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Preschool children's mathematical performance in Japan

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This study measured Japanese preschool children's mathematical performance and examined its features through and intervention using mathematical activities. Japanese preschool children do not formally learn mathematics; thus, we designed mathematical activities through guided play for 397 children aged 5–6. We conducted individual structured clinical interviews on mathematical performance, which is the basis of learning in the first grade of elementary school, with the preschool children, both before and after the intervention, and quantitatively analysed the results. The children's post-intervention interview results showed a significant increase in overall scores compared to the pre-intervention interview results. The novel contribution of this study is to show the characteristics of mathematical performance in early childhood of Japanese children with internationally high outcomes in post-school mathematics based on an extensive survey.

Keywords: Preschool children, mathematical performance, mathematical activities, guided play.

Research on the measurement of early childhood mathematical performance

As Björklund et al. (2020) state in their summary of recent research trends in early childhood mathematics education, there is a need to examine what mathematics means to young children, how it can lay the foundation for their mathematical development, and how to determine adequate teaching methods for this purpose. To this end, it is necessary to identify the mathematics that young children need to learn in their early years to gain a foundation for the mathematics learned in elementary school and to consider efforts to promote their development of mathematical skills and knowledge.

Despite the recently growing number of studies in Japan on early childhood mathematics education, there are fewer than at other stages of education. Because of the strong awareness of the importance of mental and emotional development in early childhood, early childhood education is treated comprehensively in Japan. From a holistic perspective, it is essential to clarify how the content of each area of mathematics relates to other areas to promote development (Matsuo, 2016). Moreover, mathematics education is not formally implemented in early childhood with a curriculum in Japan, and the actual condition of mathematics performance in early childhood is still being determined. However, young children can effectively learn mathematics through appropriate theoretical teaching (Inagaki, 1996). Therefore, this study aims to measure the mathematical performance of 5–6-year-old children in Japan. We address the following three research questions: What is the mathematical performance of 5–6-year-old children in Japan? To what extent does the intervention improve their mathematical performance? What are the relationships of performance in different domains?

Previous research has measured children's mathematical performance (e.g., VanDerHeyden et al., 2006). The basis for many assessment studies is Clements et al. (2008), who analysed 3–7-year-old

children's development of specific mathematical competencies. Alkhadim et al. (2021) developed a Research-based Early Math Assessment to validate development among rural kindergarteners.

In addition, studies of performance assessment in various content areas have been published. In the U.S., Purpura et al. (2015) provided numerical indicators to capture children's development. A similar assessment was conducted based on this in France (Thomas et al., 2021). Sarama et al. (2011) proposed and evaluated a learning trajectory for length and area in the early years. Moreover, although more research is needed on geometry-specific assessments, many studies have explored the strong relationship between spatial reasoning, mathematical ability, and performance (e.g., Resnick et al., 2020; Woolcott et al., 2020). However, research is limited in the number of domains examined, and multi-domain performance is not addressed at all.

This study measures early childhood mathematical multi-domain performance to encourage children to learn early mathematics, focusing on children of families living in Japan, where socioeconomic status is nearly identical. Significantly, many parents work in regular employment.

Current situation of preschools and preschool curriculum in Japan

In Japan, there are three main kinds of preschools: kindergarten, nursery school, and mixed school, called *kodomoen*. Usually, children attend preschool until the age of 6 years. This study analyses kindergartens for two reasons: first, because, compared to other preschools, kindergarten focuses on children's informal learning, and second, because many 5- and 6-year-old children attend kindergarten in Japan.

According to "The Course of Study for Kindergarten," the national curriculum proposed by Ministry of Education, Culture, Sports, Science and Technology (MEXT), the basic idea of kindergarten education is as follows: "Education during childhood is crucial in cultivating a foundation for lifelong character building" (2018, p. 1). Moreover, kindergarten education content integrates each child's development in health, human relationships, environment, language, and expression. Each area should be interrelated to afford children a variety of experiences in kindergarten education rather than from separate areas, and the curriculum content should be delivered comprehensively through specific activities developed with regard for the children's learning environment. This method differs from elementary school education, in which the curriculum comprises separate subjects, such as Japanese, mathematics, social studies, and living environment studies (MEXT, 2017).

The aim of the area of environment is particularly related to mathematics (MEXT, 2018). Integrating the area of the environment into mathematical activities in kindergarten aims "to enrich children's understanding of the nature of things, the concepts of quantities, written words, etc. through observing, thinking about and dealing with surrounding things and experiences" (MEXT, 2018, p. 6). Kindergarten teachers do not necessarily have to deal with content such as numbers, quantities, and shapes, which are the foundation of learning and life after elementary school. Therefore, the teachers do not understand how to develop students' capacity, and there needs to be a detailed explanation of developing children's mathematical learning foundation in elementary school. Given the above, we must address mathematical content for the early years by focusing on the importance of children's needs and their interest in learning about numbers, quantities, and shapes.

To investigate preschool children's mathematical performance, this study uses the primary contents of learning mathematics in the first grade of elementary school. Specifically, we select the following: acquiring knowledge and skills to count and compare numbers of objects correctly, comparing lengths directly by concrete operations or by using other objects, recognizing the shape of objects, and thinking about the composition of shapes. These skills and knowledge are chosen because we aim to develop mathematics programs in early childhood to facilitate children's mathematical performance in these domains. In Japan, there is a rapid increase in dislike for or anxiety regarding mathematics at the schooling level and a corresponding decline in interest in the subject. Because of the rapid progression to learning knowledge, skills are more important than interest in mathematical content. Therefore, experiencing activities related to the rudiments of mathematical content through guided play in preschool (Nakawa, 2020) as a foundation for learning in elementary school is expected to allow students to continue learning while maintaining their interest.

Methods

Research participants

Our pilot study involved 379 children from 23 private preschools in the Tokyo metropolitan area. The pre-intervention interview was conducted in May 2021 and the post-intervention interview in March 2022. This study focused on 379 (pre-intervention interview) and 169 (post-intervention interview) 5–6-year-old children in the highest levels of classes. The children came from middle- and upper-middle-class families in Japan. Both boys and girls participated in the study.

Data collection and analysis

The data presented in this paper are the results of pre-and post-intervention interviews. The intervention study was conducted in each preschool to ascertain the current status of the older children. A survey form was prepared for the interviews, and the authors planned structured clinical interviews (Goldin, 1998). The children answered each question, and the interviews were conducted with a preschool teacher to alleviate the children's anxiety. The children were then called to a separate room. During the implementation, each child came to the room in a random order, and the teacher in charge sat in front of the child. The teachers rehearsed the interviews to be consistent in their mathematical words and expressions. Permission to conduct this survey was obtained from the children's parents in advance. Children who did not want to be interviewed were not forced to participate in the survey, and those who did not want to answer the questions were allowed not to do so. The pre-intervention interviews took 15–25 minutes, and the post-intervention 10–15 minutes.

Nine questions were developed for the pre-intervention interviews. One (a calculation to find the remainder) was added to the post-intervention interviews, corresponding to the author's planned activities and previous research (Matsuo, 2016). The questions are shown in Table 1. During the interview, the children could use a ruler, transparent paper, and clips to answer questions Q7.1–7.2. We used knowledge and skills to count (Q1, 2.1–2.6, 3, 4, 8, 10) and compare numbers of objects correctly (Q5, 6.1–6.2), compare lengths directly by concrete operations (Q7.1–7.2), or recognize the shape of things by using other entities and think about the composition of shapes (Q9). The results were qualitatively analysed. The interview content was limited to content needed as a basis for elementary school mathematical learning in Japan, for example, without involving computing or

thinking about how to calculate. Such mathematical performance in early childhood would motivate and provide basic skills to enable learning in elementary school. The answers were tabulated using Microsoft Excel with 1 for correct and 0 for incorrect. Several months of math-related guided play activities, for example, *Sugoroku* with points numbered from 1 to 20, were conducted between the pre-and post-intervention interviews. The results of the pre-intervention interviews were analysed quantitatively by Kosaka and Nakawa (2022). The results of the post-intervention interview were analysed alongside other data by Nakawa and Matsuo (2022).

Table 1: Questions in the pre/post-intervention interview

Items	Question
Q1	Count 20 marbles.
Q2.1–2.6	Read the number of 1s, 3s, 5s, 2s, 4s, and 6s on a die.
Q3	Take the number of marbles equal to the six on the dice.
Q4	Find the sum of two dice (5, 3).
Q5	Find the difference between two dice (5, 3).
Q6.1	Show three blocks from the top of a tower of blocks.
Q6.2	Indicate the third block from the bottom of the tower with stacked blocks.
Q7.1	Find the longest of four pencils with slightly different lengths.
Q7.2	Look at the picture of four pencils of slightly different lengths and answer in order of length.
Q8	Given a pattern of shapes, answer the following.
Q9	When fitting the suitable shapes to the left triangle, which shape or shapes do you choose?

Description of mathematical activities in the intervention

We developed five play-based mathematical activities based on the framework (Matsuo, 2016). Among these activities, we carefully chose those better tailored to relate to numbers; measurement; shapes; and comprehensive content on numbers and computation, measurement, and shapes. To evaluate the improvement in children’s mathematical performance after these activities, we developed pre- and post-intervention interview questions. After completing all activities, a post-intervention interview was conducted with each child in March 2022.

The following five activities were implemented in this study: 1) How many and what number? (cardinal and ordinal numbers), 2) *Sugoroku* (similar to Western backgammon) with points numbered from 1 to 20 (addition and subtraction), 3) length comparison of pencils (measuring of length), 4) colour board fitting (embedding), and 5) planting bell pepper seedlings and stamping with blocks (seasonal objects; numbers, comparison, shapes). Each activity was conducted twice. Children were asked to answer questions in an interview of about 20 minutes before and after participating in the intervention. Teachers understood the nature of the mathematics involved in the activity, modified the play to suit the child’s situation, and conducted the activity. We reviewed them before and after the activity to listen to the teacher’s ideas. After the activity, the teachers reflected on the condition of the children, their childcare, and their self-evaluation. Teachers looked back to better implement

the activities that followed and discussed their ideas with the authors. At one school, all children participated; at another school, only those who wished to participate did so. For example, an outline of one of the activities, *Sugoroku*, with points numbered from 1 to 20, is shown as follows. The purpose of the activity is to play the game, the children must count up and down, perform simple addition and subtraction, and read the dice. In this activity, a teacher divides the students into Rabbit and Turtle teams and has them play a backgammon game in which one team goes from 1 to 20 and the other from 20 to 1.

Results and discussion

In this study, we calculated the correct answer rate based on whether the question items shown in Table 1 were correct or incorrect. A tetrachoric correlation coefficient was confirmed. Table 2 shows the test for the difference in population proportions. A two-proportion Z-test was used to compare two observed proportions. Here, item analysis was mainly conducted to clarify the difference between the pre- and post-intervention interview results. The pre-intervention interview results showed the children's actual performance in an intervention-free setting. On the other hand, the post-intervention interview results indicated that the children's mathematics performance improved significantly.

Table 2 shows each question's average correct answer rate in the pre- and post-intervention interviews. The correct answer rate increased for all the questions. Approximately half of the questions had more than 90% correct answers post-intervention, and in 14 of the 16 questions, the average percentage of correct answers was above 60%. The correct answer rate of the pencil length comparison question (Q7.2), in which the difference in length was subtle, and the scores on the shape fitting question (Q9) were below 60%. Meanwhile, the correct answer rate for counting 20 marbles (Q1), finding the dice difference (Q5), and fitting figures (Q9) showed remarkable growth. In particular, the intervention influenced the sum of the dice rolls and the difference. Children only sometimes experience these activities, even if they may read the dice roll daily.

Table 2: The results of the interview questions

Item	Mean (Pre)	Mean (Post)	Item	Mean (Pre)	Mean (Post)
Q1*	0.515	0.757	Q4*	0.686	0.852
Q2.1*	0.950	0.994	Q5*	0.277	0.639
Q2.2*	0.958	0.994	Q6.1	0.578	0.604
Q2.3*	0.889	0.964	Q6.2*	0.599	0.775
Q2.4	0.963	0.988	Q7.1*	0.723	0.905
Q2.5*	0.918	0.988	Q7.2*	0.433	0.598
Q2.6*	0.913	0.988	Q8*	0.681	0.822
Q3*	0.897	0.959	Q9*	0.127	0.337

* Statistically significant at the 5% level

We calculated the tetrachoric correlation coefficients for the post-intervention interview scores. Q2 and Q3 were excluded from analysis because of high prior correct response rates. In the pre-intervention interview, there were no coefficients above 0.4 indicating a robust correlation, but correlations were found between finding the dice difference (Q5) and showing the third from the top of the stacked blocks (Q6.2), etc.

Table 3: Tetrachoric correlation coefficient for each question in the post-intervention interview

Post-intervention interview	Q1	Q4	Q5	Q6.1	Q6.2	Q7.1	Q7.2	Q8	Q9
Q1	1.000								
Q4	0.075	1.000							
Q5	0.253*	0.497*	1.000						
Q6.1	0.227	0.324*	0.155	1.000					
Q6.2	0.225	0.515*	0.619*	0.098	1.000				
Q7.1	0.013	0.423*	0.285	0.147	0.250	1.000			
Q7.2	0.025	0.253	0.335*	0.041	0.329*	0.225	1.000		
Q8	0.187	0.377*	0.457*	0.344*	0.410*	0.252	0.280*	1.000	
Q9	0.204	0.178	0.463*	0.152	0.391*	-0.148	0.166	0.071	1.000

* Statistically significant at the 5% level

In the post-intervention interview, seven relationships exceeded 0.4 (Table 3). Finding the dice difference (Q5) was related to indicating the third block from the top of the stacked blocks (Q6.2), finding the pattern that follows (Q8), and constructing a single shape from multiple shapes (Q9), because finding the dice difference involves comparing the number of dice and the lengths and sizes of the shapes. It was assumed that shape and size judgments were used to fit the figures. In particular, there was a strong relationship between determining the dice difference (Q5) and indicating the third block from the top of the stacked blocks (Q6.2). In both types of behaviour, standards are determined and compared based on them. In particular, the results of the post-intervention interview indicate that performance in finding the difference between the dice rolls improved (63%), but more research is needed. Earlier research has shown that, prior to learning subtraction in first grade, this performance was generally adequate for only 40% or less of children (Matsuo, 2022). In addition, we do not seek differences in dice rolls in our daily lives in Japan. Therefore, our proposed program can improve children's performance through the task of finding the dice difference.

Conclusion

This study measured Japanese preschool children's mathematical performance through the guided play activities of a preschool mathematics intervention based on the mathematical learning contents in the first grade of Japanese elementary school. Many kinds of mathematical activities are included

in play, such as competitions, games, and puzzles; the program implemented in this study mainly allowed the mathematical content to become apparent. For most questions, the percentage of correct answers increased significantly from the pre- to the post-intervention interview. The children were interested in mathematics through guided play and gained the need to acquire a grounding in mathematics. Because the program allows students to learn while playing, it does not go as far as mastery of knowledge and skills, but it helps students acquire the basics and increases their interest in learning. As a result, the children could find the dice difference, determine the order, compare lengths, and insert shapes. Although this study predicted broad relationship trends, further detailed investigation of the relationships between the types of performance seen in the answers to these questions is needed.

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