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Profiling Junior High School Students' Spatial Ability in Geometry Transformations Based on Five Spatial Indicators

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Abstract. Spatial ability plays an essential role in students' cognitive development, particularly in learning mathematics and science. This study aims to map the initial profile of junior high school students' visual–spatial ability by emphasizing five cognitive indicators: spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. The research employed a mixed-methods approach, combining a quantitative descriptive design with qualitative data from interviews. The quantitative instrument consisted of five validated essay test items with acceptable reliability (α = 0.78). The research subjects were 23 ninth-grade students from a junior high school in Rejang Lebong Regency, Bengkulu. The analysis revealed that 43.48% of students were in the low category, 47.83% in the medium category, and only 8.69% reached the high category. The highest achievement was found in the spatial perception indicator (91.30%), while the lowest was in mental rotation (34.78%). Interview data supported the quantitative findings, showing that students still experienced difficulties in mentally manipulating objects. These findings highlight the importance of spatial skills in supporting the understanding of geometric concepts and indicate the need for instructional strategies that place greater emphasis on visualization and rotation aspects. This study is expected to serve as a foundation for developing effective, adaptive, and contextual spatial-based mathematics learning.

Keywords: Spatial Ability; Mental Rotation; Junior High School; Geometry Learning; Mathematics

1. Introduction

According to Lowrie et al. (2020), spatial ability is a crucial aspect of mathematics and science education. It involves the ability to manipulate, organize, and interpret information in both two- and three-dimensional dimensions (Schenck & Nathan, 2024). However, the spatial dimension of thinking is often not recognized in mathematics curricula, which may impair students' comprehension of geometric concepts and transformations (Z. C. K. Hawes et al., 2022; Li et al., 2025a).

Earlier research has indicated a positive correlation between spatial ability and mathematical proficiency, particularly in grasping geometry concepts and numerical representations (Sütçü, 2021; F. Xie et al., 2020). Meta-analyses have confirmed a causal relationship between spatial ability and students' mathematical performance, emphasizing the importance of integrating these skills into the curriculum. PISA 2018 data revealed that students' inability to visualize object rotations or mentally represent geometric shapes negatively impacts their comprehension and problem-solving skills.

Despite the recognition of the importance of spatial ability in Indonesian education, there is a lack of systematic research on the spatial ability profile of junior high school students. This study aims to address this gap by mapping students' spatial ability as a preliminary step in designing more adaptive and contextual learning strategies.

Strengthening spatial abilities is even more important from the standpoint of 21st-century education, since mastery of critical, creative, and technology-based thinking is becoming more and more necessary. According to recent research, interactive geometry software and virtual reality-based media can greatly improve students' comprehension of spatial concepts (Di & Zheng, 2022; Reen et al., 2022; Serrano-Ausejo & Mårell-Olsson, 2024). According to (Bower et al., (2020) and Putri et al. (2019), methods that involve hands-on manipulating activities like origami have also been successful in helping students strengthen their spatial vision abilities.

In order to create more efficient and contextually relevant learning methodologies in Indonesia, this study focuses on mapping junior high school pupils' basic spatial competence.

1.1. Problem Statement

In order to comprehend geometric concepts, spatial competence is essential. But many students still struggle in this area, especially when it comes to handling geometric transformation problems, which call for both precise visualization and a logical flow of operations(Gilligan-Lee et al., 2019; Z. Hawes et al., 2022; Rangkuti & Juniati, 2022). Research shows that students' weakest skills are frequently mental rotation and spatial visualization, particularly when complicated geometric transformations require manipulating objects in mental space (Fujita et al., 2022).

Furthermore, spatial barriers include spatial visualization and direction in addition to mental rotation. According to Fastame (2021), Mjenda et al. (2023b), and Zeybek & Gümüş (2023), students frequently have trouble understanding the sequence of transformations, applying formulas incorrectly, or visualizing shape changes in geometric coordinates. Limited procedural knowledge and inadequate cognitive methods exacerbate these difficulties. Additionally, the lack of interactive digital media or tangible manipulatives limits the development of students' spatial skills, and classroom practices frequently fail to offer sufficient chances for visual-spatial learning (Bower et al., 2020; İlhan & Tutak, 2021). In order to create flexible and creative teaching methods, it is imperative that students' spatial abilities be carefully mapped using important cognitive indicators.

1.2. Related Research

The connection between spatial ability and mathematical success has long been highlighted by research. The significance of spatial literacy including spatial perception, visualization, and mental rotation in grasping geometric concepts at different educational levels is highlighted by a systematic review of the literature (Octaria et al., 2025). In a similar vein, research by Sütçü (2021) showed that pupils who are stronger at spatial visualization do better in math. Li et al. (2025b) and Hawes et al.,(2022) found a favorable link between spatial skills and numerical representation, indicating their role in better mathematical performance.

Furthermore, a number of studies have examined students' challenges with mental rotation. Students frequently find it difficult to mentally image shape transformations, especially in activities involving many rotations, according to Fastame (2021), Mjenda et al. (2023b), and Zeybek & Gümüş (2023). These challenges impair students' comprehension of geometric ideas as well as their capacity to combine analytical and spatial reasoning, both of which are necessary for resolving challenging issues (Seah & Horne, 2020; Zhou et al., 2024).

The current study focuses on a thorough mapping of junior high school students' spatial abilities across five cognitive indicators: spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. This is in contrast to earlier research that primarily examined the relationship between spatial ability and mathematics achievement or the creation of instructional media. By providing a more thorough understanding of students' spatial strengths and limitations, this method aids in the creation of instructional techniques that are specifically designed to fit the requirements of individual students in the classroom.

1.3. Research Objectives

This study aims to map the initial profile of junior high school students' visual–spatial ability based on five key cognitive indicators: spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. The research focuses on identifying students' strengths and weaknesses in each indicator in order to obtain a comprehensive picture of their spatial ability. The findings of this study are expected to contribute to the design of more effective, adaptive, and contextual instructional strategies to enhance students' understanding of geometric concepts, while simultaneously supporting the development of spatial thinking skills as part of 21st-century competencies.

2. Theoretical Framework

2.1. Spatial Ability and Mathematics Learning

Spatial ability is a critical cognitive skill that plays a significant role in learning mathematics and science. This ability enables students to understand, manipulate, and interpret objects in both two- and three-dimensional forms. Numerous studies emphasize the close relationship between spatial ability and mathematics achievement, particularly in solving abstract problems, representing numerical information, and mastering geometric concepts. Recent meta-analyses have also shown that spatial training consistently leads to significant improvements in mathematics performance across various educational levels (Hawes et al., 2022). Thus, spatial ability is considered a foundational skill for academic achievement, particularly for mastering 21st-century competencies, such as critical thinking and problem-solving.

2.2. Indicators of Spatial Ability

Spatial ability is commonly described through five key cognitive indicators: spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. These indicators are not just theoretical constructs; they are integral to understanding how students, particularly junior high school students, engage with geometric concepts in real-life learning contexts.

The capacity to identify an object's size and shape from various angles is known as spatial perception. This ability is essential for junior high school students in Indonesia to identify geometric shapes in everyday situations, particularly when they encounter educational resources that call for precise comprehension of object proportions. As students learn to visualize geometric figures during transformations, spatial visualization the capacity to see shape transformations becomes increasingly important. In geometry, where the capacity to alter shapes mentally is necessary, this signal is crucial. The capacity to mentally rotate objects is known as mental rotation, and it is frequently regarded as the most difficult component of spatial ability. According to studies, poor comprehension of geometric transformations is correlated with mental rotation issues, making this skill especially difficult for Indonesian junior high school students (Fastame, 2021; Mjenda et al., 2023a). Understanding the connections between objects is the focus of spatial relations. For junior high school pupils in Indonesia, this entails knowing how objects and shapes interact in geometric environments, which is essential to gaining a deeper comprehension of geometric concepts. The capacity to ascertain relative placements and directions is known as spatial orientation. When junior high school kids learn to navigate spatial information through tasks like reading maps or solving geometry problems, this signal is especially pertinent.

These five indicators of spatial ability are crucial for mapping the strengths and weaknesses of students in the context of Indonesian junior high school education. Understanding how students perform across these indicators provides valuable insights into their cognitive processing and spatial reasoning abilities, which are directly tied to their mathematical success.

To understand the development of spatial ability, this study incorporates Bloom's taxonomy, which categorizes cognitive learning into three levels. These levels provide a framework to design tasks that target different stages of spatial representation development in students:

The ability of pupils to recall and replicate geometric content is the main focus of Level 1: Recall and Reproduction. Students at this level must be able to recall terminology, geometric shapes, and fundamental ideas like where objects are in space. This stage is essential for developing a fundamental grasp of geometry.

Students must apply their knowledge by transforming and understanding geometric information in Level 2: Transformation and Interpretation problems. At this point, students may be challenged to solve issues by using their spatial knowledge in novel contexts or to depict geometric changes depending on data. The development of spatial visualization abilities depends on this stage.

Higher-order thinking abilities are the focus of Level 3: Analytical Skills, where students examine and deconstruct challenging spatial situations. Finding connections between geometric objects, differentiating between various shapes and their characteristics, and assembling components to form new structures are among the tasks. Students must combine spatial information at this level and apply it imaginatively to solve problems.

Creating assignments that gradually test students' cognitive growth and spatial reasoning skills requires integrating Bloom's taxonomy with the five spatial indicators. This framework offers an organized method for evaluating and improving students' spatial skills, which are essential for their success in learning geometry and mathematics.

2.3. Instructional Interventions to Support Spatial Ability

Previous studies have identified mental rotation as the most challenging aspect of spatial ability, often hindering students' understanding of geometric transformations (Fastame, 2021; Gilligan-Lee et al., 2019; Mjenda et al., 2023b). This barrier affects students' ability to solve problems that require the integration of spatial logic with symbolic representation (Seah & Horne, 2020; Zhou et al., 2024). To address this, various instructional strategies have been developed. Technology-based media, such as Virtual Reality and digital geometry software, have been shown to significantly enhance spatial understanding (Di & Zheng, 2022; Reen et al., 2022; Serrano-Ausejo & Mårell-Olsson, 2024). Similarly, physical manipulative approaches, such as origami and geometric blocks, contribute to fostering students' spatial visualization in a gradual and concrete manner (Bower et al., 2020; İlhan & Tutak, 2021). Combining modern technology with traditional activities is thus seen as a highly effective approach to improving the spatial ability of junior high school students.

3. Method

3.1. Research Design

This study employed a mixed-methods approach with a convergent design. Quantitative and qualitative data were collected in parallel, analyzed separately, and then integrated to obtain a more comprehensive understanding of junior high school students' visual–spatial ability. This approach was chosen to ensure that the research findings not only present numerical distributions but also reveal students' thinking processes and cognitive strategies in solving spatial tasks. The convergent design has been shown to be effective because it enables researchers to gain deeper insights from two complementary perspectives, thereby producing more valid and reliable results (Açikgül et al., 2023; Adhikari & Timsina, 2024; Otaki et al., 2023). Furthermore, in the context of mathematics and science education, this approach is considered particularly relevant for exploring the relationship between spatial test outcomes and students' learning experiences, which are often difficult to fully capture using quantitative data alone (Khaidir et al., 2024).

3.2. Participant

The participants of this study were 23 ninth-grade students from SMP Negeri 19 Rejang Lebong, Bengkulu, who had previously studied the topic of geometric transformations. The sample was selected purposively to ensure that the subjects had relevant learning experiences. From this group, several students representing high, medium, and low ability categories were chosen to participate in qualitative interviews.

3.3. Data Collection

Quantitative data were collected through an essay test consisting of five questions, each representing one spatial cognitive indicator: spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. The test instrument was validated by experts and demonstrated good reliability ($a = 0.78$). Meanwhile, qualitative data were obtained through semi-structured interviews with selected students to gain deeper insights into their thinking strategies and the difficulties they experienced.

3.4. Data Analysis

Quantitative data were analyzed using descriptive statistics by calculating score distributions and classifying students into three categories: low (≤7), medium (8–14), and high (15–20). In order to provide a useful framework for classifying students based on their spatial skill levels, this categorization was based on the observed score range in the preliminary data. Future research could employ validation techniques like the use of percentiles or z-scores to guarantee the robustness of the classification. For example, using z-scores gives category thresholds a more statistically sound foundation (Pallant, 2020). Additionally, Z-scores provide a better understanding of each score's relative position by showing how it compares to the population mean (Andrade, 2021).

Thematic analysis was used to examine qualitative data in order to find trends in cognitive strategies and challenges based on interview transcripts. The thematic analysis concentrated on important topics such issues with mental rotation and imagery, as well as the methods students utilized to get beyond these obstacles.

In order to improve the validity of the results and offer a more comprehensive understanding of students' spatial abilities, the outcomes of both quantitative and qualitative analyses were then combined using methodological triangulation.

3.5. Validity and Reliability

The quantitative instrument was examined through expert content validation and pilot testing with students of similar characteristics. The reliability of the test was calculated using Cronbach's Alpha coefficient (α = 0.78), which demonstrated good internal consistency. The validity of the qualitative data was ensured through methodological triangulation and member checking to confirm the accuracy of interpretations. This study also observed ethical considerations, including obtaining written consent from both parents and students, maintaining the confidentiality of participants' identities, and ensuring voluntary participation.

4. Findings

4.1. Quantitative Results

To facilitate the interpretation of visual–spatial test data, students' ability levels were classified into three categories: low, medium, and high. This classification was determined based on the maximum possible score of 20, while also considering the actual score distribution of the students. The ranges applied for each category were as follows: scores ≤7 were categorized as low ability, scores of 8–14 as medium ability, and scores of 15–20 as high ability. This approach follows the interval distribution classification commonly used in cognitive measurement studies (Açikgül et al., 2023) and aligns with the principles of ability mapping in spatially based mathematics assessments (Komala et al., 2021; Ramful et al., 2016). The classification was selected to provide a comprehensive overview of students' mastery levels across visual–spatial indicators, while also supporting further analysis in identifying relevant instructional needs. Based on this classification, the distribution of students' spatial ability levels is presented in Table 1.

Tabel 1. Distribution of Junior High School Students' Visual–Spatial Ability

Percentage (%)	Percentage (%)	Percentage (%)	Percentage (%)
Low	0 – 7	10	43.48%
Medium	8 – 14	11	47.83%
High	15 – 20	2	8.69%
Total		23	100%

The visual-spatial skills of junior high school students in this study differed significantly, according to the quantitative data analysis. Ten (43.48%) of the twenty-three students were classified as low, eleven (47.83%) as medium, and two (8.69%) as high. The high percentage of students in the low category necessitates extra care, especially in relation to mental rotation issues, even if the majority of students fell into the medium range. Mental rotation is the most difficult spatial skill for junior high school students, according to earlier studies (Gilligan-Lee et al., 2019;Hawes et al., 2022; Rangkuti & Juniati, 2022), which is consistent with the continuously low performance in this area.

Table 2. Percentage of Students' Achievement in Spatial Ability Indicators

Spatial Ability Indicator	Spatial Ability Indicator	Spatial Ability Indicator	Spatial Ability Indicator
Spatial Perception	1	21	91.30%
Spatial Visualization	2	11	47.83%
Mental Rotation	3	8	34.78%
Spatial Relations	4	16	69.57%
Spatial Orientation	5	12	52.17%

There is a lot of variety in the geographic indicators' accomplishment. Mental Rotation had the lowest achievement (34.78%), whereas Spatial Perception had the best (91.30%). This result implies that although kids are rather adept at recognizing shapes from various angles, they have difficulty with activities that call for the mental manipulation of objects, such rotations, which is an essential geometry skill. We will talk further about the significance of this poor performance in Mental Rotation since it suggests that more focused interventions are required in this area.

4.1. Qualitative Results

Deeper understanding of students' comprehension tactics and typical challenges was made possible by the qualitative interview data. The interview transcripts were analyzed using a thematic approach that includes a clear coding procedure. Initially, recurrent themes including difficulties with visualization, methods for managing spatial activities, and mistakes in mental rotation were used to code the data. Students' statements were categorized into predetermined themes as part of the coding process, which was then recoded in light of new trends.

Pupils in the low-ability group frequently used trial-and-error or guesswork techniques and displayed misunderstandings, such as believing that an object that has been rotated maintains its original orientation. The coding procedure showed that these pupils struggled with the stages involved in solving multi-step rotations, suggesting a lack of comprehension of the fundamental geometric concepts. The medium-ability group's students demonstrated some comprehension, but they frequently misused transformation formulas or failed to finish multi-step transformations, especially when they had to integrate two or more spatial indicators at once.

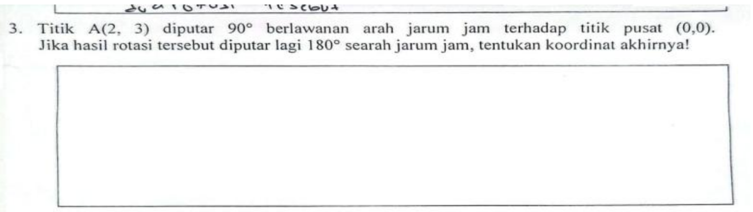
High-ability students showed systematic reasoning, frequently explaining the rotating process or drawing more illustrations to back up their answers. Even these pupils occasionally had trouble with multi-step rotations incorporating many spatial markers, but they were better at handling complex transformations.

Mental rotation was the most difficult spatial indication for all groups, according to the interview analysis, which is consistent with the quantitative results. When asked to tackle multi-step rotation tasks, the low-ability students' perplexity and passivity mirrored their quantitative findings. Although they had trouble understanding the proper application order, students in the medium-ability category could remember transformation formulas. Even high-ability students had trouble picturing many transformations at once, but they were more skilled at implementing changes step by step. The requirement for focused teaching techniques to treat mental rotation issues is supported by these qualitative findings.

To provide a more thorough knowledge of students' spatial ability, methodological triangulation was used to incorporate the results from both the quantitative and qualitative evaluations. While the qualitative data offered insights into the cognitive processes underlying these challenges, the quantitative data demonstrated the substantial difficulty with mental rotation, demonstrating the need for targeted attention in instructional preparation.

5. Discussion

The Mental Rotation indication (item 3) had the lowest accomplishment level, according to quantitative statistics, with only 34.78% of pupils properly answering. This result emphasizes that for junior high school pupils in this study, mental rotation is the most challenging spatial skill. Interviews with students in each ability category—low, medium, and high—provided a greater understanding of the reasons behind this challenge in qualitative analysis.



3. Titik A(2, 3) diputar 90° berlawanan arah jarum jam terhadap titik pusat (0,0). Jika hasil rotasi tersebut diputar lagi 180° searah jarum jam, tentukan koordinat akhirnya!

Figure 1. Original Answer of Low-Ability Student (Student 3)

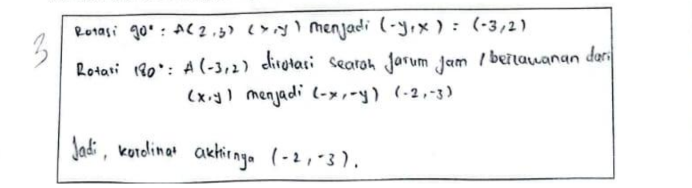
3. Point A(2, 3) is rotated 90° counterclockwise about the center point (0,0). If the result of the rotation is rotated again 180° clockwise, determine the final coordinates!

Interview Excerpt Student 3:
"I was confused about where to start because there were two rotations—one counterclockwise and one clockwise. I didn't know the formula and was afraid of making mistakes."

When asked to complete double rotation issues, low ability pupils were confused, according to Student 3's interview. "I am not sure where to begin because there are two rotations—one clockwise and one counterclockwise," said the student. I am scared of making mistakes and do not know the formula." This claim reveals a profound ignorance of fundamental rotation principles as well as a lack of proficiency with more intricate spatial manipulations. When faced with situations containing increasingly complex transformation phases, low ability students often experience insecurity, which is made worse by their incapacity to make the connections between the interconnected rotation steps.

Students with low mathematical ability often fail to grasp the fundamental concept of rotation, which is essential for solving geometric transformation problems (Loma et al., 2023). Learners with disabilities frequently experience delays in the development of spatial–cognitive mechanisms, which affects their ability to perform geometric transformations—not due to a specific skill deficit, but rather because of a general delay in spatial cognitive development (Grobecker & De Lisi, 2000). The ability to mentally rotate objects, a key component of spatial reasoning, is often underdeveloped among many students, particularly those with learning difficulties, thereby hindering their understanding of geometric transformations (Bruce & Hawes, 2015). Furthermore, low spatial ability can also negatively impact students' performance in open-ended mathematical problem-solving tasks, where spatial visualization and working memory play a crucial role(Wang et al., 2022).

Teachers, therefore, should employ methods that accommodate different cognitive styles and provide clear, step-by-step explanations of transformation concepts, making use of visual aids and scaffolded instruction (Aminah et al., 2024; Nabilah et al., 2023).



3. Titik A(2, 3) diputar 90° berlawanan arah jarum jam terhadap titik pusat (0,0). Jika hasil rotasi tersebut diputar lagi 180° searah jarum jam, tentukan koordinat akhirnya!

3

Rotasi 90° : A(2,3) (x,y) menjadi (-y,x) : (-3,2)

Rotasi 180°: A(-3,2) dirotasi searah jarum jam / berlawanan dari
(x,y) menjadi (-x,-y) (-2,-3)

Jadi, kordinat akhirnya (-2,-3).

Figure 2. Answer of Medium-Ability Student (Student 15)

Interview Excerpt Student 15:

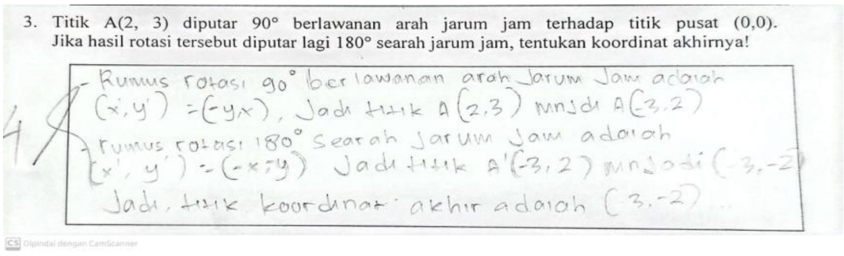
"I used the formula I remembered, the one for 90 degrees with −y, x. Then for 180 degrees I changed it to −x, −y. But I forgot whether the sequence was correct or not.""'

90° Counterclockwise Rotation: Point A(2, 3) after being rotated 90° counterclockwise about the origin (0, 0) becomes (-3, 2).
180° Clockwise Rotation: After the first rotation, point A(-3, 2) is rotated 180° clockwise, resulting in the new point (-2, -3).
So, the final coordinates are (-2, -3).

Partial comprehension was shown by a medium-ability student. This student was confused with the order of rotations but was able to recall the fundamental transformation formula. "I used the formula I recall, which for a 90-degree rotation is -y, x," they said when asked how they handled rotation problems. I then altered it to -x, -y for a 180-degree rotation. However, I can not remember if the order was proper." This suggests that even while the student understood the fundamentals, they were still unable to fully grasp the methods involved in more intricate geometric transformations.

Such difficulties are consistent with findings showing that many students have not yet mastered the overall schema of geometric transformations, particularly in applying rotation and translation formulas (Trisna et al., 2022). Other studies also emphasize the importance of providing more systematic learning opportunities in transformation geometry, so that students do not merely memorize formulas but are able to understand the logical structure underlying each operation (Xie et al., 2025).

Furthermore, recent research suggests that students' difficulties often stem from weak conceptual understanding, with a tendency to rely on procedural calculations rather than grasping the actual geometric meaning, leading to frequent errors in both rotations and translations (Sunariah & Mulyana, 2020). Cultural context and concrete visualization have also been shown to strengthen understanding; for example, integrating Batik Jambi motifs in transformation learning can provide students with more meaningful learning experiences (Andriyani et al., 2023). Therefore, students' difficulties in geometric transformations are not merely technical issues of formula application but also involve conceptual, cognitive, and pedagogical aspects. Consequently, instructional strategies that emphasize visualization, cultural contextualization, and the development of logical reasoning are needed to reinforce students' comprehensive understanding.



3. Titik A(2, 3) diputar 90° berlawanan arah jarum jam terhadap titik pusat (0,0). Jika hasil rotasi tersebut diputar lagi 180° searah jarum jam, tentukan koordinat akhirnya!

4

- Rumus rotasi 90° berlawanan arah Jarum Jam adalah (x', y') = (-y, x), Jadi titik A(2,3) mnjdi A(-3,2)
- rumus rotasi 180° searah Jarum Jam adalah (x', y') = (-x, -y) Jadi titik A'(-3,2) mnjadi (3,-2)

Jadi, titik koordinat akhir adalah (3,-2)

Figure 3. Answer of High-Ability Student (Student 20)

Point A (2, 3) is rotated 90° counterclockwise with respect to the origin (0,0). If the resulting point is then rotated 180° clockwise, determine the final coordinates.
The formula for a 90° counterclockwise rotation: (x,y)→(−y,x), so point A(2, 3) becomes A(-3, 2).
The formula for a 180° clockwise rotation: (x,y)→(−x,−y, so point A(-3, 2) becomes A(3, -2).
therefore, the final coordinates are (3, -2).

Interview Excerpt
Student 20:
"In the first step, I transformed A(2,3) using the formula (−y, x) to get (−3, 2). Then I rotated it 180° from that point using the formula (−x, −y), resulting in (3, −2)."

Students with great ability, on the other hand, were able to tackle rotation difficulties. They were able to apply the processes logically and methodically, demonstrating a solid grasp of the idea of rotation. Interviews with Student 20 revealed that they were capable of handling multi-step rotation difficulties with assurance: "I used the formula (−y, x) to convert A(2,3) to (−3, 2) in the first stage. I then used the formula (−x, −y) to rotate 180° from that position, yielding (3, −2). This shows that pupils have strong mental rotation abilities, as evidenced by their ability to methodically carry out repeated transformations, which is in line with the growth of higher spatial representations. It illustrates how learners can apply geometric transformations in a structured and logical manner, as well as interpret shape changes according to given conditions, consistent with Level 2 of spatial representation development(Totikova et al., 2020).

Mental rotation is a key component of spatial ability, enabling students to visualize and perform transformations such as rotations and translations. This skill is predictive of success in mathematics and science, underscoring the need for educational interventions to develop it (Lacombe & Dias, 2023; Von, 2013). Students with high spatial ability are able to mentally manipulate objects and understand their spatial relationships, which is essential for solving geometric problems (Rustanuarsi, 2023).

These results suggest that, for students of all skill levels, mental rotation is the most challenging subject. This problem is linked to both a greater comprehension of spatial concepts and an inability to recall mathematics. In order to improve student comprehension, it is crucial that geometry teachers focus more on reinforcing the idea of mental rotation through the use of interactive technologies and visual aids.

This study makes a substantial theoretical contribution to the body of knowledge on spatial ability, especially in Indonesian junior high schools. Students' difficulties comprehending geometric transformations can be better understood by mapping five spatial indicators: spatial perception, spatial visualization, mental rotation, spatial relationships, and spatial orientation. This mapping offers a crucial foundation for creating a theory of Indonesian students' spatial abilities, especially with regard to issues with mental rotation. This study also advances our knowledge that developing a more comprehensive and methodical spatial understanding is necessary for studying geometry.

Practically speaking, this study offers significant suggestions for creating more successful teaching methods in the classroom. The findings suggest that junior high school geometry training should focus more on the skill of mental rotation. As a result, it is critical to create instructional strategies that emphasize improving mental rotation skills. These strategies should include the use of interactive technologies like Augmented Reality (AR) and Virtual Reality (VR), which can improve students' spatial comprehension in a more visual and captivating way. This suggestion is also consistent with research showing the value of conceptual understanding-based training as opposed to formula memorization.

6. Conclusion

With a particular focus on the mental rotation indicator—which turned out to be the most difficult skill—this study effectively mapped junior high school students' spatial abilities. The results show that the majority of pupils have difficulty with mental rotation, which hinders their capacity to tackle more challenging geometric problems. In order to improve students' spatial skills, geometry education should emphasize the development of a thorough grasp of mental rotation and include interactive technologies like AR and VR. This study offers important information for creating more contextualized and successful teaching methods to raise Indonesian junior high school students' spatial proficiency.

Limitation

This study has several limitations. First, the sample size was limited to 23 students from a single junior high school, which may restrict the generalizability of the findings. Second, the spatial ability test consisted of only one item for each indicator, so the measurement may not fully capture students' spatial competence in depth. Third, this study focused on profiling students' spatial abilities without implementing instructional interventions; therefore, causal conclusions regarding improvement strategies could not be drawn.

Recommendation

Based on these findings, future research is recommended to involve larger and more diverse samples and to use more comprehensive spatial ability instruments. Further studies should focus on implementing and evaluating instructional interventions, particularly those aimed at improving mental rotation skills through technology-based media or hands-on activities. In practice, mathematics teachers are encouraged to emphasize visualization and step-by-step geometric transformations to support students' spatial reasoning development.

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Conflict of Interest Statement

The author(s) declare(s) that there is no conflict of interest.

Declaration of Generative AI and AI-assisted Technologies

This manuscript was prepared with the assistance of generative AI tools (e.g., ChatGPT, Grammarly, and Translator), which were utilized solely to support drafting and language refinement. All intellectual contributions, critical analyses, and final revisions were entirely carried out by the authors. The authors bear full responsibility for the accuracy, originality, and integrity of the content presented in this work.

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