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DEVELOPMENT OF DESIGN THINKING AS A TOOL TO IMPROVE SPATIAL REASONING IN PRESCHOOLERS

DESARROLLO DEL DISEÑO DEL PENSAMIENTO COMO HERRAMIENTA PARA MEJORAR EL RAZONAMIENTO ESPACIAL EN PREESCOLARES

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ABSTRACT

The study addresses the indirect development of young children's spatial reasoning across a range of ages from 2–3 years through the development of design thinking. This mode of thinking has been shown to develop effectively through well-organized special design activities. The design activity has been detailed and instantiated as appropriate to illustrate the organization practices for design activities in preschool environments. The method for stimulating the development of a preschooler's spatial reasoning is an "entry point" to initiate the upcoming development of his/her mathematical thinking. The benefits of the method when used with preschool children have been justified particularly from the psychological perspective. The paper substantiates the effectiveness of the proposed approach to encourage the development of preschoolers' spatial reasoning. The author has disclosed the essential aspects of the potential development of a child's mathematical thinking.

Keywords:

Design thinking, design-oriented task-based approach, skills in preschoolers.

RESUMEN

El estudio aborda el desarrollo indirecto del razonamiento espacial de los niños pequeños en un rango de edades de 2 a 3 años a través del desarrollo del pensamiento de diseño. Se ha demostrado que este modo de pensar se desarrolla eficazmente mediante actividades de diseño especiales bien organizadas. La actividad de diseño se ha detallado y ejemplificado según corresponda para ilustrar las prácticas de organización para las actividades de diseño en entornos preescolares. El método para estimular el desarrollo del razonamiento espacial de un niño en edad preescolar es un "punto de entrada" para iniciar el próximo desarrollo de su pensamiento matemático. Los beneficios del método cuando se utiliza con niños en edad preescolar se han justificado especialmente desde la perspectiva psicológica. El artículo fundamenta la eficacia del enfoque propuesto para fomentar el desarrollo del razonamiento espacial de los niños en edad preescolar. El autor ha revelado los aspectos esenciales del desarrollo potencial del pensamiento matemático de un niño.

Palabras clave:

Pensamiento de diseño, enfoque basado en tareas orientado al diseño, habilidades en niños en edad preescolar.

INTRODUCTION

The principles of early childhood education fail to provide comprehensive evidence as to whether the intentional development of mathematical thinking at preschool age is viable. Everyone knows that Mozart's father taught him how to play the piano at the age of three. The best age to start young children ice-skating or skiing is around 3 or 4 years old before they can build their confidence and proceed with the actual practice by five or six. In a trilingual family, a child grows up learning three languages, starts speaking all three at around 2–3 years of age, and never gets confused with keeping them apart. Typically, three-year-olds are ready to start coloring and drawing... However, when it comes to mathematics... The basic concepts for developing a schoolchild who appears particularly talented in mathematics are evident: providing increasingly challenging problem-solving tasks through systematic practice will bring up a mathematical mind. However, one deals with the result, i.e. a gift of unknown origin, in this scenario. An excellent runner will have the highest chance to grow up as a champion. All the others cannot choose but keeping pace or jogging at best.

The trouble is that "real" mathematics has to do with purely and highly abstract things. This might be a reason why most people who have not been prepared to operate its vague concepts keep feeling incompetent against a ten-year school course of mathematics, e.g. in Russia. It is like expecting slalom tricks from a person who has just started ice-skiing. However, six- or seven-year-olds show amazing results after several years of skiing practice. As with Mozart who gave concerts at the age of 6.

However, it is not argued that a three-year-old child who is put to the piano will most likely fail to become another Mozart. The point is that a child should be prepared for any kind of activity. Otherwise, by the time this activity needs to be performed, the child will not have a clue or be ready to come through. Ultimately, it goes without saying that a level of success is a significant motivator for a child (and for an adult too) to engage in the activity. There is no need for external reinforcement (through high grades, money, or praise). This is absolutely for the love of the game and for sheer pleasure. Unfortunately, most people take "pleasure" and "mathematics" as mutually exclusive things. This study aimed to overcome this centuries-long disadvantage. The paper demonstrates the results of nearly 20-year research efforts.

It should be noted that the development of mathematical thinking is one of the most attractive issues for educational psychologists. However, the area lacks effective and systematically operated systems (technologies). Although the topic has been widely studied within educational psychology for successful teaching of adolescents (Krutetsky, 1968; Atakhanov, 1993; Uruntaeva, 2015; Mujica & Márquez, 2022), developing mathematical thinking during the primary school or preschool years remains largely unaddressed. This paper establishes a psychological rationale for the organization of systematically operated systems (technologies) useful in the development of mathematical thinking through the development of design thinking in the preschool classroom.

MATERIALS AND METHODS

Let us finalize the definitions. The approach to preschool mathematical development defines a constructional design as object modeling of various objects, concepts, and relations. A model designed and constructed in this way is called a layout object, or a construct. Since visual active thinking comes out on top for preschoolers of 3–5 years, the educational value of constructional design consists in using visual active methods to teach primary modeling techniques. Thus, the paper demonstrates a broader context of constructional design than it has been traditionally recognized by constructional design methods for preschool children.

Teaching constructional design concerns with training universal design skills to develop design thinking as appropriate. Design thinking is defined as the ability to see (perceive) an object taken as a whole and visualize the communication of its components. This means an ability to imagine an object as if it were transparent, however, making all efforts to trace through the distinct outline of its components, i.e. to "see" (visualize) invisible lines and details, mentally rotate the object, "look at" it from different perspectives, mentally disassemble, assemble, and transform it.

The definition of design thinking demonstrates a close relationship to spatial reasoning recognized as the ability to create a mental model and mentally manipulate it by the preset parameters, i.e. to move, dissect, and transform. Based on this relationship, it may be reasonably assumed that the preschool development of design thinking creates a method and tool great for stimulating and developing spatial reasoning, which makes an integral part of mathematical thinking. Thus, the approach, which has been tested in long-term experiments, implies the indirect active influence on the development of mathematical thinking as early as the preschool years.

Since preschoolers have not developed full-scale spatial patterns of various mathematical concepts yet, educational work should be based on much simpler operations.

It was assumed that spatial reasoning could be developed through the activities focused on the child's design thinking. Through child-friendly design activities using various object models, this approach to the development of a preschooler's spatial reasoning skills helps to generate basic patterns of concepts (memory images) and ways of action (operational images). Internalization that involves both single operations and universal ways of action will contribute to assembling the images that stimulate the development of a child's spatial reasoning (and thereby encourage the further development of mathematical thinking).

Special design-oriented tasks are an effective tool to develop design thinking, while task processing practice, i.e. creating new images, comes up to a child's usual design skills. Actually, the terms "design-oriented task" and "design skills" need to be defined.

A design-oriented task is a learning activity in which children practice manipulating basic spatial (two-dimensional) relations, metric and volumetric dependencies. The relations and dependencies are retained and reflected by a visual model easy to perceive, understand, and use by children aged 3 to 5. Carrying out a number of simple manipulations (transformations), a child will be able to identify and investigate the relations and dependencies of the model elements. To solve a design-oriented task, a child deals with unassisted search, identification, and manipulations. The output result of a design-oriented task focuses on recognizing the properties of modeled objects.

Thus, design skills include as follows:

- an ability to recognize and identify an object (to focus on the basics, i.e., an ability to abstract);

- an ability to assemble an object using made-up elements (synthesize);

- an ability to disassemble and identify its components (analyze);

- an ability to modify an object by the preset parameters, thus obtaining a new object with the assigned properties (transform).

Mastering these universal design skills, children expand their educational opportunities through constructional design activities and manipulating any materials. In addition, there is also a conventional vision of constructional design behind a preschooler's design skills (construction kits, natural materials, etc.).

In this setting, constructional design implicates a particular specific kind of modeling as a general process of manipulating mathematical concepts and relations. Thus, exploring and modeling mathematical concepts and relations are supposed to encourage the development of a child's design skills. Since visual active and visual creative patterns are best matched to preschoolers' abilities and needs, using an object model (a layout object or construct) to gain insights into a concept or relation is an adequate approach to give an idea of an abstract object.

This approach to the child's mathematical development is based on inherent aspects of mathematics as a study of quantitative behavior and spatial properties of real objects and processes. Moreover, it also deals with common ways of manipulating real-world mathematical models and modeling techniques.

Methodologically, the constructional design activity as part of preschool mathematical development should be harmonized with the conventions for conceptual modeling and cognitive development milestones. Basic geometric shapes are the most helpful to practice. Using geometric shapes provides a basis for the two-step principle of constructional design activity in preschool training.

The first step is focused on object-oriented manipulation of geometric shape models (constructional design as such). A child performs a variety of tasks with different (starting with the simplest level to become more challenging) sets of geometric shapes. This includes creating patterns, pictures, scenes, ornaments, and other constructs following a sample, task, or representation.

In the second step, the child performs the same tasks graphically, i.e. using the technique called "constructive drawing". The second-step technique is essentially based on using geometric shape stencils (identical to shapes applied for object modeling) to draw the appropriate shapes. The stencil has multiple roles: replicating a shape that absolutely fits the assigned one (a teacher offers samples using the same shapes). In addition, tracing the stencil many times over encourages the child to follow the shape and refine his/her kinesthetic sense. Stenciled coloring of the shape (filling in the tracing with color) helps develop fine motor skills and consolidate the images of plane shapes. Since constructs (drawings and designs) consist of multiple combinations of shapes in any and all positions, the child learns to perceive and recognize the shapes in any combinations, perspectives, overlays, and sections over time. Thus, systematic practice ultimately results in an absolutely durable image of shapes and an ability to manipulate it in any manner, create a wide variety of designs (constructs), disassemble, modify, and otherwise transform the shapes.

The play-based design-oriented tasks aimed at achieving the goals summarized above are attractive for preschoolers. Even school-age children find designs amusing and generally interpret this learning tool as a game. Having a flexible and gentle nature, this approach to preschool education has been recognized by many psychologists as the best possible. The focus on the "second method of learning" is a hallmark of the suggested approach. The second method of learning was defined by Rubinstein (198), as follows: ***"There are ... two types of learning or rather two methods of learning and two types of activity, which results in mastering knowledge and skills. One of them specifically makes knowledge and skills a direct point. The other captures knowledge and skills by realizing other goals. In this latter case, learning is a component and result of another incorporating activity, rather than an independent activity".*** (p. 600)

When it comes to the approach of interest, the "other activity" is the child's constructional design dealing with a wide variety of models created for the concepts and relations to be explored. An eye-catching result (a funny drawing, cut and paste craft, construct) is an effective method and tool to motivate a child: he/she wants to do something on his/her own, work it out on his/her hands, and explore the constructed design. Children normally care deeply about their work-they take great pride and show the designs to peers and parents. They are happy to keep looking through their notebooks and albums, take stencils home, and proudly give the teacher the designs that have been made on their own. Thus, they actively develop what is known as "cognitive interests", "cognitive activity", and "motivation of cognitive activity" in learning theory.

An indirect nature of the approach to develop such components of cognition does not detract from its effects, nor contradicts the general learning theory. Whereas younger children are usually not able to adequately understand their motivation to learn, it makes no sense to expect preschoolers to become aware of the content and learning goals postulated in the scaffolding theory focused on school-age children (Zankov, Davydov). In the real-world setting, even elementary school students can hardly ever stay motivated until they start secondary or high school, or even later.

The learning process may be based on the child's internal motivation to learn if he/she understands the significance and goals of the activity, which are then interiorized and transformed into a drive for the activity. Children get willingly engaged in learning (which is considered a tool for establishing goals), and learning simplicity becomes the key to the successful expansion of work. Actual learning skills and subject matter arise as an effect and result of the challenging activity; it can be suggested that a reflexive learner works out through a well-organized process of peripheral perception representing a right hemisphere dominance. At this stage, the verbal communication between the subjects (a teacher and child, a child and other children, and even a child and learning material, since the process of designing or drawing may involve the verbal communication between a child and his/her project, i.e., the child talks to it or accompanies the process with a verbal description) mainly retains the outcomes of perception and comprehension activities.

The rapid and extensive learning of both the activities and their substance, or a substance itself promotes intelligence and overall mental development. Some children might show their natural talents; while others greatly advance in mental performance or significantly improve any developmental deficits and delays.

To characterize full-scale constructional modeling activity, a number of operational constituents may be identified and summarized. Characterization of the approach and nature of modeling activities can pave the way for its practical implementation in the learning activity. The following types of modeling operations can be distinguished as constituents of the modeling activity (regardless of the basic material):

A. visual assessment of objects;
B. task-based selection of a model type;
C. transformation of verbal or visual information into a selected model (schematic, graphic, object, mental, symbolic);
D. task-based transformation of the model;
E. analysis of the obtained results by comparing the initial and finalized objects;
F. transfer of the obtained results to an extended variety of objects of this type.

Even for school-age children who carry out a particular task, all the listed operations may not always be followed. However, the full-scale modeling activity cannot be developed immediately, so the various steps may involve at least 2 or 3 modeling operations of one or more related tasks. In this case, the child's modeling activity becomes a process with each following step driven by the results of the previous one. This methodological approach to the development of the child's modeling activity will ensure its continuous incremental progress to the full value.

Practice has shown that tasks for preschoolers may be compiled using nearly all types of modeling operations. Below are the examples of related tasks (fragments) for children aged 4–5.

Fragment 1.

Task 1. Figure 1

Task goal: to improve the accuracy of perception, visual estimation, and the ability to mentally move objects.

Procedure: lay out a geometric shape with one part missing on a flannel board (Figure 1); give a child several individual parts.

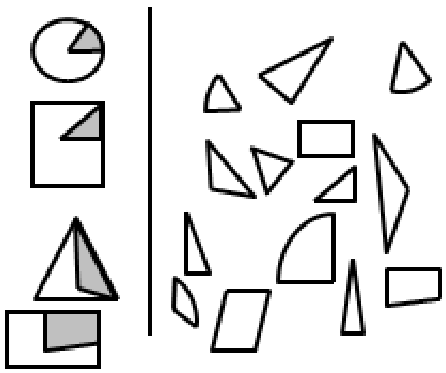

Figure 1. Task 1.

Task: find a missing part of each shape on the right and position it correctly.

Children freely carry out the task on the flannel board. The child who makes a mistake gives place to the next child.

Note: The flannel board is a 40x60cm board covered with flannel fabric. Each object is backed with flocking which helps an object to cling to the flannel board. Thus, the objects can be easily and securely attached to the flannel board. Those who advocate computer-based learning will obviously consider it old school; however, a child may use his/her own hands to interact with this tool and feel the "material" nature.

Task 2.

Task goal: creating a scene using a variety of geometric shapes.

Materials: a sample of cut-and-paste geometric shapes. Being slightly larger than the stencil, the figures however fit the stencil shape (Figure 2).

The teacher tells the children a fairy tale story: "Once on Christmas Day, the children made a snowman, put him in the yard, and said: 'Tell Father Christmas that we need a tree for the holiday!' On Christmas Eve, the most magic night of the year: the Snowman came to life and went to see Father Christmas. Many adventures happened to him (a teacher can briefly tell the children a suitable fairy tale). In the morning, the children woke up, went out into the yard, and saw a beautiful green Christmas tree standing next to the Snowman."

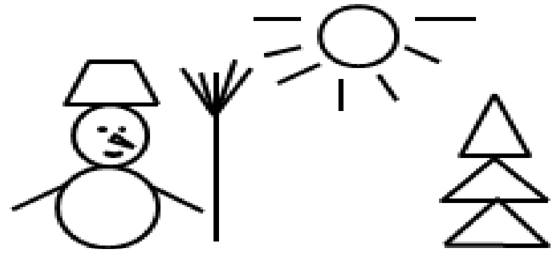

Figure 2. Task 2a.

The teacher and children look at the cut-and-paste craft to identify the parts they will need to replicate it. The children create a craft model on the flannel board using the prepared figures. There should be as many figures fitting the stencil as needed to fill it out. Children select proper figures from the variety and construct the scene on the flannel board.

Note: a copybook-sized plastic stencil seems to be the easiest to use. The stencil should not be transparent so that the child will have to keep the image in mind. Figure 3 shows sample stencils for 3-5-year-old children and 5-6-year-old children.

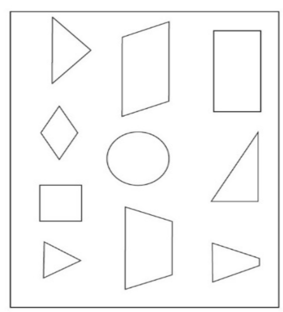	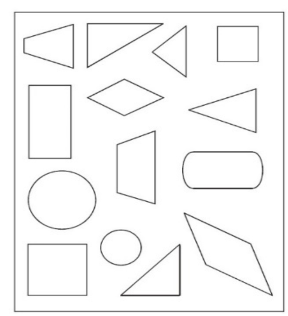
A stencil for 3-5-year-old children	A stencil for 5-6-year-old children

Figure 3. Task 2b.

Task 3.

Task goal: to create the construct parts using a stencil without the teacher's assistance.

Procedure: Children should make a cut-and-paste craft similar to that shown in Figure 2 on their own. Children cut the parts out of colored paper using the stencil as follows: placing the stencil on a sheet of colored paper, tracing the part, and cutting it out. This kind of activity is partially exploratory by nature, because the children are encouraged to find the necessary part on the stencil all by themselves. For a large circle that is the Snowman's body, the teacher uses one more template: a triangle with a circle inside (Figure 4).

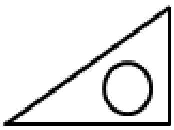

Figure 4. Task 3.

The children cut the craft parts around the outer edge and paste them using a glue stick. Since the snowman is to be made out of white paper, it is useful to attach it to a colored background. Children draw the broom, arms, nose, and eyes with a felt-tip pen. After the work is completed, the teacher invites the children to compare their crafts with the sample and assess the quality.

Analyzing a fragment:

Task 1 is preliminary by nature: the children get ready for the activity of choosing and fitting the necessary shapes to be performed next.

Task 2 launches the visual analysis of the material and transformation of the obtained visual information into a preset model (with a type assigned by the teacher).

Task 3 involves the task-based model transformation, i.e. a child replicates a large-sized model in a cut-and-paste craft using smaller shapes that he/she created on his/her own. This may be considered as a transfer of mastered design skills to another set of objects.

Task 3 aims to analyze the results through the comparison between the initial and finalized objects.

Thus, this task series may be useful to carry out 5 types of modeling operations. The children were excited to manipulate the geometric shapes with their own hands; they compared, generalized, analyzed, and assessed the results of their activity, i.e. they performed full-scale ***learning operations***. A fairy-tale story was used as a tool for children's motivation.

RESULTS AND DISCUSSION

In the experiment focused on testing the approach to the development of preschoolers' spatial reasoning through mastering design thinking, 4-5-year-old children were randomized 1:1 to two groups. No specific criteria were applied. If the teachers agreed to participate, the children were simply assigned to either of two groups. Figure 5 and Figure 6 show the results of the first summative assessment essentially aimed at assessing the initial development of preschoolers' spatial reasoning in the control and experimental groups.

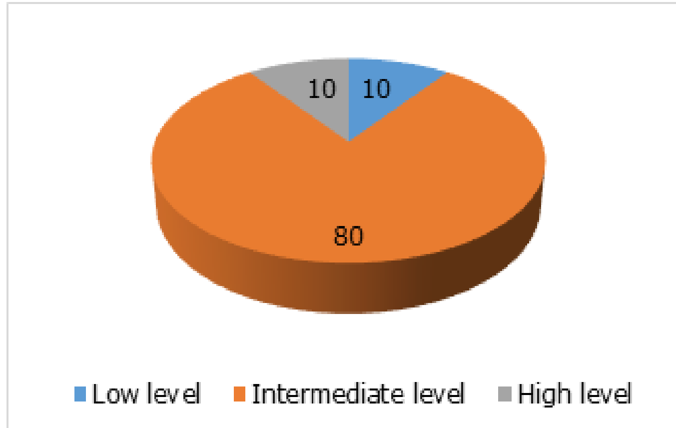

Figure 5. Assessing the development of spatial reasoning in the control group.

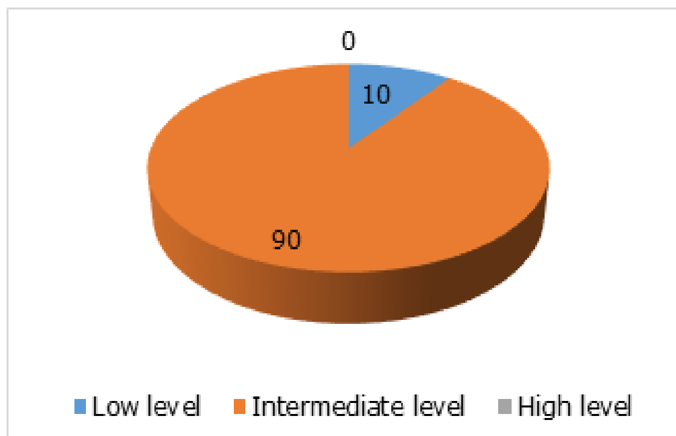

Figure 6. Assessing the development of spatial reasoning in the experimental group.

The pie graphs above (Figure 5 and 6) show that initially, the experimental group had a lower level of spatial reasoning than the control group. The educational experiment was conducted in the experimental group. It implied systematic mathematics practice using a specialized system of exercises and games for 3-5-year-olds (Beloshistaya, 2005abc). The system focuses on the development of preschoolers' spatial reasoning through constructional design activities following the principles described above. The educational experiment involved math classes over several months. In addition to the constructional design activity in the classroom setting, the teachers also set up a mathematical space in the activity room, where the children could find stencils of geometric shapes; Cuisenaire rods; colored cardboard geometric shapes;

fluffy geometric shapes stuck to the panel with magnets; albums of geometric collages; patterns and designs created with Cuisenaire rods; training games with split-type geometric shapes; flash cards depicting various objects, animals, story-telling pictures using geometric shapes.

The experiment has demonstrated that as the children mastered spatial reasoning in the classroom setting, they became increasingly involved in constructional design activities during free play and chose to play in the mathematical space more often. The educational experiment was followed by another summative assessment. It was based on the tasks identical to those used for the baseline summative assessment, however more challenging. Figure 7 and Figure 8 show the results of the repeated assessment in the control and experimental groups. The control group showed a higher level of spatial reasoning at baseline, however had no practice focused on the development. The children had typical lessons of preschool mathematics.

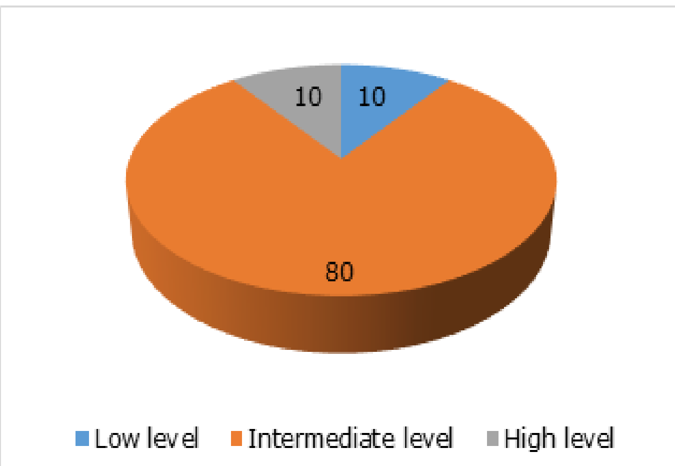

Figure 7. Assessing the development of spatial reasoning in the control group.

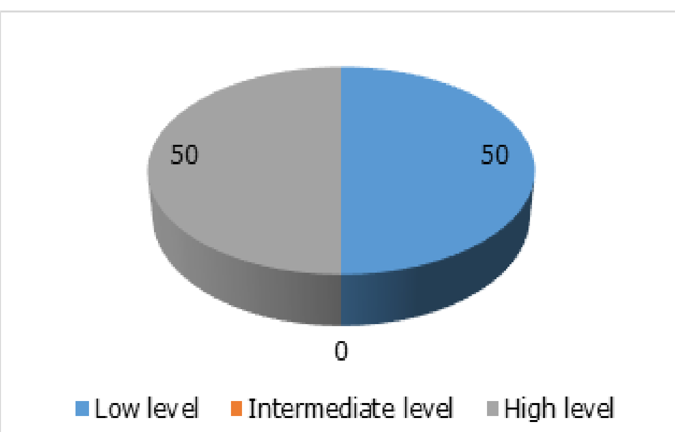

Figure 8. Assessing the development of spatial reasoning in the experimental group.

As can be seen from the pie graphs shown in Figure 7 and Figure 8, the proportions of children's spatial reasoning levels in the control group remained unchanged: 10% showed each of the high and low development of spatial reasoning, with 80% accounting for the intermediate level. In other words, although the children also practiced the approved preschool mathematics curriculum, the summative assessment for spatial reasoning has demonstrated consistently unchanged proportions of the development levels. The experimental group has shown quite different outcomes. By the end of the experiment, there were no children with low-level spatial reasoning, with the group having equal proportions for the high-level (50%) and intermediate-level (50%) development of spatial reasoning. Interestingly, there were no children with the high-level development of spatial reasoning in this group at baseline.

Obviously, it might be highly interesting to continue until the school-age years, i.e., the age of 6, and then investigate the level of mathematics success in elementary school. However, studies investigating the correlation between the development of a schoolchild's spatial reasoning and his/her mathematics abilities have already been conducted (Tsukar, 1999; Gradova, 2010; Gutkina, 2016; Plotnitsky, 2019; Beloshistaya, 2020). These studies have shown a direct positive correlation between the development of spatial reasoning and success in mathematics. Kolmogorov (2001), an outstanding Russian mathematician and author of mathematics textbooks, described the same positive correlation between the development of a student's spatial reasoning and his/her mathematical talent. Thus, this study seems to find its primary significance in maintaining the ongoing development of a child's spatial reasoning at the preschool age, when a child's brain is the most sensitive to the developmental practice (Ananiev & Rybalko, 2014; Belkina, 2015; Poddyakov, 2017; Simanovsky, 2019; Venger, 2019; Celi Rojas et al., 2021). The studies listed above (Krutetsky, 1968; Atakhanov, 1993; Tsukar, 1999) have demonstrated that the high-level development of a child's spatial reasoning is a substantial assurance of better understanding and high success in mathematics.

CONCLUSIONS

The results of the experimental testing of the task-based approach to the development of preschoolers' spatial reasoning through improving design thinking have convincingly demonstrated that the preschool age is the most sensitive for the development of this kind of thinking. The approach established in the study has proven to be significantly effective. In addition, it should be noted that children were happy to carry out the play-based tasks. Then they were excited to play the task games.

Thus, it may be safely suggested that focused efforts in the preschool development of spatial reasoning will pave the way to successful and emollient learning during school years.

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