

The effects of digital block play on children's mathematical problem-solving ability and flow: A collaborative action research approach*

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Abstract

Digital blocks, equipped with various digital technologies, expand children's play experiences and enrich the process of problem-solving. The purpose of the present study was to explore the effects of digital block play, implemented through a collaborative action research approach, on children's mathematical problem-solving ability and flow. Thirty-four 5-year-old children (16 in the experimental group and 18 in the control group) from a public preschool in South Korea participated in the study. Children in the experimental group engaged in free play using digital blocks, while those in the control group engaged in free play followed their usual routines without digital blocks. The results revealed that the children in the experimental group exhibited statistically significant improvements in mathematical problem-solving skills compared to the control group. Although the level of flow among children in the experimental group increased more compared to the control group, it was not statistically significant. The present study indicates that digital block play, supported by educator's close scaffolding, facilitates the mathematical thinking process. The implications of these findings for educational practices and the integration of digital blocks in early childhood education are discussed.

Keywords : *Digital blocks, Free play, Mathematical problem-solving skills, Flow*

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* This study is based on the first author's master's thesis.

Introduction

We live in the digital age, in which young children experience diverse digital devices, such as smartphones, tablets, wearable devices, and the Internet of Toys (IoToys) in their daily lives and educational settings (Matton et al., 2015). Given the increasing national emphasis on early childhood education (ECE) in South Korea and other countries, discussions around what digital technology should be introduced and how it should be experienced within ECE settings have become crucial (Holloway et al., 2013; Kewalramani et al., 2020; Robin et al., 2024). Although most studies in ECE have focused on screen-based digital media, such as tablets (Matton et al., 2015; Neumann & Neumann, 2014; Robin et al., 2024), there remains a lack of pedagogical understanding and play-based practices for integrating physical toys such as IoToys into ECE curricula. Given their tangible and interactive nature, IoToys can serve as educational media that promote expanded play experiences and cognitive development in young children. Despite their potential, there is a limited understanding of how children and educators engage with these tools to support playful learning (Kewalramani et al., 2020).

The digital blocks used in this study are IoToys, which are physical toys connected to the Internet through Bluetooth or Wi-Fi (Wang et al., 2010). The digital blocks, designed to be compatible with traditional LEGO Duplo blocks, incorporate input and output functions. Each block is connected using a Bluetooth network function, allowing each function to be operated through interactions between the input and output blocks (Lee, 2017; Lee & Kim, 2018). Digital blocks provide real-world, physical phenomena-centered play because children can assemble digital blocks with traditional blocks, allowing for a more fluent play experience (Kewalramani et al., 2020). They also enable children to experience logical design and thinking opportunities using IoT technology (Lee, 2017).

Problem-solving abilities have been highlighted in early math curricula as a core standard for learning (Blake et al., 1995; Lee, 2019; Lee & Lee, 2017), representing a significant aspect of early mathematical development (Lee et al., 2019). The National Council of Teachers of Mathematics (NCTM, 2000) and New Zealand Ministry of Education (2010) conceptualized problem-solving as a mathematical process, defining it as the ability to

employ appropriate problem-solving strategies rooted in mathematical knowledge and skills acquired through prior experiences and learning (Kim & Lee, 2009). These abilities require children to integrate and utilize their mathematical knowledge in novel ways to solve problems they have not encountered before (Vessonen et al., 2024).

Children encounter various mathematical problems while exploring and manipulating concrete materials in their daily lives (Blake et al., 1995; Kim & Lee, 2007; Yang & Kim, 2019). For example, they experience various trial-and-error processes while playing with concrete manipulatives (Bers, 2017; Blake et al., 1995). They express their thoughts, identify the causes of problems, and repeatedly engage in understanding and modifying their thoughts. In particular, block play frequently offers such an environment, enabling children to encounter diverse symbolic mathematical concepts and cultivate critical thinking, spatial reasoning, and creativity (Linderman & Anderson, 2015; Resnick, 2017; Wolfgang, 2001). Engaging in block play encourages exploration, inquiry-based experimentation, and problem-solving, establishing a robust groundwork for mathematical reasoning (Kuykendall, 2007; Verdine et al., 2014).

Digital blocks are tangible didactic materials that retain most of the advantages of traditional LEGO blocks, allowing children to have easy and intuitive access to play with them. Similar to traditional blocks, they support diverse and open-ended activities, making them a highly suitable medium for play-based learning. Additionally, the immediate feedback offered by the blocks encourages children to actively participate in hands-on experimentation, fostering their cognitive development and problem-solving skills (Kami & DeVries, 1993). Previous studies on digital blocks have shown positive effects on children's problem-solving abilities (Kim, 2021; Lee & Yoo, 2019; Strawhacker & Bers, 2015) and logical-mathematical performance (Kim & Kim, 2019; Lee & Kim, 2018). Research by Lee and Yoo (2019) showed that coding block activities based on cooperative problem-solving learning positively influenced children's mathematical problem-solving abilities. Considering the positive effects of both traditional and coding blocks on problem-solving abilities and mathematical knowledge, digital blocks are considered suitable educational materials for enhancing young children's mathematical problem-solving abilities.

Digital block play is also a flow-producing activity. Flow is a fuzzy conception of positive

emotional and conscious mental states based on Csikszentmihalyi's (1997) framework of psychological perspectives on passion, indicative of a highly focused mind on some activity. Na (2013) described children's mental states as flow when they voluntarily engage in and concentrate on play to the extent that they lose awareness of themselves and time. A flow state indicates that a child is achieving growth by harnessing their ability to concentrate for as long as it takes to achieve a goal and by tapping into their inherent potential to continue and expand play, thereby reaching optimal development (Hunter-Doniger, 2021; Kim et al., 2022). Since children's flow experiences have important values for cognitive and emotional development and subsequent educational achievements, providing an environment that stimulates children's interest and leads to flow during play is necessary (Hunter-Doniger, 2021; Lee, 2022).

Digital blocks contain even more elements that enhance children's flow in the play activity. Previous studies have suggested a possible link between digital block play and flow (Kim et al., 2019; Lee, 2023). Various digital features, such as lights, sounds, text, numbers, Bluetooth functions, and the movement of wheel motors, add exciting elements to the fun of traditional LEGO blocks. Children become deeply engaged and immersed in block building and imaginative play using digital blocks. To make digital blocks function properly, high-level problem-solving is required, such as matching blocks of the same color and aligning the direction of rolling wheels (Kim, 2021). It appears that children's curiosity about digital technology stimulates their motivation for play, leading to a tendency to immerse themselves in play (Yoo et al., 2011). The spontaneous and simultaneous responses, along with the interactive functions inherent in digital technology, create diverse situations that further enhance children's flow experiences (Lee & Chang, 2018).

While many children are accustomed to digital tools, teachers play a crucial role in providing scaffolding to support children's exploration, creation, and with digital tools. That is, teachers should have sufficient time and opportunities to reflect on and discuss strategies for integrating these tools into their teaching and learning practices (Undheim, 2022). Research by Kewalramani et al (2020) showed that, with a teacher's appropriate intervention and interaction, children were motivated and able to extend their play using IoToys, which enriched their learning experiences. Therefore, in the present study, we applied a

collaborative action research approach where the researcher and teacher worked together with an open-ended curriculum implementation plan. The researcher used qualitative observation methods, shared in-depth observation records with the teacher, discussed curriculum implementation intensively, and provided support for children's play using digital blocks. The collaborative action research approach facilitated children's agency in digital block play and enhanced a teachers' agency in implementing and contemplating children's digital block play (Lee, 2022; Song & Oh, 2021).

Based on the needs and objectives of this research, the research questions of the present study are as follows:

RQ1. What is the effect of digital block play using a collaborative action research approach on the mathematical problem-solving ability of five-year-old preschool children?

RQ2. What is the effect of digital block play using a collaborative action research approach on the flow of five-year-old preschool children?

Methods

Study Participants

The study participants were from a public kindergarten located in Gyeonggi province, South Korea. Thirty-four 5-year-old children (16 in the experimental group, 18 in the control group) from two classrooms in a public preschool in South Korea participated in the study. Children were, on average, 74 months old. Table 1 provides information on the general background of the participants. Children in the experimental group engaged in free play using digital blocks, while those in the control group engaged in free play with traditional blocks. The experimental and control groups had no prior experience using digital blocks. The children in the experimental group were typically interested in block play and actively engaged in play by building structures with blocks and creating stories around them.

The teacher of the experimental group attended three times of workshop before providing digital blocks to their classroom. In this process, the teacher, as well as how to use digital

blocks, discuss the role in the collaborative action research and how to provide these blocks with the researchers. The integration of digital blocks into learning environment was designed and reflected by the teacher and the researchers. However, collaborative action research was not applied in the control group. Thus, the teacher of the control group never worked with the researchers for planning and supporting children's block play.

Written informed consent to participate in this study was provided by the participant children's parents. Only the children whose parents agreed to participate in the research were included in the study.

Table 1. *Sociodemographic Characteristics of Participant Children*

Group	N	Gender		Age in months (SD)
		Males	Females	
Experimental group	16	9	7	74.50(3.34)
Control group	18	11	7	74.33(3.56)
Total	34	20	14	74.41(3.45)

Measures

Mathematical Problem-solving Ability

To assess children's mathematical problem-solving ability, the study utilized the Problem-Solving Level 1 developed by the New Zealand Ministry of Education (2010) and adapted by Lee (2016). This assessment tool consists of problems requiring mathematical problem-solving ability, presented in six levels. For this study, Level 1, designed for five-year-old children, comprising a total 15 of items, was used. The sub-scales of this tool are numbers and operations, algebra, geometry, measurement, and statistics, with three items in each scale. The overall reliability of the mathematical problem-solving is .90, with the sub-scale reliabilities as follows: numbers and operations .70, algebra .70, geometry .50, measurement .60, and statistics .50. Detailed contents and reliabilities are presented in Table 2 below.

Table 2. *Mathematical Problem-solving Ability of Young Children*

Scale	Contents	Number of items	Cronbach's α
Numbers and Operations	Solving problems using the concepts of numbers and operations	3 (1-3)	.70
Algebra	Solving problems based on an understanding of patterns	3 (4-6)	.70
Geometry	Solving problems based on basic concepts of space and shapes	3 (7-9)	.50
Measurement	Solving problems based on basic measurement	3 (10-12)	.60
Statistics	Solving problems based on basic data collection results	3 (13-15)	.50
Total		15	.90

Flow

To assess children's flow, we utilized the flow scale developed by Na (2013) based on Csikszentmihalyi's (1975; 1997) conceptualization. This scale was developed based on existing flow scale items (Skill-Challenge balance, Action-awareness merging, Clear Goals, Unambiguous feedback, Concentration on the task at hand, Sense of control, Lack of self-consciousness, Transformation of time, Autotelic experience) and comprises four sub-scales: problem-solving process, concentration on the play, loss of self-consciousness, and altered sense of time. The scale includes a total of 44 items: 29 items for the problem-solving process, 5 items for concentration on play, 7 items for loss of self-consciousness, and 3 items for an altered sense of time. The flow of each participant child was rated by the lead teacher in the classroom, with each item rated on a Likert scale from 1(not at all) to 5(very much). Higher scores indicate a higher degree of children's flow during free play. The overall reliability of the flow scale was .95. The sub-scale reliabilities are as follows: problem-solving process .95, concentration on play .70, loss of self-consciousness .80, and altered sense of time .70. Detailed contents and reliabilities are presented in Table 3 below.

Table 3. *Children's Flow*

Scale	Definition	<i>M</i> (<i>SD</i>)	Cronbach's α
Problem-solving Process	Before playing, set clear goals, regulate oneself, take on challenges, and realize whether one is performing tasks correctly while solving problems	29	.95
Concentration on play	Focus on the teacher's stories or the play without paying attention to unnecessary external stimuli and information	6	.70
Loss of self-consciousness	Immerse oneself in play without being conscious of one's appearance or actions, concentrating solely on the play	6	.80
Altered sense of time	When focused on play, perceive time as passing more quickly or slowly than usual	3	.70
Total		44	.95

Digital Blocks

The experimental tool used in this study, the digital blocks, are educational toys that incorporate various functions into existing LEGO Duplo blocks. These functions allow the blocks to interact and operate with each other through a wireless Internet of Things (IoT) network (Lee, 2017). The digital blocks are composed of blocks with various functions, which are classified into input blocks and output blocks. The input blocks include control and switch blocks, while the output blocks include number, signal, light, letter, motor, and sound blocks. Digital blocks are compatible with the commonly used Duplo blocks, allowing for a wide range of designs and constructions. Detailed components of digital blocks are presented in Figure 1.

Procedure

The study lasted approximately seven weeks, from September 11, 2023, to October 25, 2023, in two classes of 5-year-old children from the Gyeonggi province in South Korea. Participant observation was carried out in the classroom of the experimental group. The first author recorded observations of children's digital play from 09:00 AM to 10:40 AM because digital block play only occurred in the morning free play time. Pre- and post-tests were conducted at the beginning and end of the study.

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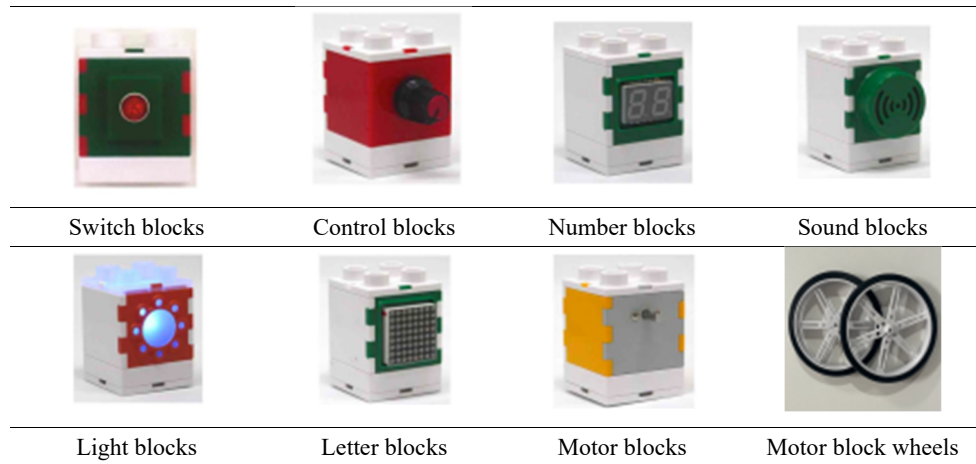


Figure 1. Digital block's components (copyright from CREAMO Inc.)

Table 4. Classroom Schedules of the experimental group and control group

Experimental group	Time	Control group
Greeting	8:30-9:00 AM	Greeting
Free Play		
*Digital block play	9:00-10:40 AM	Free Play
Circle Time		
*Reflection circle (Class sharing time of the day's digital block play)	10:50-11:10 AM	Circle Time
Outside Play	11:10 AM-12:00 PM	Outside Play
Lunch/Bathroom	12:00-13:30 PM	Lunch/Bathroom
Teacher-directed Activity Time	13:30-13:55 PM	Teacher-directed Activity Time
Pack up and Dismissal	13:55-14:00 PM	Pack up and Dismissal

Collaborative action research approach was also conducted to support children's digital block play. The researcher shared observation recordings with the lead teacher in the intervention classroom and discussed observed digital block play phenomena and made joint decisions on play support. The spiral action research model, proposed by Kemmis and McTaggart (2004), was applied to collaborative action research for the intervention group.

The researcher maintained a collaborative relationship with a teacher by sharing observation notes via Google Drive after each session and continuously exchanging opinions on play, children's reactions, and future play support. Furthermore, various alternatives were introduced based on the needs and requests of the teacher, allowing them to choose their own methods. The specific processes and roles of the teacher and researcher are detailed in Table 5 below.

Table 5. *Contents of Collaborative Action Research for Digital Block Play*

Execution phase and duration	Contents of digital block play	Teacher's role and support	Researcher's role and support
	- exploring digital blocks - discussing the components and functions of digital blocks and their operation methods 	- 1st environment set up - creating an atmosphere for free exploration (e.g. "How can we make this block produce sound?") - conducting play evaluation (providing opportunities to share explored content) - facilitating play	- observation of exploratory play - sharing of participatory observation data(transcript) - proposal for play evaluation - accumulation of content on problem situations and solutions
1 st execution process (September 11 th ~October 5 th)	- utilizing digital blocks in existing structures (amusement park) - spinning top competition 	- observation - facilitating play (e.g. "What can we do to make the spinning top stronger?") - implementation of play evaluation (accumulation of problem-solving processes using padlet) - implementation of experimental activities (e.g. "Let's check if shorter length actually makes it stronger", "How should we measure to accurately determine the lengths of the two spinning tops?")	- observation and sharing of data (utilizing padlet; making boards program to collect, organize, and present anything) - academic support - writing for researcher journals

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Table 5. *Contents of Collaborative Action Research for Digital Block Play* (continued)

Execution phase and duration	Contents of digital block play	Teacher's role and support	Researcher's role and support
2 nd execution process (October 6 th ~October 27 th)	- vehicles (bus, train, airplane) construction play 	- 2nd environment set up : discussion and environment arrangement for expanding the digital block play area, providing additional digital blocks	
		- observation and recording - supporting play - facilitating play - maintaining teaching behaviors that encourage investigative processes (using question-driven inquiry; "The two wheels are attempting to move in opposite directions. How can we make them move forward?") - providing feedback on children's thought	- suggestions for play documentation to support digital block play - academic support - suggestions for promoting thinking processes and feedback - writing for researcher journals
	- setting up a driving license test site - driving practice play - airplane tag play	- observation and recording - execution of play evaluation - environmental support to utilize lobby	- observation and sharing of data - sharing of play flow and children's reactions - collaboration on activity plans related to play - writing for researcher journals

Data Analysis

Quantitative data was collected and analyzed statistically using SPSS Statistics 23.0. Independent t-tests were conducted on the two groups to verify the treatment effects and ensure homogeneity. If homogeneity was not confirmed, Analysis of Covariance (*ANCOVA*) analysis was conducted using the pre-test scores as covariates.

Results

The effect of free play using digital block on children's mathematical problem-solving ability

As shown in Table 6, there was no significant difference in the pre-test scores for overall mathematical problem-solving ability between the experimental group ($M=40.31$, $SD=6.59$) and the control group ($M=36.88$, $SD=7.69$). However, the independent t -test conducted for the post-test scores revealed a statistically significant difference between the experimental and control groups ($t=7.82$, $p<.001$). This indicates that free play using digital blocks has a positive effect on the mathematical problem-solving ability of 5-year-old children.

Table 6. Pre- and Post- tests Comparisons of Mathematical Problem-solving Ability

		Experimental group		Comparative group		t
		M	SD	M	SD	
Total	Pre	40.31	6.59	36.88	7.69	7.82***
	post	54.06	3.71	39.22	7.01	

Mathematical problem-solving ability

As shown in Table 7, there was no significant difference in the pre-test scores for numbers and operations, algebra, measurement, and statistics between the experimental group and the comparative group. The independent t -test conducted for the post-test scores revealed that in the numbers and operations ($t=5.05$, $p<.001$), algebra ($t=5.00$, $p<.001$), measurement ($t=4.18$, $p<.001$), and statistics ($t=5.91$, $p<.001$), the scores of the experimental group were higher than those of the control group, showing statistically significant differences.

As shown in Table 8, there was a significant difference in the pre-test scores of geometry between the two groups, *ANCOVA* was conducted. Controlling for the pre-test scores, the mean of the experimental group ($M=11.18$, $SE=.98$) was found to be higher than that of the control group ($M=8.33$, $SE=2.05$).

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Table 7. *Pre-and Post-test comparisons of Mathematical Problem-solving ability*

		Experimental group		Comparative group		<i>t</i>
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
Numbers and Operations	Pre	8.00	1.71	7.67	2.22	5.05***
	post	10.19	1.17	7.94	1.39	
Algebra	Pre	6.00	2.61	5.61	2.55	5.00***
	post	10.56	1.50	6.89	2.68	
Measurement	Pre	7.13	2.66	6.83	1.98	4.18***
	post	10.38	1.71	7.50	2.23	
Statistics	Pre	8.94	2.52	8.17	3.07	5.91***
	post	11.75	0.68	8.56	2.18	

Table 8. *Pre- and post- tests Comparisons of Geometry*

		Pre		Post		Adjusted post	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SE</i>
Geometry	Experimental	10.25	1.29	8.61	2.20	11.18	0.98
	Comparative	11.19	0.98	8.33	2.06	8.33	2.05

Table 9. *Analysis of Covariance (ANCOVA) of geometry(post-test)*

	Sum of Squares(<i>SS</i>)	<i>df</i>	<i>MS</i>	<i>F</i>
Pre-test score (covariate)	34.21	1	34.21	20.30***
Group	25.99	1	25.99	15.43***
Error	52.22	31	1.68	
Corrected total	155.44	33		

As presented in Table 9, the post-test scores for geometry showed a statistically significant difference between the two groups after controlling for the pre-test scores ($F(1,31)=15.43$, $p<.001$)

The effect of free play using digital block on children's Flow

As shown in Table 10, there was no significant difference in the pre-test scores for overall flow between the experimental ($M=148.56$, $SD=22.43$) and control group ($M=158.89$,

$SD=13.20$). Independent t -tests were conducted for the post-test scores. The experimental group exhibited a larger score change than the control group; however, the result was not statistically significant ($t=-.68$, $n.s.$).

Table 10. *Pre-and post-tests Comparisons of Flow*

		Experimental group		Comparative group		t
		M	SD	M	SD	
Total	Pre	148.56	22.43	158.89	13.20	-.68
	post	160.37	28.60	165.50	9.81	

As shown in Table 11, there was no significant difference in the pre-test scores for problem-solving process, loss of self-consciousness, and altered sense of time between the experimental group and the comparative group. The independent t -test conducted for the post-test scores revealed that in the problem-solving process ($t=-1.10$, $n.s.$), loss of self-consciousness ($t=1.90$, $n.s.$), and altered sense of time ($t=1.87$, $n.s.$), the scores of the experimental group were higher than those of the comparative group, showing no statistically significant difference.

Table 11. *Pre-and Post-test Results of Children's Flow*

		Experimental group		Comparative group		t
		M	SD	M	SD	
Problem-solving process	Pre	96.81	17.51	106.06	9.69	-1.10
	post	105.50	21.47	111.72	7.29	
Loss of self-consciousness	Pre	20.81	3.10	20.00	2.38	1.90
	post	21.94	3.62	20.06	2.01	
Altered sense of time	Pre	10.56	1.50	9.83	1.50	1.87
	post	11.19	2.19	10.00	1.32	

As shown in Table 12, there was a significant difference in the pre-test scores of concentrations on play between the two groups, we performed *ANCOVA*. Controlling for the pre-test scores, the mean of the experimental group ($M=22.50$, $SE=.65$) was found to be lower than that of the control group ($M=23.04$, $SE=.61$). As presented in Table 13, the post-test

scores for concentration on play indicate that when the influence of pre-test scores is removed, the experimental group showed a significant change in scores compared to the control group. However, the difference in means between the two groups was not statistically significant ($F(1,31)=.33, n.s.$).

Table 12. *Pre-and post-tests Comparisons on Flow*

		Pre		Post		Adjusted post	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SE</i>
Concentration on play	Experimental	20.38	2.92	21.75	3.55	22.50	.65
	Comparative	23.00	2.97	23.72	2.24	23.04	.61

Table 13. *Analysis of Covariance (ANCOVA) of concentration on play(post-test)*

	Sum of Squares (<i>SS</i>)	<i>df</i>	<i>MS</i>	<i>F</i>
Pre-test score (covariate)	82.63	1	82.63	13.34**
Group	2.04	1	2.04	.33
Error	191.97	31	6.19	
Corrected total	307.55	33		

Discussion

The present study explored children's digital block play in conjunction with an applied collaborative action research approach and examined its impact on the mathematical problem-solving abilities of five-year-old children. We found that the digital block play group showed significant improvements in all sub-factors of mathematical problem-solving, suggesting that the digital blocks were used with appropriate tools in the ECE environment. Similarly, Lee and Kim (2018) reported that the storytelling-based Smart Block program positively impacted children's logical-mathematical performance.

At the end of the seven weeks period, both the traditional and digital block play groups showed tendencies to improve in their mathematical problem-solving abilities, which was likely due to the various trial-and-error experiences related to mathematical knowledge and

skills they encountered, while manipulating and playing with traditional blocks (Bers, 2017; Blake et al., 1995; Linderman & Anderson, 2015). However, greater improvement was shown in the digital block play group because using the functions of digital blocks effectively requires higher cognitive skills (Kim, 2021; Lee & Kim, 2018) and the problem-solving process is more involved, such as adjusting the rolling direction to make the wheels move as desired, compared to traditional blocks (Kim, 2021). This result supports the claim of Kewalramani et al. (2020) that the pre-programmed functions of the IoToy provide a platform for children to problem-solve, be creative, and be cooperative.

The findings also demonstrate that a collaborative action research approach is highly effective in regard to improving children's problem-solving abilities. Based on participant observations, a teacher in the experimental group intervened promptly to support mathematical reasoning and problem-solving. Ginsburg's (2006) argument is evident that, rather than simply attributing the promotion of inquiry processes and thinking to children's play alone, the roles of teachers' linguistic interactions might play significant roles in children's mathematical development. For instance, the teacher verbalized the challenges encountered by the children, such as "The two wheels are attempting to move in opposite directions. How can we make them move forward?" and "What should be the length and width of the blocks?" In particular, the teacher presented inquiry-based problems during circle time and facilitated the children's critical thinking and cooperative discussions. Throughout the activity, the teacher actively supported the children in sustaining their planning, collaboration, and execution for problem-solving, while also cooperating with the researcher. This supported the assertion that teachers need to reorganize their environments with clear objectives, provide continuous support for mathematical learning, and give feedback to ensure the children's mathematical experiences are not superficial or accidental (Hong, 2010; Lee & Yoo, 2019).

Based on the qualitative analysis, children in the experimental group tended to exhibit more flow behaviors during digital play compared to the control group; however, the result was not statistically significant. Lee (2023) found that digital block activities using gamification influenced children's play-flow. It was assumed that the children in the experimental group showed individual differences in flow. The flow scores in the

experimental group exhibited high variability, indicated by high standard deviation values. It was observed that most of the children showed interest in the digital blocks initially, actively exploring and immersing themselves in the IoT features and functions (Kim, 2021; Lee & Chang, 2018; Yoo et al., 2011). However, after the exploration phase, individual differences in participation frequency and duration of play emerged, reflecting their unique play tendencies when using the digital blocks. The characteristics of the study population might have influenced this variability in participation and flow during play. In future research, it is suggested that the children be clustered based on their level of flow or be randomly assigned to the experimental and control groups.

In addition, the teachers' eagerness to participate in the study and their levels of education may have influenced the study results. In South Korea, the educational level of teachers in public preschools tends to be higher than in private preschools/and or childcare centers. Therefore, the instructional support provided by the teachers for the digital play may have influenced the study results. Yoo and Shim (2022) claimed that the children in their study were able to immerse themselves and engage in self-directed exploration in unplugged block play since the teacher actively participated in and supported the play. In the present study, the teacher not only performed appropriate teaching roles, but also actively interacted to sustain and deepen the children's flow in their digital block play. The teacher also conducted circle time to discuss and evaluate various phenomena in the children's digital play. It is considered that this child-centered curriculum helps children continuously explore their curiosity, contributing to enhanced flow (Hunter-Doniger, 2021; Lee, 2022). This aligns with Lee's (2019) findings, who reported that play planning-execution-evaluation activities positively influence children's flow. These findings ultimately indicate that, while providing new technological media, such as digital blocks is important, the role of teachers in supporting play using media is also crucial.

In summary, it is conclusive that free play using digital blocks has a positive effect on enhancing children's mathematical problem-solving abilities and also has some positive effect on their flow. The empirical evidence in this study has demonstrated that free play with digital blocks contributes to the improvement of mathematical problem-solving abilities. These findings suggest that digital blocks can serve as effective educational tools for

fostering young children's competencies in early childhood education settings.

The first limitation of this study is that the sample is too small to allow the researchers to generalize the findings. Subsequent research should consider creating a sample that contains children from diverse regions and age groups. The results from such an additional study, when combined with this study, will enable further generalization of the findings.

Second, digital block play occurred in the mornings, as theme-based activities unrelated to digital blocks were conducted in the afternoons. Therefore, a researcher only conducted participant observations during the mornings' free play time. Future studies should consider providing opportunities for digital block play in the afternoons or conducting small group activities related to morning digital block play in the afternoons.

Third, the reliability scores for two of the sub-factors related to mathematical problem-solving abilities were low. Each sub-factor related to mathematical problem-solving abilities was measured using three items and this small number of items may have contributed to the low reliability. Therefore, future studies should consider improving the tool used to measure mathematical problem-solving abilities.

Fourth, besides the quantitatively derived results regarding the effects of free play with digital blocks, qualitative analyses should be conducted to explore how children navigate various problem situations that arise during free play with digital blocks and how teachers interact and provide support in such situations. A closer examination of these interactions may also inform teacher training programs by highlighting effective strategies for scaffolding digital play.

Fifth, since IoT toys, like digital blocks, are not yet widely accessible, future research should explore their usage and accessibility in diverse sociocultural settings and develop strategies to prevent educational disparities.

References

- Blake, S., Hurley, S., & Arenz, B. (1995). Mathematical problem solving and young children. *Early childhood education journal*, 23, 81-84.

- Bers, M. U. (2017). *Coding as a Playground: Programming and Computational Thinking in the Early Childhood Classroom*. Routledge Press.
- Chang, Y. (2018). Effects of mathematical activities using educational robots on young children's mathematical ability and math problem solving [Unpublished master's thesis]. Chung-ang University. <https://doi.org/10.23169/cau.000000226769.11052.0000486>
- Cho, M., & Lim, S. (2022). Future education curriculum content analysis: Focusing on semantic network analysis of research report from National research institutes related to future education. *The Journal of Future Education*, 12(3), 1-20.
<https://doi.org/10.26734/JFE.2022.12.03.01>
- Cho, H., & Lee, M. (2012). The Effects of the Mathematic-center Activity based upon Inquiry on the Children's Mathematical Problem-Solving Ability and Attitude toward Mathematics. *Korean Education Inquiry*, 30(1), 25-44.
- Csikszentmihalyi, M. (1975). *Beyond boredom and anxiety*. San Francisco: Jossey-Bass.
- Csikszentmihalyi, M. (1997). *Finding Flow*. New York: Brockman, Inc.
- Ginsburg, H. P. (2006). Mathematical Play and Playful Mathematics: A Guide for Early Education. In D. Singer, R. M. Golinkoff, & K. Hirsh-Passed (Eds.), *Play=Learning: How play motivates and enhances children's cognitive and social-emotional growth* (pp. 145-165). New York: Oxford University Press.
<https://doi.org/10.1093/acprof:oso/9780195304381.003.0008>
- Holloway, D., Green, L., & Livingstone, S. (2013). *Zero to Eight: Young Children and Their Internet Use*. LSE, London: EU Kids Online.
http://eprints.lse.ac.uk/52630/1/Zero_to_eight.pdf.
- Hong, H. (2010). The Future Directions and Challenges in Early Childhood Mathematics Education. *Early Childhood Education Research & Review*, 14(4), 29-51.
- Hunter-Doniger, T. (2021). Early childhood STEAM education: The joy of creativity, autonomy, and play. *Art Education*, 74(4), 22-27.
- Kamii, C. & DeVries, C. (1992). *Physical Knowledge in Preschool Education: Implications of Piaget's Theory*. New York: Teachers College Press.
- Kewalramani, S., Palaiologou, I., Arnott, L., & Dardanou, M. (2020). The integration of the internet of toys in early childhood education: A platform for multi-layered interactions.

- European Early Childhood Education Research Journal*, 28(2), 197-213.
<https://doi.org/10.1080/1350293X.2020.1735738>
- Kim, Y. (2021). Moving cars and airplanes: Affordances of Digital Blocks and free play experiences of preschoolers. *Korean Journal of Children's Media & Education*, 20(3), 103-132. <https://doi.org/10.21183/kjcm.2021.09.20.3.103>
- Kim, Y., Song, H., & Jeong, Y. (2019). Smart Technology and Child Development in the Fourth Industrial Revolution Era. *Korean Journal of Psychology: General*, 38(4), 487-517. <https://doi.org/10.22257/kjp.2019.12.38.4.487>
- Kim, N., Go, J., & Choi, M. (2022). The effects of decision-making ability and social competence on the play flow of young children. *The Journal of Eco Early Childhood Education & Care*, 21(2), 127-149. <https://doi.org/10.30761/ecoece.2022.21.2.127>
- Kim, K. (2011). The Effects of the Robot Based Instruction on Improving Immersion Learning. *The Journal of Korean association of computer education*, 14(2), 1-12. <https://doi.org/10.32431/kace.2011.14.2.001>
- Kim, E., & Lee, J. (2009). The effects of geometry activities based on problem-solving for geometric development of young children. *Korean Journal of Early Childhood Education*, 29(1), 31-55. <https://doi.org/10.18023/kjece.2009.29.1.002>
- Kim, D. (2016). Analyses of the Region and Gender Differences in Creativity, Problem Solving and Flow of Robot: Based Programming Learning in Elementary School Daycare Program Environments [Unpublished doctoral dissertation]. Kon-kuk University.
- Kim, E., & Lee, J. (2007). Establishing a Theoretical Rationale for Mathematical Problem Solving in Early Childhood Education. *Korean Journal of Child Studies*, 28(4), 319-331.
- Kim, S., & Kim, S. (2019). The effect of a robot-based education program on young children's logic-mathematical knowledge and creative problem-solving. *The Korean Journal of Future Early Childhood Education*, 26(1), 209-229. <https://doi.org/10.22155/JFFCE.26.1.209.229>
- Lee, M. (2023). The Effect of Smart Block Activities Using Gamification on Children's Creative Problem Solving and Play Flow [Unpublished master's thesis]. Gangneung-

wonju National University.

- Lee, J. (2020). Effects of the robot-based education activities for children aged 3, 4, and 5 on their creativity and sequential thinking [Unpublished master's thesis]. Chung-ang National University.
- Lee, Y., & Lee, Y. (2021, Mar). The effects of a software education program utilizing coding robots on young children's computational thinking and playfulness. *The Korean Society For Early Childhood Education academic conference material*, 205-207.
- Lee, S. (2022). Exploring the Improvement of 5-Year-Old Children's Creativity Through the <Block Play> Project Activities [Unpublished master's thesis]. Daegu National University of Education.
- Lee, H. (2019). The Effects of Play Planning, Execution and Evaluation Activities on Children's Self-Leadership and Play Flow Experiences [Unpublished master's thesis]. Han-yang University.
- Lee, K. (2019). The Effect of coding robot activities based on collaborative problem solving study on teacher learning support behavior and children's mathematical problem solving ability [Unpublished master's thesis]. Gangneung-wonju National University.
- Lee, B. (2017). An Exploratory research on Smart Toy program based on Storytelling approach. *The Journal of Learner-Centered Curriculum and Instruction*, 17(13), 441-464. <https://doi.org/10.22251/jlcci.2017.17.13.441>
- Lee, K. (2016). The effects of teacher's instructional support interaction and five-year-old children's executive function on children's mathematical problem-solving ability [Unpublished doctoral dissertation]. Kon-kuk University.
- Lee, K., & Lee, J. (2017). The Effects of Young Children's Executive Function on Mathematical Problem-solving Ability. *Journal of Children's Literature and Education*, 18(1), 311-334.
- Lee, T., & Chang, J. (2018). A Study on Digital Play Types of Virtuality through the Play Theory of Roger Caillois. *Journal of Digital Convergence*, 16(9), 383-390. <https://doi.org/10.14400/JDC.2018.16.9.383>
- Lee, H., Han, J., & Jo, M. (2013). Effect Analysis of Learning with a Robot for Improving Creativity in the Regular Curriculum of Elementary School. *The Korean Journal of*

Child Education, 22(2), 19-35.

- Lee, K., & Yoo, G. (2019). The Effect of coding robot activities based on collaborative problem solving study on teacher learning support behavior and children's mathematical problem solving ability, *The Journal of Korea Open Association for Early Childhood Education*, 24(4), 345-371. <https://doi.org/10.20437/KOAECE24-4-15>
- Lee, B., & Kim, Y. (2018). The effects of S-Block program on children's logical-mathematical and spatial ability. *Korean Journal of Children's Media & Education*, 17(2), 1-19. <https://10.21183/kjcm.2018.06.17.2.1>
- Lim, B. (2020). An Exploration of the Relationship between 'Play' and 'Contents' in 2019 National Nuri-Curriculum. *Childhood Education Review*, 10(2), 5-32. <https://doi.org/10.26834/kscice.2020.10.2.5>
- Linderman, K. W., & Anderson, E. M. (2015). Using blocks to develop 21 century skills. *Young Children*, 70(1), 36-43.
- Undheim, M. (2021). Children and teachers engaging together with digital technology in early childhood education and care institutions: a literature review. *European Early Childhood Education Research Journal*, 30(3), 472-489. <https://doi.org/10.1080/1350293X.2021.1971730>
- Mattoon, C., Bates, A., Shifflet, R., Latham, N., & Ennis, S. (2015). Examining computational skills in prekindergarteners: The effects of traditional and digital manipulatives in a prekindergarten classroom. *Early Childhood Research & Practice*, 17(1), 1-9.
- Ministry of Education of South Korea (2019). *Guide on Nuri Curriculum* 2019. Retrieved from <https://www.moe.go.kr/boardCnts/viewRenew.do?boardID=312&boardSeq=79419&lev=0>
- Ministry of Education of South Korea (2021). *Outline of 2022 Revised Curriculum*. Retrieved from <https://www.moe.go.kr/boardCnts/viewRenew.do?boardID=294&boardSeq=89671&lev=0&searchType=null&statusYN=W&page=1&s=moe&m=020402&opType=N>
- Na, E. (2013). Development and Validation of a Play Flow Scale for Young Children.

Journal of Children's Literature and Education, 14(4), 589-608.

- National Council of Teachers of Mathematics (NCTM) (2000). *Principles and standards for school mathematics*. Reston, VA: The National Council of Teachers of Mathematics, Inc.
- Neumann, M. M., & Neumann, D. L. (2014). Touch Screen Tablets and Emergent Literacy. *Early Childhood Education Journal*, 42, 231–239. <https://doi.org/10.1007/s10643-013-0608-3>
- New Zealand Ministry of Education (2010). *Mathematics problem solving level 1*. <http://nzmaths.co.nz/level-1-problems>
- Park, J. (2019). Effects of Mathematical Activities using Educational Robots “Bee-Bot” on Young Children’s Math Problem solving and Creativity – Focused on Math Activities - [Unpublished master’s thesis]. Chung-ang University.
- Robin Samuelsson, Sara Price & Carey Jewitt (2024) How young children’s play is shaped through common iPad applications: a study of 2 and 4–5year-olds, *Learning, Media and Technology*, 49 (2), 151-169, <https://doi.org/10.1080/17439884.2022.2141252>
- Song, J., & Oh, C. (2021, Nov). Exploration of Research Trends in Digital Play for Young Children [Oral presentation]. *The Korean Association for Children's Media & Education's Autumn Season Regular Symposium*, Chungbuk, South Korea.
- Strawhacker A., & Bers, M. U. (2015). “I want my robot to look for food”: Comparing kindergartner’s programming comprehension using tangible, graphic, and hybrid user interfaces. *International Journal of Technology & Design Education*, 25, 293-319.
- Vessonen, T., Hellstrand, H., Aunio, P., & Laine, A. (2024). Individual differences in mathematical problem-solving skills among 3-to5-year-old preschoolers. *International Journal of Early Childhood*, 56(2), 339-357.
- Wang, W. N., Kuo, V., King, C. T., & Chang, C. P. (2010). Internet of toys: an e-Pet overview and proposed innovative social toy service platform. *International Computer Symposium (ICS)*. Tainan, 16-18 December. Retrieved from: <http://ieeexplore.ieee.org/document/5685507/?reload=true>
- World Economic Forum (WEF) (2016). The future of jobs: Employment, skills and workforce strategy for the fourth industrial revolution. Global Challenge Insight Report,

3-32.

Wellhousene, K., & Kieff, J. (2004). *Constructivist approach to block play in early childhood*. Cengage Learning, Inc.

Wolfgang, C. H., Stannard, L. L., & Jones, I. (2001). Block play performance among preschoolers as a predictor of later school achievement in mathematics. *Journal of research in childhood education*, 15(2), 173-180. <https://doi.org/10.1080/02568540109594958>

Yang, S., & Kim, J. (2019). The Effects of an Everyday Life Problem-Solving Centered Preschool Mathematical Program on Children's Mathematical Problem-Solving and Attitude. *Korean Journal of Child Studies*, 40(4), 1-13. <https://doi.org/10.5723/kjcs.2019.40.4.1>

Yoo, G., Kim, M., & Lee, J. (2011). Construction and Effects of Kindergarten Free-Choice Activities Program Using an Intelligent Robot. *The Journal of Korea Open Association for Early Childhood Education*, 16(4), 493-520.

Yoo, G., & Shim, N. (2022). Effects of unplugged block coding play on children's creative inquiry and creative expression abilities. *The Journal of Korea Open Association for Early Childhood Education*, 27(5), 109-138. <https://doi.org/10.20437/KOAECE27-5-05>