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The effect of learning trajectories-based coding education program on preschoolers' mathematical measurement skills

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Abstract

This study was conducted to investigate the effects of learning trajectories-based coding (LTs) and LTs-based program on preschoolers' length, area, volume, and angle measurement skills. A quasi-experimental research design was utilized with a quantitative approach. The study's participants were 47 children between the ages of 55–71 months who attended a state kindergarten. The children were randomly assigned to three groups: experimental 1 (n = 15), experimental 2 (n = 17), and control (n = 15). The current preschool education curriculum was implemented in the control group, LTs-based coding activities were implemented in experimental 1, and LTs-based activities were implemented in experimental 2. Data regarding the children's measurement skills were collected using the Early Measurement Assessment Tool (EMAT) before the implementation of programs, immediately after, and four weeks after the final session. The EMAT scores were analyzed using Hierarchical Linear Modeling (HLM), and the results indicated that both programs had a significant and permanent effect on preschoolers' measurement skills when compared to the control group. However, there was no significant difference between the experimental groups. The results were consistent across length, area, volume, and angle and turn subtests. The study contributes to the existing literature on the effectiveness of the LTs approach in improving preschoolers' mathematics skills and highlights the potential benefits of incorporating the LTs approach and coding into preschool education.

Keywords Learning trajectory · Early childhood · Mathematical measurement skills · Robotics · Coding · Intervention

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1 Introduction

Mathematics is essential for understanding, using, and advancing technology and science. Therefore, mathematics education has become more crucial for modern society, and educators often emphasize the role of early childhood mathematics education for several reasons. First, mathematical abilities develop cumulatively, and it is much easier to detect and support children's lack of learning in early childhood. Second, studies indicate that students often struggle to connect their informal and intuitive knowledge with school mathematics, and early childhood mathematics education facilitates this connection. Third, young children's mathematical knowledge is one of the best predictors of their later academic achievement, indeed a better predictor than early reading and early attention skills (Duncan et al., 2007; Nguyen et al., 2016; Watts et al., 2014).

For these reasons, mathematics is an integral part of early childhood education, and measurement is a key focus of the mathematics curriculum during this time (National Council of Teachers of Mathematics [NCTM], 2006). Measurement draws on several connected mathematical content topics, such as number, geometry, and data analysis. It provides children with opportunities to engage in mathematical processes of problem-solving. Children could experience reasoning, data collection, data representation, and proof through measurement activities. Measurement also serves as a bridge between mathematics and science (Lehrer, 2003). However, curriculum in many countries does not adequately emphasize key conceptual principles in measurement (Smith et al., 2016). As a result, children's understanding of measurement is weaker than in other mathematical domains (Smith et al., 2013). Measurement activities should span key concepts in length, area, volume, and angle and turn measurement. To develop measurement abilities in early childhood, it is essential to provide developmentally appropriate learning experiences in all measurement areas.

Now with the advancement of technology, learning experiences have evolved, and various new technologies have been integrated into classrooms, such as programming robots, web 2.0 tools, mobile devices, and digital games. For instance, web 2.0 tools enhance young children's motivation, help them solve problems, and facilitate communication in mathematics education (Cicconi, 2014). Tablets and computers are also increasingly used for educational purposes and are effective tools for improving early childhood students' comprehension of numbers (Nikolopoulou, 2021; Papadakis et al., 2018). Moreover, programming robots offer a dynamic and interconnected way for children to use their mathematical knowledge (Shumway et al., 2021). Coding activities performed with programming robots increase young children's early mathematical reasoning skills (Somuncu & Aslan, 2022), geometry (Bartolini Bussi & Baccaglini-Frank, 2015), computational thinking (Bati, 2022; Yang et al., 2022), and mathematical structure and patterns (Miller, 2019). In addition, coding with programming robots helps to develop positive attitudes toward technology, science, and robotics in early childhood (Zviel-Girshin et al., 2020).

Despite the positive effects of technology on children's learning in mathematics, most studies have only tested one experimental group without a second condition.

It is well-known that interventions generate an immediate positive effect on young children's mathematics abilities by changing the processes underlying children's learning (Kang et al., 2019; Watts et al., 2017). Thus, there is a need for a study that investigates the effects of coding with programming robots in at least two experimental conditions. To see the effect of coding in early childhood mathematics education, we conducted two experimental conditioning, one with a learning trajectories-based coding education program using programming robots, and the other one with a learning trajectories-based education program without coding or robotics. The study aimed to have a better understanding of the effect of coding on preschoolers' mathematics skills by comparing control and learning trajectories-based education programs. It is important to note that, learning trajectories (LTs) were at the heart of both experimental conditions because we assumed that coding should be integrated with a proper theoretical framework for targeted skills. The LTs-based coding education program aimed to teach children measurement skills. The coding process and programming robots were used as an instrument to teach children measurement skills by enriching the learning environment.

1.1 Theoretical and conceptual background

1.1.1 Learning trajectories

Learning trajectories (LTs) is a contemporary approach that explains how children acquire math skills. The LTs consist of three components (Clements & Sarama, 2014; Simon, 1995). (1) A mathematical goal which is the targeted developmental level. (2) A developmental progression that "is a sequence of theoretically and research-based increasingly sophisticated patterns of thinking that most children pass on the way to achieving the goal or target" (Baroody et al., 2022, p. 1). (3) Instructional activities which help students to move through developmental progressions. The LTs framework also incorporates empirical findings to establish content-specific learning goals and an associated instructional sequence (Blanton et al., 2015).

The LTs is used as a theoretical framework in mathematics education research (Barrett et al., 2011; Blanton et al., 2015; Sarama et al., 2021; Szilágyi et al., 2013), as well as curriculum (Baroody et al., 2004), assessment (Clements et al., 2008), and pre-service teacher education (Callejo et al., 2021). Moreover, the LTs is a useful framework to connect mathematics standards with the curriculum (Confrey et al., 2014). Several studies revealed the efficacy of LTs in early childhood mathematics education (Baroody et al., 2022). This study focuses on preschool children's measurement skills, specifically length, area, volume, angle and turn measurement. It is important to note that we used Clements and Sarama (2014)'s LTs to development of instructional activities rather than seeking new LTs.

1.1.2 Coding in early childhood

Coding must be presented in a developmentally appropriate manner in a meaningful context to young children (Lee, 2020). Therefore, two ways of activities arise in early childhood based on the using materials and coding platforms. The first way is unplugged activities which are learning coding without a computer or robot. The only materials needed are cards, strings, crayons, and other household items. The activities cover a wide range of coding-related topics such as binary numbers, algorithms, and data representation (Bell et al., 1998). The second way is plugged-in activities. Plugged-in activities are needed for screen-based visual programming environments or programming robots. Both coding experiences help to improve children's knowledge and skills in science, technology, engineering, and mathematics (STEM) areas (Miller, 2019; Papadakis et al., 2018) and computational thinking (Bati, 2022; Çetin & Demircan, 2020; Lee & Junoh, 2019; Metin, 2022). With the help of coding, mathematical interactions shift from statics to dynamic forms (Roschelle et al., 2017). Such dynamic mathematical interactions often rely on robots' movement in code parkour, counting or measurement of continuous quantities, and coding the robot regarding a problem. The coding process seems to be natural companies with mathematics, and it is used for mathematics education at an ever-increasing pace (English, 2018). In the current study instructional activities regarding measurement LTs enriched by coding process and programming robots to support children's mathematical measurement skills.

1.2 Present study

The present study aimed to investigate the effect of the LTs-based coding education program on preschoolers' measurement skills such as length, area, volume, and angle and turn. The study utilized the EMAT to assess the children's measurement skills prior to programs implementation. The programs were implemented in two experimental groups: experimental 1 received the LTs-based coding education program, while experimental 2 received the LTs-based education program without coding. A post-test was administered to all participants following program implementation, and a follow-up test was conducted four weeks later to determine the permanency of the programs' effects.

To guide the study, the following research questions were formulated:

1- What is the effect of the programs (LTs-based coding and LTs-based without coding) on preschoolers' measurement skills by comparison to the control group? And is it permanent after four weeks?
2- What is the effect of the LTs-based coding education program on preschoolers' measurement skills by comparison to the LTs-based education program without coding?

2 Method

2.1 Design

To address these issues, we employed a quantitative approach with a quasi-experimental research design to investigate the effect of the LTs-based coding education program on preschoolers' measurement skills such as length, area, volume, and angle and turn. The quasi-experimental design was selected to examine the effect of the teaching method on children and involved the use of quantitative data and statistical tests. To address the research questions, the LTs-based coding education program, the LTs-based education program without coding, and a control program that followed the national education program (which does not involve LTs or coding) were implemented.

One of the authors implemented the experimental programs, and all groups were tested using the EMAT before and after program implementation, as well as four weeks later in a follow-up test. Figure 1 illustrates the research design used in this study.

2.2 Participants

The study included 47 children (26 males) aged 55 to 71 months old (mean = 62.98, SD = 4.68) attending a public kindergarten in Türkiye. The kindergarten comprised six preschool classrooms, and experimental 1 (LTs-based coding), experimental 2 (LTs-based), and control groups were randomly assigned to three kindergarten classes within the same school. The current national preschool education curriculum was implemented in the control group while learning LTs-based coding activities were implemented in experimental 1, and LTs-based activities were implemented in experimental 2. There were 15 children in experimental 1 (5 females, 10 males; mean age 62.87); 17 children in experimental 2 (8 females, 9 males; mean age 62.47), and 15 children in the control group (8 females, 7 males; mean age 63.67). None of the children had prior experience in either coding or LTs. Additionally, all participants came from lower-class backgrounds, and the majority of their parents were elementary or high school graduates.

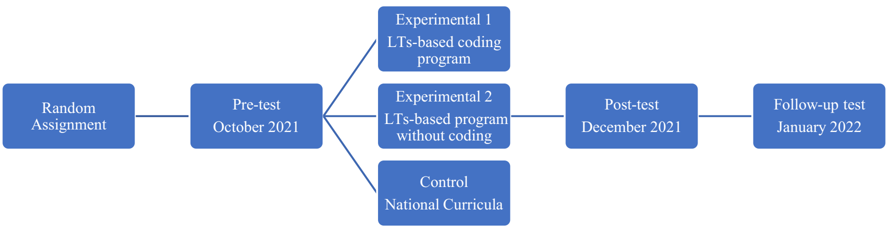

Fig. 1 Research Design

2.3 Implementations

The LTs-based coding education program and the LTs-based education program were implemented to support the measurement abilities of preschoolers. The LTs-based coding education program aimed to develop measurement abilities while integrating coding to enrich the learning environment. Table 1 summarizes the commonalities and differences between the LTs-based coding education program and the LTs-based education program without coding.

As shown in Table 1, the LTs-based coding education program and LTs-based education program without coding had similar structures and content except for the use of coding activities. Activities and target skills for both programs are presented in Table 2.

As shown in Table 2, the first and second sessions of both the LTs-based coding education program and the LTs-based education program without coding focus on basic math skills rather than measurements. Measurement-related activities start with the third session, which focuses on length measurement, and continue with area, volume, and angle and turn measurements. The focus of measurement activities starts with lower levels of developmental progressions regarding LTs. For example, in the third session, LTs-based activities focus on comparing and ordering ropes while LTs-based coding activities focus on comparing and ordering the distance of the robots' movement. The fourth session focuses on understanding the unit of length measurement. Children's steps were used in LTs-based activities, and the robots' steps were used in LTs-based coding activities to draw attention to the importance of the unit. Learning trajectories were at the heart of both implementations.

The third group, the control group, did not receive any additional sessions regarding LTs or coding. Instead, they followed the national curriculum provided by their teachers, which is a developmental program aiming to develop children's cognitive, social-emotional, psychomotor, and language skills. Math-related activities are under cognitive development learning outcomes, and the national curriculum includes five measurement outcomes: (1) predicting measurement results, (2) measuring with non-standard units, (3) telling the results of measurements, (4) comparing measurements with predicted results, and (5) using standard measurement tools. All groups had the same implementation except for the experimental sessions.

2.4 Data collection tool and procedure

The data for this study were collected using the EMAT, a performance-based assessment tool developed by the authors. The EMAT evaluates the measurement skills of children aged 48 to 96 months old and consists of 38 items, including 12 in length, 10 in area, eight in volume, and eight in angle and turn measurements. The LTs approach was used as the theoretical framework for the test. To validate the interpretation of the EMAT scores, the test was administered to 211 children aged 48 to 96 months old (mean = 72.27, s.d = 14.05). The interpretation of test scores was validated using both multidimensional item response theory (MIRT) and classical

Table 1 Comparison of LTs-based Coding and LTs-based Education Programs

Program Features	LT-based Coding Education Program	LTs-based Education Program Without Coding
Learning Goals	Development of preschoolers' measurement abilities, such as length, area, volume, and angle and turn. In addition, quantity, number, subitizing, and shape LTs	Development of preschoolers' measurement abilities, such as length, area, volume, and angle and turn. In addition, quantity, number, subitizing, and shape LTs
Duration	16 sessions, each lasting approximately 75 min	16 sessions, each lasting approximately 75 min
Content and Materials	Instructional activities regarding LTs, including both coding and unplugged activities, robotics (Matatalab and CubeCode), and simple materials such as crayons, toy blocks, ropes, marbles, puppets, etc	Instructional activities regarding LTs, including simple materials such as crayons, toy blocks, ropes, marbles, puppets etc., without any coding or technological tools
Implementation	Presented to expert opinions and revised accordingly by the authors, implemented in the fall of 2021 by one of the authors in six weeks	Presented to expert opinions and revised accordingly by the authors, implemented in the fall of 2021 by one of the authors in six weeks

Table 2 Activities and target skills

Activity name		Target skills
LTs-based coding education program	LTs-based education program without coding	
I am a robot	Graphic with balloon	Counting, quantity, number, and subitizing
I am teaching shapes to my robot	I am learning geometric shapes	Geometric shapes
My robot's steps	I am sorting ropes	Length measurement
Robots are racing	Measuring step by step	Length measurement
I am measuring my parkour	Friends on the farm	Area measurement
The robot who waters the flowers	The water in my bucket	Volume measurement
The robot's buckets	Colored waters	Volume measurement
The volume of my jar	The volume of my jar	Volume measurement
The volume detective	The volume detective	Volume measurement
The robot's way	I am driving on a ramp	Angle and turn measurement
Robot the painter	The car which doesn't have a steering wheel	Angle and turn measurement
Figure hunter	Figure hunter	Area, angle and turn measurement
Robots are going to school	The way to school	Angle and turn measurement
The length of my tower	The length of my tower	Length measurement
Guess what, which one is taller?	Guess what, which one is taller?	Length measurement
The measurement station	The measurement station	Length, area, volume, angle and turn measurement

test theory (CTT). The children's scores were best fitted into a unidimensional two-parameter logistic model. Furthermore, the MIRT scores were evaluated across ages, showing a significant increase in children's EMAT scores with age. Criterion-related validity was evaluated using the Test of Early Mathematics Ability-3 (TEMA-3), showing a strong correlation. Moreover, one-fifth of the children were retested after six weeks to obtain test–retest reliability. In summary, the EMAT was found to be a psychometrically valid and reliable instrument to assess the measurement abilities of 48–96 months old children in length, area, volume, and angle and turn measurements.

The EMAT was administered by one of the authors in a separate section of the school. The test was conducted through one-on-one interviews and lasted approximately 25 to 35 min per child. Data regarding children's measurement skills were collected in the academic year 2021/2022, before the implementation of programs, immediately after, and four weeks after the final session. For children who reported feeling tired and wanting to continue later, the test process was divided into two sessions.

2.5 Ethical issues

Ethical approval was obtained from the Ethics Committee of the Social Sciences Institute of Çukurova University and research permission was obtained from the Adıyaman Provincial Directorate of National Education before the data collection process. Informed consent forms were used to inform and obtain approval from the parents of the participants and to collect demographic information. In addition, teachers and parents were informed about the study and the data collection process. No child or parents was forced to test, or programs implementation. The teachers were also in classrooms throughout the implementations, and children's developmental needs were considered.

2.6 Data analysis

The children's pre-post and follow-up EMAT scores were analyzed. First, the KR-20 test was applied with Jmetrik to obtain the reliability coefficients of the measurements (Meyer, 2014). Next, Hierarchical Linear Modeling (HLM) (Woltman et al., 2012) was performed to determine the change in children's EMAT scores. The HLM enabled us to compare the change in children's scores between and within groups. The HLM was conducted using the HLM 8.0 student version. The HLM analyses the variance caused by the variables at different levels in the dependent variable. In the present study, there were two levels: level-1 was children's pre-post and follow-up EMAT scores, and level-2 was children and their groups as experiments or control.

The HLM was conducted in three models. First, an unconditional model (no predictors at both levels) was performed to obtain the intra-class correlation (ICC), which shows the degree of dependencies. Next, a predictor was added at level-1 (time as pre-post or follow-up scores), and then a predictor was added at level-2 (experiments or the control). The models are presented in Table 3. The level-1 predictor enabled us to see whether there was a significant change

Table 3 Research models

Aim	Model	Dependent variable	Level 1 input variables	Level 2 input variables
The effect of programs	Unconditional model	Pre and post-EMAT scores		
	Model 1	Pre and post-EMAT scores	Time of EMAT scores (pre or post)	
	Model 2	Pre and post-EMAT scores	Time of EMAT scores (pre or post)	Children's group (experimentals and the control)
The effect of LTs based coding program	Unconditional model	Pre and post-EMAT scores		
	Model 3	Pre and post-EMAT scores	Time of EMAT scores (pre or post)	
	Model 4	Pre and post-EMAT scores	Time of EMAT scores (pre or post)	Children's group (experiment 1 and experiment 2)
Permanence	Unconditional model	Post and follow up EMAT scores		
	Model 5	Post and follow up EMAT scores	Time of EMAT scores (post or follow-up)	

in children's scores between tests (pre vs post, and post vs follow-up) while the level-2 predictor enabled us to efficacy of training (experimental 1 and 2 vs the control, and experimental 1 vs experimental 2). The level-1 and level-2 equations are presented below.

Level-1

$$EMAT_{ti} = \pi_{0i} + \pi_{1i} * (T_{ti}) + e_{ti} \tag{1}$$

Level-2

$$\begin{aligned} \pi_{0i} &= \beta_{00} + \beta_{01} * (Group_i) + r_{0i} \\ \pi_{1i} &= \beta_{10} + \beta_{11} * (Group_i) + r_{1i} \end{aligned} \tag{2}$$

Mixed

$$\begin{aligned} EMAT_{ti} = &\beta_{00} + \beta_{01} * (Group_i) + \beta_{10} * (T_{ti}) + \beta_{11} * (Group_i) * (T_{ti}) \\ &+ r_{0i} + r_{1i} * (T_{ti}) + e_{ti} \end{aligned} \tag{3}$$

Where

$EMAT_{ti}$	dependent variable, which is the score of children (i) at (t) time (pre, post or follow-up),
(T_{ti})	value on the level-1 predictor, time of the measurements (pre, post or follow-up),
π_{0i}	intercept for level-2 which is the EMAT pretest score of children (i),
π_{1i}	regression coefficient associated with the time of the measurements (pre, post or follow-up),
e_{ti}	random error associated with children (i) at (t) time (pre, post or follow-up),
β_{00}	overall mean intercept adjusted for EMAT pretest scores,
β_{01}	regression coefficient associated with EMAT pretest scores regarding groups,
r_{0i}	random effects of the level-2 unit adjusted for EMAT scores on the intercept,
β_{10}	overall mean intercept adjusted for EMAT post-test scores,
β_{11}	regression coefficient associated with EMAT post-test scores regarding groups,
r_{1i}	random effects of the level-2 unit adjusted for EMAT scores on the slope.

3 Results

The findings presented in this study were obtained through three administrations of the EMAT to participants, including the pre-test, post-test, and follow-up test. The results for each administration are displayed in Table 4.

Table 4 Descriptive statistic of measures

EMAT	Groups	N	$\bar{x}$	S.d	Range	Skewness (S.e.)	Kurtosis (S.e.)	Kr-20
Pre-test	Experimental 1	15	10.93	4.69	17	1.35 (0.58)	1.78 (1.12)	
	Experimental 2	17	11.00	5.38	22	1.87 (0.55)	4.21 (1.06)	0.87
	Control	15	11.00	4.14	15	0.10 (0.58)	0.10 (1.12)	
Post-test	Experimental 1	15	21.73	5.94	19	0.00 (0.58)	-1.12 (1.21)	
	Experimental 2	17	20.41	6.50	26	0.69 (0.55)	0.69 (1.06)	0.92
	Control	15	14.13	4.80	18	0.41 (0.58)	0.08 (1.12)	
Follow-up test	Experimental 1	15	22.00	6.61	22	0.08 (0.58)	-1.01 (1.12)	
	Experimental 2	17	20.65	6.85	25	0.71 (0.55)	0.01 (1.06)	0.92
	Control	15	15.00	4.50	16	0.44 (0.58)	-0.12 (1.21)	

Table 4 displays the descriptive statistics and KR-20 reliability coefficients for all measures, indicating an acceptable range in all measures. The results show that children's measurement skills improved from pre-test to post-test and follow-up test in all groups. To determine whether this increase was statistically significant, HLM was conducted. Table 5 presents the HLM models that were analyzed to answer the research questions.

The results presented in Table 5 indicate that the coefficient for children's pretest EMAT score was significant at 11.00 [t(45) = 10.65, p < 0.05]. However, the group (experimental and control) coefficient was not significant [-0.03, t(45) = -0.02, p > 0.05], indicating that there was not a statistically significant difference between the experimental and control groups in terms of pretest scores. The overall mean coefficient adjusted for the EMAT post-test was significant at 3.13 [t(46) = 6.53, p < 0.05], and the group (experimental and control) coefficient were also significant at 6.93 [t(45) = 9.58, p < 0.05]. This suggests that children's

Table 5 Results of Model 2 and Model 4

Fixed Effects	Coefficient	S.E	*t* value	*p*
For Intercept (π_0)				
Overall mean intercept adjusted for EMAT pretest scores, (β_{00})	11.00	1.03	10.65	0.001
Group $_{\text{(experimentals and the control)}}$, ($\beta_{01}$)	-0.03	1.35	-0.02	0.98
For slope to the effect of experiments (π_1)				
Overall mean intercept adjusted for EMAT post-test β_{10}	3.13	0.48	6.53	0.001
Intercept regarding group $_{\text{(experimentals and the control)}}\beta_{11}$	6.93	0.72	9.58	0.001
Intercept regarding group $_{\text{(experimental 1 and experimental 2)}}\beta_{12}$	-1.39	1.07	-1.30	0.20
Random effects	Variance component	*d.f*	χ^2	*p*
Intercept (r_0)	19.71	45	361.78	0.001
Time (pre to posttest), slope (r_1)	2.21	45	62.78	0.04
Level-1 (*e*)	2.80			

overall post-test scores increased by 3.13 units, while the experimental groups increased by 6.93 units higher than the control group, and both increases were statistically significant. The coefficient for the group (experimental 1 and experimental 2) was not significant at -1.39 [t(45) = -1.07, $p > 0.05$], indicating that there was no significant difference between experimental 1 and experimental 2. Furthermore, both Model 2 and Model 4 were found to be superior to the unconditional model (Model 2—[$\Delta\chi^2(2) = 125.30$, $p < 0.05$], Model 4—[$\Delta\chi^2(2) = 89.69$, $p < 0.05$]), suggesting that the HLM models were effective in answering the research questions.

Table 6 shows that the coefficient regarding children's post-test EMAT score was significant at 20.66 [$t_{(31)} = 19.43$, $p < 0.05$]. However, the overall mean coefficient adjusted for EMAT follow-up test scores was not significant at 0.25 [$t_{(31)} = 0.96$, $p > 0.05$]. Model 5 was not found to be superior to the unconditional model [$\Delta\chi^2(2) = 1.70$, $p > 0.05$]. This means that children's post-test scores are estimated as 20.66 units, and there is not a statistically significant difference between post and follow-up test scores. Therefore, it is reasonable to assume that both programs have a permanent effect on children's measurement skills.

The EMAT score was comprised of four subtests, which are length, area, volume, and angle and turn measurement. Table 7 presents the descriptive statistics of subtests.

Table 7 shows that children's length, area, volume, and angle and turn measurement skills improved from pre-test to post-test in all groups. To determine whether this increase was statistically significant, HLM was conducted for all sub test scores. The results were presented in Table 8.

The results presented in Table 8 indicate that the coefficient for children's pre-test length subtest score was significant at 2.60 [t(45) = 4.81, $p < 0.05$]. However, the group (experimental and control) coefficient was not significant [0.21, t(45) = -0.33, $p > 0.05$], indicating that there was not a statistically significant difference between the experimental and control groups in terms of pretest scores. The overall mean coefficient adjusted for the length subtest post-test was significant at 1.93 [t(46) = 7.50, $p < 0.05$], and the group (experimental and control) coefficient were

Table 6 Results of Model 5

Fixed Effects	Coefficient	S.E	*t* value	*p*
For Intercept (π_0)				
Overall mean intercept adjusted for EMAT post-test scores, (β_{00})	20.66	1.06	19.43	0.001
For slope to the effect of permanence (π_1)				
Overall mean intercept adjusted for EMAT follow-up test scores, (β_{10})	0.25	0.6	0.96	0.35
Random effects	Variance component	*d.f*	χ^2	*p*
Intercept (r_0)	30.07	31	159.50	0.001
Time (r_1)	0.55	31	41.00	0.10
Level-1 (e)	0.85			

Table 7 Descriptive statistics of subtests

Subtest	Time	Groups	N	$\bar{x}$	S.d	Range	Skewness (S.e.)	Kurtosis (S.e.)
Length	Pre-test	Experimental 1	15	3.00	1.81	8	1.33 (0.58)	3.78 (1.12)
		Experimental 2	17	2.65	2.09	9	2.02 (0.55)	5.06 (1.06)
		Control	15	2.60	2.16	7	0.50 (0.58)	-0.61 (1.12)
	Post-test	Experimental 1	15	6.47	2.67	7	-0.16 (0.58)	-1.70 (1.12)
		Experimental 2	17	6.29	2.75	8	0.46 (0.55)	-1.01 (1.06)
		Control	15	4.53	2.77	8	0.35 (0.58)	-1.03 (1,12)
	Follow-up test	Experimental 1	15	6.87	2.88	8	-0.30 (0.58)	-1.40 (1.12)
		Experimental 2	17	6.53	3.20	9	0.46 (0.55)	-1.32 (1.06)
		Control	15	4.67	2.55	8	0.52 (0.58)	-0.69 (1.12)
Area	Pre-test	Experimental 1	15	2.80	1.20	4	0.15 (0.58)	-0.93 (1.12)
		Experimental 2	17	3.00	1.76	6	2.30 (0.55)	4.64 (1.06)
		Control	15	3.00	1.06	4	0.00 (0.58)	-0.40 (1.12)
	Post-test	Experimental 1	15	4.93	1.79	7	0.71 (0.58)	0.55 (1.12)
		Experimental 2	17	4.47	1.84	7	1.17 (0.55)	1.62 (1.06)
		Control	15	3.33	1.11	4	1.02 (0.58)	1.13 (1.12)
	Follow-up test	Experimental 1	15	4.87	1.96	8	0.80 (0.58)	0.16 (1.12)
		Experimental 2	17	4.41	1.94	7	0.97 (0.55)	1.02 (1.06)
		Control	15	3.67	1.23	4	0.21 (0.58)	1.13 (1.12)
Volume	Pre-test	Experimental 1	15	2.20	1.13	3	0.43 (0.58)	-1.69 (1.12)
		Experimental 2	17	2.00	1.36	4	1.49 (0.55)	1.16 (1.06)
		Control	15	2.27	1.48	4	-0.52 (0.58)	-1.22 (1.12)
	Post-test	Experimental 1	15	4.67	1.23	4	-0.57 (0.58)	-0.21 (1.12)
		Experimental 2	17	4.00	1.50	6	0.00 (0.55)	0.13 (1.06)
		Control	15	2.53	1.36	5	-0.38 (0.58)	0.44 (1.12)
	Follow-up test	Experimental 1	15	4.80	1.37	5	-0.35 (0.58)	0.30 (1.12)
		Experimental 2	17	4.18	1.18	5	0.64 (0.55)	1.15 (1.06)
		Control	15	2.87	0.99	4	0.30 (0.58)	0.62 (1.12)
Angle and Turn	Pre-test	Experimental 1	15	3.07	1.22	5	0.67 (0.58)	1.17 (1.12)
		Experimental 2	17	3.35	1.32	5	0.73 (0.55)	0.64 (1.06)
		Control	15	3.13	0.99	4	-0.29 (0.58)	0.61 (1.12)
	Post-test	Experimental 1	15	5.67	0.97	3	0.25 (0.58)	-1.13 (1.12)
		Experimental 2	17	5.41	1.46	5	0.13 (0.55)	-0.20 (1.06)
		Control	15	3.73	0.88	3	1.31 (0.58)	1.82 (1.12)
	Follow-up test	Experimental 1	15	5.40	1.24	4	0.65 (0.58)	-0.32 (0.34)
		Experimental 2	17	5.53	1.42	5	0.23 (0.55)	-0.48 (0.23)
		Control	15	3.87	0.83	3	1.12 (0.58)	1.95 (1.12)

also significant at 1.63 [t(45) = 3.78, $p < 0.05$]. This suggests that children's overall post-test scores increased by 1.93 units, while the experimental groups increased by 1.63 units higher than the control group, and both increases were statistically significant. The coefficient for the group (experimental 1 and experimental 2) was not significant at 0.18 [t(45) = 0.26, $p > 0.05$], indicating that there was no significant difference between experimental 1 and experimental 2.

The coefficient for children's pretest area subtest score was significant at 3.00 [t(45) = 11.25, $p < 0.05$]. However, the group (experimental and control) coefficient was not significant [-0.09, t(45) = -0.25, $p > 0.05$], indicating that there was not a statistically significant difference between the experimental and control groups in terms of pretest scores. The overall mean coefficient adjusted for the area subtest post-test was not significant at 0.33 [t(46) = 1.48, $p > 0.05$], while the group (experimental and control) coefficient was significant at 1.44 [t(45) = 4.86, $p < 0.05$]. This suggests that children's overall post-test scores was not statistically increased, however the experimental groups statistically significantly increased by 1.44 units higher than the control group. The coefficient for the group (experimental 1 and experimental 2) was not significant at -0.67 [t(45) = -1.74, $p > 0.05$], indicating that there was no significant difference between experimental 1 and experimental 2.

The coefficient for children's pretest volume subtest score was significant at 2.26 [t(45) = 6.11, $p < 0.05$]. However, the group (experimental and control) coefficient was not significant [-0.17, t(45) = -0.40, $p > 0.05$], indicating that there was not a statistically significant difference between the experimental and control groups in terms of pretest scores. The overall mean coefficient adjusted for the volume subtest post-test was not significant at 0.26 [t(46) = 1.11, $p > 0.05$], while the group (experimental and control) coefficient was significant at 1.95 [t(45) = 5.60, $p < 0.05$]. This suggests that children's overall post-test scores were not statistically increased, however, the experimental groups statistically significantly increased by 1.95 units higher than the control group. The coefficient for the group (experimental 1 and experimental 2) was not significant at -0.47 [t(45) = -0.92, $p > 0.05$], indicating that there was no significant difference between experimental 1 and experimental 2.

The coefficient for children's pretest angle and turn subtest score was significant at 3.13 [t(45) = 12.68, $p < 0.05$]. However, the group (experimental and control) coefficient was not significant [0.08, t(45) = -0.25, $p > 0.05$], indicating that there was not a statistically significant difference between the experimental and control groups in terms of pretest scores. The overall mean coefficient adjusted for the angle and turn subtest post-test was significant at 0.60 [t(46) = 2.91, $p < 0.05$], and the group (experimental and control) coefficient were also significant at 1.71 [t(45) = 5.70, $p < 0.05$]. This suggests that children's overall post-test scores increased by 0.60 units, while the experimental groups increased by 1.71 units higher than the control group, and both increases were statistically significant. The coefficient for the group (experimental 1 and experimental 2) was not significant at -0.54 [t(45) = -1.28, $p > 0.05$], indicating that there was no significant difference between experimental 1 and experimental 2.

Table 8 HLM Results for Subtests

	Fixed Effects	Coefficient	S.E	*t* value	*p*
Length	For Intercept (π_0)				
	Overall mean intercept adjusted for Length pre-test scores, (β_{00})	2.60	0.53	4.81	0.001
	Group $_{\text{(experimentals and the control)}}$, ($\beta_{01}$)	0.21	0.64	0.33	0.74
	For slope to the effect of experiments (π_1)				
	Overall mean intercept adjusted for Length post-test β_{10}	1.93	0.25	7.50	0.001
	Intercept regarding group $_{\text{(experimentals and the control)}}\beta_{11}$	1.63	0.43	3.78	0.001
	Intercept regarding group $_{\text{(experimental 1 and experimental 2)}}\beta_{12}$	0.18	0.69	0.26	0.80
Area	For Intercept (π_0)				
	Overall mean intercept adjusted for Area pre-test scores, (β_{00})	3.00	0.26	11.25	0.001
	Group $_{\text{(experimentals and the control)}}$, ($\beta_{01}$)	-0.09	0.37	-0.25	0.80
	For slope to the effect of experiments (π_1)				
	Overall mean intercept adjusted for Area post-test β_{10}	0.33	0.22	1.48	0.14
	Intercept regarding group $_{\text{(experimentals and the control)}}\beta_{11}$	1.44	0.30	4.86	0.001
	Intercept regarding group $_{\text{(experimental 1 and experimental 2)}}\beta_{12}$	-0.67	0.38	-1.74	0.09
Volume	For Intercept (π_0)				
	Overall mean intercept adjusted for Volume pre-test scores, (β_{00})	2.26	0.37	6.11	0.001
	Group $_{\text{(experimentals and the control)}}$, ($\beta_{01}$)	-0.17	0.44	-0.40	0.70
	For slope to the effect of experiments (π_1)				
	Overall mean intercept adjusted for Volume post-test β_{10}	0.26	0.24	1.11	0.27
	Intercept regarding group $_{\text{(experimentals and the control)}}\beta_{11}$	1.95	0.34	5.60	0.001
	Intercept regarding group $_{\text{(experimental 1 and experimental 2)}}\beta_{12}$	-0.47	0.51	-0.92	0.37
Angle and Turn	For Intercept (π_0)				
	Overall mean intercept adjusted for Angle and Turn pre-test scores, (β_{00})	3.13	0.25	12.68	0.001
	Group $_{\text{(experimentals and the control)}}$, ($\beta_{01}$)	0.08	0.33	0.25	0.80
	For slope to the effect of experiments (π_1)				
	Overall mean intercept adjusted for AT post-test β_{10}	0.60	0.21	2.91	0.01
	Intercept regarding group $_{\text{(experimentals and the control)}}\beta_{11}$	1.71	0.30	5.70	0.001
	Intercept regarding group $_{\text{(experimental 1 and experimental 2)}}\beta_{12}$	-0.54	0.42	-1.28	0.21

4 Discussion

The present study examines the effect of the LTs-based coding education program on preschoolers' measurement skills. To address this issue, the LTs-based coding education program, and the LTs-based education program without coding were implemented for preschoolers. It was found that both programs significantly increased preschoolers' measurement skills compared to the control group whereas there was not a significant difference between experimental groups. The results were consistent across length, area, volume, and angle and turn subtests. In addition, the effect of the programs was permanent four weeks later. The results were discussed in two sections: the effect of both programs compared to the control, and the effect of the LTs-based coding compared to the LTs-based education without coding.

4.1 The effect of experimental programs compared to the control

The results showed that both experimental groups outperformed the control group and they had significantly higher post-test scores than the control group. The results were consistent across all subtests. The LTs approach was a key component of both programs, and it appears to have played a significant role in improving preschoolers' measurement skills. Measurement is an essential part of mathematics education, and it is closely linked to other topics such as numbers, geometry, and patterns. Previous research has shown that the LTs approach is an effective method for teaching math (Baroody et al., 2022; Barrett et al., 2011; Sarama et al., 2021) and is a useful framework for connecting math standards with the curriculum (Confrey et al., 2014). Specific instructions and strategies that focus on a mathematical goal can help children build their existing knowledge (Clements & Sarama, 2014). In the current study, children in both educational programs were supported with educational activities that aligned with their developmental progress in measurement skills. These activities spanned a range of levels, from distinguishing measurable attributes to unit iteration, and provided appropriate activities for each level. In summary, the present study expanded on previous research demonstrating the effectiveness of the LTs approach in improving preschoolers' math skills.

4.2 The effect of the LTs-based coding education program compared to the LTs-based education program

Although experimental 1 (LTs-based coding) showed a slightly higher increase, there was no significant difference in preschoolers' measurement skills between the experimental groups. Both experimental groups outperformed the control group, showing that both programs were effective in improving preschoolers' measurement skills in all subtests. The addition of coding to the LTs approach was expected to result in a higher increase in post-test scores for experimental 1, based on previous research (Bartolini Bussi & Baccaglini-Frank, 2015; Fessakis et al., 2013; Shumway et al., 2021; Somuncu & Aslan, 2022; Sullivan & Bers, 2016) that has shown the positive effects of coding on young children's various math skills. However, the results suggest that coding did not have a significant effect on preschoolers' measurement skills compared to the LTs approach and this was consistent across length, area, volume, angle and turn measurement. As pointed out by Lopez-Caudana et al. (2020), robotics and coding are mediating tools, while Roschelle et al. (2017) stated that the coding experience facilitates measurement activities for young children by providing a dynamic learning environment. Also, Aladé et al. (2016) suggested that coding robots might support preschoolers' learning by providing real-life experiences and immersive learning environments. Furthermore, Cicconi (2014) pointed out that coding can help children perform better by facilitating collaboration, communication, and interaction. Moreover, Cejka et al. (2006) pointed out that supervised play with robotic toys motivates and encourages children in measurement activities. Therefore, the LTs approach could be equally effective as the LTs-based coding implementation in providing interactive learning and keeping children motivated by presenting them with developmentally appropriate instructional tasks. These findings were also supported by the results of the follow-up test.

Alternatively, it is possible that both experimental groups showed a significant increase in a short time, and a longer-term teaching experiment may be necessary to demonstrate the effect of coding. The children may have reached their developmental limits with regard to measurement skills, as their progress is limited by developmental factors (Clements & Sarama, 2014).

In summary, both programs significantly improved preschoolers' measurement skills in all subtests, with no significant difference between the two. These findings suggest that the LTs approach is effective in improving preschoolers' measurement skills and that coding may have other benefits, such as problem-solving and computational thinking skills. Further studies are needed to better understand the long-term effects of coding on preschoolers' measurement skills, as well as its potential benefits for other areas of mathematics learning.

5 Limitations and future studies

The present study has demonstrated the effectiveness of the LTs-based coding program and LTs-based program without coding in improving preschoolers' measurement skills, it is important to acknowledge some limitations that may provide opportunities for future studies. For instance, the study did not investigate the coding, computational thinking and problem-solving skills of young children, and future studies may consider measuring those skills to address this gap. Additionally, the study did not explore the potential impact of individual differences, such as gender and age, on the effectiveness of the programs. Future studies may consider investigating these individual differences to develop more targeted interventions for specific groups of children. Furthermore, the present study was conducted in a quantitative method, and future studies conducted in a qualitative method could provide a better understanding of how implementation effected children's measurement skills. Finally, the study was conducted with a relatively small sample size, and future research could expand on this by using a larger sample size to enhance the generalizability of the findings.

6 Conclusion and recommendations

The present study was conducted to investigate the effect of LTs-based coding program and the LTs-based program without coding on preschoolers' measurement skills. The results revealed that both programs had a significant and permanent effect on preschoolers' measurement skills compared to the control group whereas there was not a significant difference between experimental groups. The study showed the potential benefits of incorporating the LTs approach and coding for preschoolers. Educators and policymakers may consider incorporating the LTs approach and coding into early childhood education curricula to enhance mathematical skill development and prepare young children for a rapidly changing teaching environment.

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

Declarations

Ethics approval The research was approved by the local ethics committees of Cukurova University and The Republic of Turkish Ministry of National Education.

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

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