0.001
Group $_{\text{(intervention-1 and intervention-2)}}$, ($\beta_{01}$)	-4.10	1.48	-2.76	0.010
For slope to the effect of interventions (π_{01})				
Overall mean intercept adjusted for GSCT post-test β_{10}	2.83	1.33	2.14	0.038
Intercept regarding group $_{\text{(interventions and the non-intervention)}}\beta_{11}$	5.52	1.62	3.41	0.001
For slope to the effect of interventions (π_{11})				
Overall mean intercept adjusted for GSCT post-test β_{20}	5.06	1.13	4.46	0.001
Intercept regarding group $_{\text{(intervention-1 and intervention-2)}}\beta_{21}$	6.22	1.49	4.18	0.001
Random effects	Variance component	*d.f*	χ^2	*p*
Intercept (r_0)	9.64	50	85.35	0.002
Time (pre to post-test), slope (r_1)	3.86	50	57.10	0.23
Level-1 (*e*)	13.62			
Intercept (r_{10})	10.22	32	66.99	0.001
Time (pre to post-test), slope (r_2)	1.93	32	35.30	0.315
Level-1 (*e*)	9.33			

in post-test scores, with an average rise of 5.06 units (95% CI: 3.93–6.19). However, intervention-1 children gained an additional 6.22 units (95% CI: 4.73–7.71) compared to intervention-2, demonstrating a stronger average impact of the intervention in that group. In addition, both models were found to be superior to the unconditional model (Model 2—[$\Delta\chi^2(2)=62.21$, $p<0.05$], Model 4—[$\Delta\chi^2(2)=65.87$, $p<0.05$]), suggesting that the HLM models were effective in answering the research questions. These results revealed the effectiveness of the intervention applied in both groups, with intervention-1 demonstrating a significantly larger average score improvement.

Finally, we analyzed the permanence of the interventions by comparing follow-up test and post-test scores. The findings revealed that there was no statistical difference between them (-0.76, $t(33)=-1.51$ $p>0.05$). These results suggest that both interventions had a permanent effect on young children's understanding of geometrical concepts.

4 Results and discussion

This study investigates the impact of robotic toys on the geometrical concepts of young children. The results indicated that children in both intervention groups demonstrated a significantly greater and permanent improvement in their average score for geometrical concepts compared to the non-intervention group. The study revealed that the intervention-1 group, where the research-based robotic coding program was applied, demonstrated a significantly greater improvement in the classification of geometric shapes compared to both intervention-2, where the research-based no-coding program was utilized, and the non-intervention group. We discussed the research results in two sections. The first section discusses the impacts of both interventions on children's geometrical concepts compared to the non-intervention group. The second section presents a comprehensive analysis of the intervention groups in comparison to each other.

4.1 The impacts of interventions on young children's geometrical concepts

Both intervention groups were at the forefront of contemporary research on early childhood mathematics education, resulting in higher score increases compared to the non-intervention group. Research indicates that the defining properties of shapes are often neglected in early childhood geometry education because educators often present typical examples of geometric shapes to young children (Aslan and Aktas Arnas, 2007; Gecu-Parmaksiz & Delialioglu, 2019; Hannibal, 1999; Hannibal & Clements, 2000). Indeed, the regular program applied in the non-intervention group lacks specific content standards for mathematics and geometric shapes are only included under the cognitive development area without any details on how they should be taught. So, the current national preschool education program does not emphasize the defining properties of geometric shapes. Considering that young children cannot reliably distinguish geometric shapes, but only visually (Clements et al., 1999), geometry education should focus on defining properties of the shapes by providing rich context with nontypical examples (Aslan, 2004). Otherwise, children may fail to distinguish nontypical examples (Aktas Arnas and Aslan 2010). Both intervention programs were focused on the defining properties of the geometric shapes in each activity (see Table 1 and Table 2). In conclusion, this study extends the findings of intervention studies on promoting geometric concepts in early childhood.

4.2 The impacts of the robotic coding intervention compared to the no-coding intervention

Both intervention programs had a significant impact on improving children's geometrical concepts. However, intervention-1, which involved the use of robotic coding, had a greater impact. The only difference between the two research-based interventions was the use of technological tools, specifically programmable robotic toys. Previous research highlights the benefits of diverse technology in enhancing young children's understanding of geometry. Bazargani et al. (2022), for instance, utilized an IoT-based method, Gecu-Parmaksiz and Delialioglu (2019) employed augmented reality technologies, and Özçakir et al. (2019)

utilized digital learning activities. They found that these technological tools significantly improved young children's understanding of geometry concepts.

Previous studies have shown that robotic coding has a significant influence on young children's understanding of geometry-related concepts including mathematical measurement (Ceylan & Aslan, 2023), mathematical reasoning (Somuncu & Aslan, 2022), formal and informal mathematical abilities (Emen-Parlatan et al., 2023), problem-solving (Çakır et al., 2021), computational thinking (Sung et al., 2023), scientific processes (Turan & Aydoğdu, 2020), executive functions (Di Lieto et al., 2017), spatial reasoning (Berson et al., 2023), and cognitive development (Liu et al., 2023). Programmable robotic toys can increase young children's motivation by providing engaging and tangible learning experiences (Misirli & Komis, 2023). Additionally, the coding process can promote a deeper understanding of algorithmic, logical, and sequential thinking (Bers, 2020; Yang, et al., 2022). Therefore, children in intervention-1 not only focused on defining properties of geometric shapes but also engaged in problem-solving and spatial relationships (Berson et al., 2023; Çakır et al., 2021). The programmable robotic toys provided immediate feedback and broke down problems into smaller steps to improve young children's problem-solving skills (Bers, 2020). Guiding the robot through the parkour challenges children to bridge the gap between their spatial reasoning and concrete action. They must think critically about the robot's position, direction, and distance relative to obstacles, translating their understanding into precise instructions (Berson et al., 2023). In conclusion, we suggest that incorporating programmable robotic toys has a twofold purpose for young children's learning.

Additionally, incorporating programmable robotic toys into the learning environment also helps to improve older children's geometric understanding. Kim et al. (2021) demonstrated that robotic instructions enhance fifth-graders' grasp of geometry by providing an informal, yet thoughtful and challenging, learning approach. Similarly, Bartolini and Baccaglini-Frank (2015) reported that the robot's movement by coding contributes to first-graders definition of some geometric shapes. The children constructed squares and rectangles using code blocks and explored the code similarities required to produce these shapes with the robot's path. These studies suggest that robotic instructions offer a promising tool for directly developing geometrical concepts for young children. For instance, children in the robotic coding program experienced the side, corner, angle, and limit of parkour through the robot's movement and they saw patterns to produce specific geometric shapes. As a result, we suggest that robotic instructions have also a direct effect on improving the geometrical concepts of young children.

Finally, the impacts of the intervention programs on children's geometric concepts persisted even after four weeks. The lasting impact of robotic coding on children's development parallels past research (e.g., Ceylan & Aslan, 2023; Montuori et al., 2023). Ceylan and Aslan (2023), for instance, found that the significant impact of robotic coding activities on preschool children's mathematical measurement skills continued in the follow-up test.

5 Conclusion and recommendation

We employed two intervention programs to explore the effectiveness of robotic coding on children's understanding of geometric concepts. Both programs were designed based on contemporary research on the geometrical thinking of young children, with the sole difference being the inclusion of robotic coding instructions in one program. Our findings revealed a significant and permanent impact of robotic coding on the geometric understanding of children, even compared to the well-designed and engaging no-coding program. This suggests that the addition of robotic coding instructions holds significant potential for improving young children's grasp of geometric concepts. We concluded that robotic coding can enhance young children's understanding of geometry concepts.

The present study highlights the potential of robotic coding as a valuable tool for early childhood education, particularly in promoting geometry learning. Incorporating robotic coding activities into early childhood curricula can offer a fun and engaging way to teach geometric concepts. The study contributes to the growing body of evidence demonstrating the potential of robotic coding in early childhood education, specifically in enhancing young children's understanding of geometry concepts.

Finally, we can recommend some educational implications regarding the study results. First, we highly recommend using educational robotic toys to foster young children's geometrical concepts. Robotic toys not only enhance motivation but also the coding process provides a deeper understanding of spatial relationships. Second, to maximize the impact of robotic toys, robotic instructions should be developed in accordance with contemporary theories and practices regarding young children's learning. Third, the professional development of educators to effectively utilize robotic coding in the classroom is necessary.

6 Limitations and future studies

Our study has several limitations. First, we utilized two specific types of programmable robotic toys, Cubetto and Bee-Bot. Future research could benefit from exploring the effectiveness of robotic coding with a wider range of platforms and interfaces to determine whether specific design features influence outcomes. Second, the present study was conducted with a relatively small sample size thus, we couldn't analyze the bias of the program which is how the program affects different individuals such as gender, and socio-economic status. Third, our quasi-experimental design allowed for initial exploration of the impact of robotic coding, and incorporating qualitative methods in future studies would offer deeper insights into the cognitive and motivational processes underlying children's learning experiences with this technology. Such qualitative data could help explain the "how" behind the observed results, enriching our understanding of how robotic instructions shape young children's comprehension and learning of geometric concepts. Addressing identified limitations and delving into the suggested research avenues will pave the way for a more thorough comprehension of how robotic coding can benefit young children's geometric understanding. This comprehensive knowledge will guide the development of engaging and effective learning experiences within early childhood education.

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Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Ethical approval This study was conducted in compliance with the ethical principles determined by the Republic of Türkiye Ministry of National Education.

Conflict of interest We declare that we have no conflict of interest.

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