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Research Article

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The important aspects for students in learning geometry: Mathematics teachers' perspective

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ABSTRACT

Geometry is one of the required mathematics courses for students at every educational level. This study examined mathematics teachers' perspectives on the important aspects of learning geometry. Three junior high school mathematics teachers participated in this study, which formed the basis for this exploratory investigation. A qualitative approach was used for this study and interviews were conducted to gather data. Using semi-structured interviews, each teacher's conversation lasted between thirty and one hour. The teachers' perspective highlighted three cognitive abilities to consider when assisting students in learning geometry: spatial thinking, problem-solving abilities, and higher-order thinking skills (HOTS). Spatial thinking is one of the skills that students must acquire to make geometry easier to study. Students' mental visualization and manipulation of geometric objects is a component of spatial thinking. Students' ability to perceive objects holds the key to understanding geometry holistically. Problem-solving proficiency and HOTS are other areas in which students continue to struggle. Introducing students to problem-solving exercises can be a beneficial exercise for improving their thinking skills, which in turn will help familiarize them with HOTS. Teachers provide contextual problems as a way to help students overcome their inability to understand the mathematical context of geometry, which makes geometry easier for them to understand.

Keywords: higher-order thinking skills, problem-solving, spatial thinking, thinking skills

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INTRODUCTION

Students can acquire conceptual understanding and actively construct knowledge from prior knowledge and experiences, as well as be aware of the practical applications in ordinary life, which is one of the primary reasons for effective teaching and learning (Slavin, 2018). This concept is also applied to the study of geometry, which is classified as a branch of mathematics. Children begin to develop an understanding of geometry concepts at a young age, beginning with the recognition of basic shapes and progressing to the ability to differentiate between examples and non-examples of specific geometric figures (Clements & Sarama, 2020; Clements et al., 2018). The ability to excel in mathematics may be a challenge for individuals who lack an understanding of geometry conceptually (Ayan & Isiksal-Bostan, 2019; Hwang et al., 2019). Consequently, to guarantee that students comprehend the fundamental principles of geometry and can effectively apply them in practical situations, educators must implement innovative teaching methods and resources.

Students may encounter difficulties in learning geometry, including the inability to understand geometric concepts and the inability to visualize geometric figures (Battista et al., 2018; Taylor et al., 2023). The inability of students to visualize geometric figures may be attributed to their lack of spatial thinking abilities which encompasses visualization abilities, which enable individuals to mentally identify, generate, or manipulate geometric figures (Lowrie et al., 2019). Studies indicated a positive correlation between geometry achievement and spatial thinking. In comparison to students with lower levels of spatial reasoning, those who possess high-level spatial thinking skills tend to accomplish superior results in geometry and mathematics (Adams et al., 2023; Battista et al., 2018; Sinclair et al., 2018). Geometric reasoning is closely associated with spatial thinking, which allows students to reimagine and reinforce the concept of geometry (Buckley et al., 2019; Novita et al., 2018). Some students may experience difficulty in applying geometric principles to problem-solving situations (Harris et al., 2021) and may struggle to comprehend the relevance of geometry to their daily lives (Hwang et al., 2019), in addition to the absence of spatial thinking. Students who flourish in problem-solving activities are more likely to possess exceptional spatial thinking abilities (Buckley et al., 2019; Harris et al., 2021). Students can cultivate higher-order thinking abilities by engaging in problem-solving, which necessitates the execution of analysis and evaluation during the process of problem-solving (Casey & Fell, 2018; Hodiyanto, 2018; Nurkaidah et al., 2021).

Considering the crucial role of spatial thinking, problem-solving and higher-order thinking skills (HOTS), implementing those thinking skills in learning will have a positive impact on students' successful learning of geometry. The utilization of manipulatives and hands-on activities can captivate students and render abstract geometric concepts more tangible (Chaumba & Chaumba, 2023; Novita et al., 2018; Patahuddin et al., 2018). For instance, students may find it easier to comprehend and visualize the concepts of volume and surface area when they are taught using construction blocks (Chaumba & Chaumba, 2023). Teachers can also develop educational activities that utilize tools such as puzzles to be used as learning media to assist students in developing their understanding of geometry (Bofferding & Zhu, 2023). The utilization of visual technologies in learning activities shows a positive effect on enhancing students' proficiency in geometry (Abdullah et al., 2022; Yahya et al., 2021). Moreover, distance learning can be facilitated through the use of spatial-based technology (Eroğlu, 2023).

Despite the numerous learning methods, teachers have remained instrumental in assisting students in unlocking their full potential and nurturing confidence and proficiency in geometry by addressing obstacles and offering innovative instruction. Teachers are required to actively engage students in geometry learning by participating in ongoing professional development to remain informed about the most recent teaching methods and strategies. By consistently improving their instructing abilities, teachers can ensure that they are providing the most effective instruction to help students achieve success in learning geometry. The impact of effective geometry instruction is not limited to academic achievement; it also promotes the cultivation of higher-order thinking abilities, problem-solving skills, and a strong foundation for future success in both academic and professional contexts (Bognar et al., 2024; Clements, 2003). The objective of this research was to investigate the important aspects for students in learning geometry, as perceived by teachers.

METHODOLOGY

Data was collected through interviews in this preliminary investigation using a qualitative approach. This study aimed to examine the viewpoints of junior high school mathematics teachers. The purposive convenient sampling method was employed to select the participants in this study. The researcher is able to select participants who are willing and able to participate in the study through purposeful expedient sampling (Creswell & Guetterman, 2019). Nevertheless, the researchers established certain participant criteria, such as an academic degree and teaching experience. Participants in this study were required to have at least a bachelor's degree in mathematics education and a minimum of five years of teaching experience. As a consequence, three senior mathematics teachers were included as participants. Each of the three senior mathematics teachers who participated in this research was interviewed for a maximum of one hour. The semi-structured interviews were conducted with individuals to obtain information and their perspectives as senior mathematics teachers regarding the needs of junior high school students in the study of geometry.

The outcomes of each interview were transcribed and analyzed in order to address the research questions:

1. What challenges do junior high school students encounter when studying geometry?
2. What are the methods for teaching students about geometry?

The results of these two substantial research queries will indicate the important aspects students must possess to learn geometry successfully.

Table 1. Challenges in learning geometry

Difficulties	Participants (P)		
	P1	P2	P3
Visualizing geometric objects	+	+	+
Seeing the relations among geometric objects	–	+	+
Applying geometry concepts into real-life problems	+	+	+
Solving problems related to combined geometric objects	+	+	+

Note. The plus sign (+) means that participants mentioned the difficulty during the interviews and the minus sign (–) means that participants did not mention the difficulty.

RESULTS

The results of interviews from each participant (later will be addressed by number for each individual) were presented and analyzed to address the two research questions.

Challenges Encountered by Students When Studying Geometry

The interview revealed that there are typically four challenges commonly encountered by students. **Table 1** provides a concise overview of the challenges that students face when studying geometry, as indicated by teachers.

These difficulties are resented in the following transcript data according to the interviews from each teacher.

1. *Visualizing geometric objects*

Students often face challenges in visualizing geometric objects especially when they have to imagine and capture the visualization of objects into drawing figure representations.

> P1: "If students just read or hear from the teacher, they will typically struggle to visualize geometric objects. Ehm … moreover if they were asked to draw the objects. They will ask me to give them an example first."

> P2: "I noticed that children had trouble visualizing geometric shapes in their heads. For example, if I present material and ask my students to express it, they will struggle. For another example, they found it difficult when I asked students to draw a geometric shape with the following characteristics: The quadrilateral ABCD has all sides of the same length, with point E being the midpoint of side AB and F being the midpoint of side AD. Then I ask pupils to design a triangle in ABCD that connects points E and F."

> P3: "Of course, not all students... but most students find it hard to draw geometry shapes if they only read the question, especially if the question is different from the example that was given before ... They won't be able to figure it out."

It is imperative to possess the capacity to visualize in order to mentally capture the images of geometric objects, which is essential for the study of geometry. This is consistent with the argument that spatial thinking and STEM learning are closely related, as STEM learning is facilitated by visualization, while visualization is facilitated by the capacity to perceive space, which is also true of spatial thinking (Taylor

et al., 2023). The example provided by P2 demonstrates that students who encounter challenges in solving problems typically possess a low level of spatial visualization ability. Spatial visualization facilitates the generation, transformation, and visualization of object movements in 2D and 3D space (Battista et al., 2018; Patahuddin et al., 2022).

2. Seeing the relations among geometric objects

Two participants agreed that students tend to have difficulties seeing the relation among geometric objects. Some students were confused while attempting to differentiate between various shapes or encountered challenges in perceiving the links between distinct shapes.

> P2: "Yes, most students indeed struggle to see the relation between geometric objects. It can be hard for students to tell the difference between squares and rhombuses. Some kids even mix up rectangles and cuboids haha but it is a rare case … just for students with low levels of mathematics."

> P3: "If we talk about how geometric objects are related to each other, I think most of the students still can't see it, especially the ones who aren't good at mathematics."

The degree of students' comprehension of geometry concepts, including the concepts of shapes, is demonstrated by their capacity to identify the relationship between geometric objects (Clements et al., 2018). Shape is a fundamental concept in the cognitive development of children, as they begin to develop a conceptual comprehension of the geometric figure at a young age. The successful development of the conceptual comprehension of geometric figures is demonstrated by the ability of children to identify between examples and non-examples of specific shapes (Clements & Sarama, 2020; Clements et al., 2018). The ability of HOTS can also be demonstrated through the identification process, as it involves the analyzing and evaluating processes, which are both part of the HOTS cognitive process (Krathwohl, 2002). The incapacity to erroneously identify 3-D figures as 2-D is primarily attributed to the students' deficiency of geometric understanding (Ayan & Isiksal-Bostan, 2019). This leads us to the recognition that perceiving connections between geometric objects necessitates a complex cognitive process, as students must develop a conceptual comprehension of geometry concepts and HOTS.

3. Applying geometry concepts into real-life problems

The participants highlighted an additional challenge encountered by students in their study of geometry, which is the application of geometric concepts to real-world problems. Put simply, students will encounter challenges when attempting to solve geometry problems that are connected to real-world situations.

> P1: "It can be somewhat difficult for students to apply geometry concepts to real-world problems. Particularly if students still do not completely understand geometric concepts."

> P2: "When students have to solve real-life geometry problems, they often find it hard to use what they've learned in class."

> P3: "Students must be guided in solving real-life geometric problems using what they have learned about geometry concepts because they get confused when it comes to applying them."

Table 2. Geometry teaching methods

Teaching methods	Participants (P)		
	P1	P2	P3
Teaching mathematics visually	+	+	+
Using contextual problem-solving activities	–	+	+
Motivating students to engage in higher-order thinking	+	+	+

Note. The plus sign (+) means that participants mentioned the difficulty during the interviews and the minus sign (–) means that participants did not mention the difficulty.

The conceptual understanding of students may be the root cause of their inability to apply geometry concepts to real-life issues. This is consistent with the research conducted by Ayan and Isiksal-Bostan (2019), which investigated the challenges encountered by middle school students in Turkey when confronted with geometry problems. Students frequently employ incorrect strategies to resolve problems due to their inability to identify the context of real-life problems related to geometry, which is a consequence of their lack of conceptual understanding (Ayan & Isiksal-Bostan, 2019).

4. Solving problems related to combined geometric objects

The final issue that all three participants identified was the difficulty students experience when attempting to solve problems involving combined geometric objects.

> P1: "Most of the time, it takes my students longer to finish math problems with shapes that are made up of more than one geometric objects."

> P2: "Students usually have trouble figuring out the area of a shape made up of two or more geometric objects when they are given that shape … This could be because it takes them longer to understand the shape."

> P3: "While it's true that not every student struggles the same, many times students will make mistakes when attempting to solve geometry problems involving several shapes."

Students' challenges in resolving geometry problems that involve combined geometric objects may be caused by their lack of spatial ability, particularly spatial structuring ability. Spatial structuring is a mental process that involves the construction of spatial organization or form for an object or set of objects, and this process allows us to identify the individual components of the object or to combine them among objects (Battista et al., 2018). Other research has demonstrated that students are better at identifying shapes than at connecting the mathematical context to calculations which has the potential to affect the problem-solving processes of students, as they may encounter difficulty in solving problems that entail calculations, even if they are able to identify the shapes involved (Altay et al., 2017).

Methods For Teaching Students About Geometry

Teachers can use a variety of methods to help students learn geometry, and the interviews revealed common teaching methods used by participants as junior high school mathematics teachers. Participants mentioned teaching methods in **Table 2**, which can help students overcome or lessen the challenges they face when learning geometry.

The three participants were nearly unanimous in their agreement regarding all three of the summarized teaching methods, with the exception of contextual problem-solving activities. The use of visual representations by teachers was indicated by the fact that all three participants identified teaching mathematics visually as their primary

method. Teachers frequently employed this approach to address students' difficulties in visualizing geometric objects, as indicated by the interviews.

> P1: "To assist students in visualizing specific geometric shapes, I typically utilize geometric media. I'll use folded paper that has been formed into two-dimensional figures, for instance."

> P2: "If students struggle to visualize a specific geometric shape, I typically present a picture of the shape. For instance, when discussing 2D shapes, I may cut paper into geometric shapes."

> P3: "Students usually find it easier to understand geometric shapes if I show them examples in picture form first."

Students' spatial visualization abilities will be enhanced by the implementation of visual representations in geometry instruction, as they will be able to mentally visualize geometric figures with greater ease (Clements et al., 2018; Hawes et al., 2017). The use of problem-solving activities also can be a valuable method for students moreover using the contextual problems that are linked to geometry contexts (Harris et al., 2023).

> P2: "Sometimes I would give students opportunities to work in groups and address contextual difficulties together. For example, when we learn about 3D geometry figures, we will ask students to create some boxes or product packaging and describe the geometry figures that represent the boxes."

> P3: "I often give students geometric problems related to everyday life in the hope that they can see the relationship between geometric contexts and the real world. Then they have to talk about how they came up with their answers."

Meanwhile, it is already known that problem-solving can also promote HOTS (Casey & Fell, 2018; Jailani et al., 2023). Additionally, all participants share the same perspective regarding the necessity of introducing students to higher-order thinking as a method for helping them learn geometry. This is anticipated that this method will help students overcome the challenges previously mentioned.

> P1: "I will get students to think during problem-solving tasks by asking them questions that make them think more deeply."

> P2: "When students ask me a question, I won't answer right away. Instead, I'll ask them something that will make them think more."

> P3: "I occasionally have to challenge my students to reflect more thoroughly. For example, if they are having trouble grasping the connection between two-dimensional shapes, I will help them by asking insightful questions and encouraging them to watch again and reflect more thoroughly."

The promotion of HOTS in learning activities has a beneficial effect on both students' and teachers' pedagogical approach, as it enables them to more effectively prepare teaching methods that are customized for the requirements of the students (Azid et al., 2022).

DISCUSSION

The findings indicate that students experience the most difficulty with three cognitive abilities: spatial ability (visualization), HOTS, and problem-solving. Studies found a strong correlation between mathematical achievements and the three cognitive abilities (Buckley et al., 2019; Casey & Fell, 2018; Mix, 2019). Buckley et al. (2019) study found a relationship between spatial ability and problem-solving performance in geometry: the higher the spatial ability, the better the problem-solving performance. Casey and Fell (2018) found that spatial ability can be used as an indicator of mathematics performance. Additionally, Mix's (2019) study highlights the relationship between spatial ability and both problem-solving skills and the development of HOTS. According to the analysis results, the first issue is the visualization problem. This suggests that students often find it difficult to mentally manipulate and visualize geometric figures, which is indicative of their limited conceptual understanding of geometry.

In order to facilitate the development of geometry competence, it is imperative that we first develop students' capacity to recognize geometric shapes, as this is a critical component of their cognitive development (Clements et al., 2018). The student's success in learning geometry will be dependent upon the effective conceptual development of geometry concepts and children begin to cultivate their conceptual comprehension of geometric figures during their early childhoods (Battista et al., 2018; Clements & Sarama, 2020). Students' conceptual comprehension of geometric figures may be significantly enhanced by learning activities that emphasize the cultivation of visual-spatial thinking abilities (Clements et al., 2018). This understanding is consistent with the findings of this study, which reveal the teacher's viewpoints on the most effective methods for teaching geometry visually through the use of visual media, such as physical or pictorial geometry representations. Using geometric physical representations, such as folded paper or origami paper, greatly improves students' ability to visualize (Cakmak et al., 2014). Teachers can also enhance students' spatial visualization skills and promote their conceptual understanding of geometry concepts through the use of pictorial representations such as maps and graphs (Newcombe, 2016) or pictures of geometry figures (Eroğlu, 2023; Sinclair et al., 2018). Students frequently face another three challenges in their geometry studies, indicating a lack of proficiency in problem-solving skills and the use of HOTS.

Introducing students to problem-solving exercises can be a beneficial exercise for improving their thinking skills, which in turn will help familiarize them with HOTS as the two skills are closely interconnected. Nurkaidah et al. (2021) showed the connection between spatial ability, problem-solving ability, and HOTS. The findings of this investigation suggest that students with low spatial abilities were unable to engage in HOTS (analyze, evaluate, develop, and create) during the problem-solving process. Students with moderate spatial abilities were able to analyze, but they were unable to evaluate and create. Students with high spatial abilities were able to analyze and evaluate, but they were unable to create. A teaching method that involves asking students for guidance questions was suggested by the teachers who participated in this study. This method fosters students' thinking skills and motivates them to engage in more in-depth thought processes. Students will be encouraged to employ HOTS and elevate their problem-solving skills through guidance questions since students will conduct a critical analysis of their responses and identify

potential solutions (Maclean & Bayley, 2023). Moreover, the integration of contextual problem-solving activities not only improves students' problem-solving abilities but also promotes their comprehension of theory and its practical application. Hwang et al. (2019) demonstrated that the utilization of contextual problem-solving significantly improves students' capacity to estimate, achievements in geometry, spatial ability, and comprehension of geometric concepts.

Teachers have a significant obligation to ensure that students grasp these three cognitive abilities accurately throughout geometry lessons, as they play a crucial role in facilitating students' learning. Put simply, teachers must possess sufficient expertise in spatial thinking abilities, problem-solving, and HOTS before using the methods. Studies imply a positive connection between teachers' spatial thinking abilities and the way they teach (Abidin, 2018; Azid et al., 2022; Jailani et al., 2023). Teachers that possess strong spatial thinking abilities will employ efficient spatial communication techniques to facilitate students' learning. Similarly, teachers who possess exceptional problem-solving abilities and HOTS tend to provide impactful learning experiences for students.

CONCLUSION

According to teachers, three cognitive aspects students need to have in order to effectively learn geometry are spatial thinking, problem-solving skills, and HOTS. This study unveiled the difficulties frequently encountered by students while acquiring knowledge in geometry, indicating their lack of proficiency in these three cognitive aspects. Teachers can incorporate learning activities that include the three cognitive aspects due to their mutually beneficial relationships.

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Declaration of interest: The authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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