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phenomenon@walisongo.ac.id

Analysis Of Mathematical Spatial Abilities Of Vocational School Students In Solving Transformation Geometry Problems

Intan Nabila[1], Yusfita Yusuf[2]*

[1,2] *Universitas Sebelas April*

Abstract

Geometry is one of the branches of mathematics that is important for students to master to support their profession in the future. However, there are still difficulties in geometry materials, especially transformation geometry. In fact, there are many test questions about transformation geometry when taking the university or job entrance test. Therefore, it is necessary to conduct an analysis of spatial ability in solving the transformation geometry problem. This study uses a descriptive qualitative approach involving 24 grade XII students in Sumedang Regency as subjects. The results showed that students with high spatial abilities were able to visualize transformations well, although they still faced difficulties in translating them into proper mathematical models. In contrast, students with moderate and low spatial abilities showed significant challenges in understanding the basic concepts of geometric transformations. This study underlines the importance of applying spatial-based learning strategies to improve students' competence in understanding and applying geometry concepts effectively.

Keywords: *Spatial Ability, Transformation Geometry, Spatial-Based Learning Strategies*

Analisi Kemampuan Spasial Matematis Peserta Didik Sekolah Menengah Kejuruan Dalam Menyelesaikan Masalah Transformasi Geometri

Abstrak

Geometri merupakan salah satu cabang matematika yang penting untuk dikuasai oleh siswa untuk menunjang profesi mereka kelak. Namun, masih mengalami kesulitan pada materi geometri khususnya geometri transpormasi. Padahal banyak soal tes mengenai geometri transformasi pada saat melakukan tes masuk perguruan tinggi ataupun pekerjaan. Oleh karena itu maka perlu dilakukan analisis mengenai kemampuan spasial dalam menyelesaikan soal geometri transformasi. Penelitian ini menggunakan pendekatan kualitatif deskriptif dengan melibatkan 24 siswa kelas XII di Kabupaten Sumedang sebagai subjek. Hasil penelitian menunjukkan bahwa siswa dengan kemampuan spasial tinggi mampu memvisualisasikan transformasi dengan baik, meskipun masih menghadapi kesulitan dalam menerjemahkannya ke dalam model matematika yang tepat. Sebaliknya, siswa dengan kemampuan spasial sedang dan rendah menunjukkan tantangan signifikan dalam memahami konsep dasar transformasi geometri. Penelitian ini menggarisbawahi pentingnya penerapan strategi pembelajaran berbasis

Universitas Sebelas April
Email: *yusfita@unsap.ac.id*

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spasial untuk meningkatkan kompetensi siswa dalam memahami dan mengaplikasikan konsep-konsep geometri secara efektif.

Kata kunci: *Kemampuan Spasial, Geometri Transformasi, Strategi Pembelajaran Berbasis Spasial*

INTRODUCTION

Mathematics is a discipline that plays a fundamental role in various aspects of life, both in education and in the development of science and technology (Yusuf et al., 2017) Its relevance is not only for students aiming to succeed in higher education but also for society at large. One of the branches of mathematics that holds significant importance is geometry, which provides the foundation for various scientific and technological fields. Professions such as architects, engineers, and scientists frequently apply geometric concepts in their work (Santi & Santosa, 2016). Geometry, as noted by (Anissa et al., 2022), serves as a key to understanding the forms and structures that shape our world. Galileo also emphasized that geometry is the language of the universe, composed of basic shapes like triangles and circles (Alimuddin. & MS., 2019). Therefore, a deep understanding of geometry from an early stage to higher education is crucial (Sudirman & Alghadari, 2020). Among the geometry topics taught at vocational high schools (SMK), transformation geometry is particularly important. It discusses the rules by which shapes can change position and size based on specific transformations such as translation, reflection, rotation, and dilation (Maulani & Setiawan, 2021). However, students still experience difficulties in understanding these concepts and their applications (Maulani & Zanthy, 2020). These difficulties often stem from errors in conceptual understanding, procedural application, and visualization, which can hinder proof construction in geometric transformations (Kandaga et al., 2022). Furthermore, epistemological obstacles related to van Hiele's levels of geometric thinking exacerbate challenges in mastering transformation geometry, as students struggle to progress from visualization to higher levels of abstraction (Kandaga et al., 2022).

According to the National Council of Teachers of Mathematics (NCTM, 2000), important components of geometry learning include visualization, spatial reasoning, and modeling. These components emphasize the need to integrate spatial ability into mathematics education. Spatial ability refers to a person’s capacity to visualize,

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Email: yusfita@unsap.ac.id

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manipulate, and transform objects mentally in space (Putra et al., 2022). This ability includes subskills such as mental rotation, spatial orientation, and spatial visualization (Hasanah et al., 2024; Lowrie, 2016). (Fahmi et al., 2022) highlights that many students face difficulties in enhancing their spatial perception skills, which are crucial for grasping geometric concepts and for applying mathematical reasoning to both academic tasks and everyday situations. Research has shown that spatial ability contributes significantly to the understanding of complex geometric concepts (Teapon et al., 2023), yet many students struggle to apply spatial reasoning in problem-solving contexts (Mananeke et al., 2017). This contribution is evident across different mathematical content domains, where spatial reasoning, including mental rotation and visualization, predicts performance in areas like geometry and algebra (Harris et al., 2020). Additionally, spatial thinking acts as a critical yet often overlooked element in mathematics curricula, facilitating deeper conceptual understanding and problem-solving (Gilligan-Lee et al., 2022).

Furthermore, spatial ability is not only relevant in academic settings but also plays a crucial role in selection tests for higher education and employment. Tests such as the Academic Potential Test (TPA) and psychological tests often include spatial items related to transformation geometry (Afriyana & Mampouw, 2019; Saputra et al., 2017). This indicates the importance of equipping students with sufficient spatial skills to support their future academic and professional endeavors. Previous studies have analyzed students' spatial abilities in various contexts. For instance, (Afriyana & Mampouw, 2019) investigated students' profiles in solving 3D geometry problems and found that spatial visualization skills strongly influence problem-solving strategies. Similarly, (Alimuddin. & MS., 2018) examined students with high logical-mathematical intelligence and reported their strengths and weaknesses in understanding spatial aspects of geometry. (Febriana, 2015) focused on junior high school students' spatial abilities in 3D geometry, revealing difficulties in mental rotation. (Fitriana & Lestari, 2022) analyzed students' mathematical literacy on PISA items related to space and shape, showing that spatial ability levels affected their reasoning. (Pasaribu & Suratman, 2022) applied GeoGebra in learning conic sections, highlighting its role in improving spatial visualization. (Putra et al., 2022) reported frequent errors among high school and vocational students in planar geometry due to weak spatial reasoning.

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Email: yusfita@unsap.ac.id

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(Sudirman & Alghadari, 2020) conducted a literature review emphasizing the need for spatial-based learning strategies, while (Sugiarni et al., 2018) demonstrated that problem-based learning with GeoGebra can enhance students' spatial ability. (Utami, 2020) identified common errors students make in spatial problem solving, and (Yulia & Amanda Putri, 2024) analyzed spatial ability in solid geometry, showing that many students struggled to connect visualization with mathematical models, research focusing specifically on spatial ability in transformation geometry remains limited. This is a notable gap considering the relevance of transformation geometry in both academic assessments and real-world applications.

Previous studies predominantly focused on students' spatial abilities in three-dimensional geometry (Afriyana & Mampouw, 2019; Febriana, 2015; Yulia & Amanda Putri, 2024), spatial structures and visualization with digital tools (Alimuddin. & MS., 2018; Pasaribu & Suratman, 2022), mathematical literacy in PISA space and shape items (Fitriana & Lestari, 2022), or common errors and spatial-based learning strategies (Putra et al., 2022; Sudirman & Alghadari, 2020; Sugiarni et al., 2018; Utami, 2020). However, none of these studies explicitly investigated students' spatial reasoning in transformation geometry—translation, reflection, rotation, and dilation—which are essential in both academic tests and professional practice. To address this, recent work has unpacked the relation between spatial abilities and creativity in geometry, showing that higher spatial skills correlate with innovative problem-solving in transformations (Panagiotis et al., 2021). Moreover, errors in understanding transformation geometry through concept mapping reveal misconceptions in mental rotation and visualization, underscoring the need for targeted interventions (Napfiah & Sulistyorini, 2020).

Therefore, the gap identified in prior research reveals the need for a focused study that examines vocational school students' spatial abilities in the context of transformation geometry, as this area has not been sufficiently addressed despite its practical and academic importance. Unlike general geometry or building space topics, transformation geometry requires mental manipulation and conceptual understanding of changes in position, size, and orientation. This is supported by previous studies which reported that students often face more difficulties in transformation geometry than in other geometry topics, because it requires integrating spatial visualization with formal mathematical rules

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Email: yusfita@unsap.ac.id

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(Maulani & Zanthy, 2020; Sudirman & Alghadari, 2020). Moreover, transformation tasks demand core spatial sub-skills such as mental rotation, spatial orientation, and spatial visualization (Hasanah et al., 2024; Lowrie, 2016), which are cognitively more complex than merely identifying or constructing geometric shapes. Strategies used in solving transformational geometry problems, such as analytic and visual approaches, further highlight the role of spatial abilities in achieving success (Boulter & Kirby, 1994). Learners engaging with transformation geometry often rely on cooperative models to enhance understanding, as seen in studies where group-based learning improved conceptual grasp (Bansilal & Naidoo, 2012). This study seeks to address that gap by analyzing the level of spatial abilities of vocational school students in solving transformation geometry problems. The sample in this study was drawn from Grade XII students of one vocational high school in Sumedang Regency, selected based on varying levels of spatial ability. The results of this research are expected to provide valuable insights for the development of effective, spatially-oriented instructional strategies to improve students' understanding of transformation geometry. The main objective of this study is to explore how students with different levels of spatial ability perform in solving problems related to geometric transformations. The study also aims to identify common difficulties and propose instructional improvements. By doing so, it contributes to the enhancement of geometry learning that is aligned with cognitive development and professional preparation. High school students' spatial ability also correlates with creativity in geometry, suggesting that fostering spatial skills can lead to more innovative mathematical thinking (Guzel & Sener, 2009). Furthermore, systematic reviews of geometry education at secondary levels reinforce the need for such integrations to address ongoing trends and gaps in curriculum design (Sunzuma, 2023)

RESEARCH METHODS

This research employed a qualitative approach with a descriptive design to explore the mathematical spatial abilities of vocational school students. The study was conducted at a vocational high school (SMK) located in Sumedang Regency, West Java, Indonesia, during the second semester of the 2024/2025 academic year. The population of this study consisted of all Grade XII students in the Machining Engineering Program (TPM) at one

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Email: yusfita@unsap.ac.id

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vocational high school in Sumedang Regency. From this population, 24 students were selected as the research sample using purposive sampling, considering class representativeness and teacher recommendations. Furthermore, three students were purposively chosen as key informants to represent different levels of spatial ability: one with high, one with medium, and one with low ability. The determination of these three informants was based on the results of a preliminary spatial ability test combined with teacher input, ensuring that each ability level was adequately represented.

The material studied in this research focused on geometric transformation, specifically covering mental rotation, spatial orientation, and spatial visualization. The research instrument was a spatial ability test in the form of three essay-type questions developed to reflect indicators from (Lowrie, 2016), are summarized in Table 1.

Table 1. Indicators of Mathematical Spatial Ability

	Spatial Visualization	Mental Rotation	Spatial Orientation
Indicators	Students understand the principle of transformation, which demonstrates being able to transform or manipulate objects, both before and after being transformed correctly	Students are able to rotate objects vertically, horizontally, as a whole or objects correctly without drawing or as a component of the object0°	Students understand the influence of the transformation orientation given. This is characterized by being able to determine the position of the object precisely

Each question was designed to assess one specific indicator. The test items were validated by an expert in mathematics education (a university lecturer) and a practicing teacher through expert judgment and a limited trial run at the school. Revisions were made based on feedback to ensure clarity, relevance, and appropriateness for the students' level. Data collection was carried out through written test responses, semi-structured interviews with selected students, and a documentation study (e.g., students' written answers and field notes). The interview protocol was designed to explore students' reasoning, strategies, and difficulties related to each indicator.

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The primary method of data analysis employed in this study was qualitative content analysis, implemented through three stages based on the model developed by Miles and Huberman (Rijali, 2019). The first stage, data reduction, involved selecting, simplifying, and organizing information relevant to spatial ability indicators, allowing the researcher to focus on essential data for deeper analysis. The second stage, data display, involved arranging the categorized data into descriptive narratives and tables to reveal emerging patterns and meaningful trends. The final stage, conclusion drawing and verification, consisted of analyzing the findings to determine students' spatial ability levels, while also ensuring the accuracy and reliability of the interpretations. To support the interpretation of test results, a scoring rubric adapted from (Mahfuddin & Caswita, 2021) was used to classify students' spatial abilities into three levels.

Table 2. Assessment criteria for the mathematical spatial ability test

It	Score Range	Criterion
1	$75 \leq skor \leq 100$	Tall
2	$60 \leq skor < 75$	Keep
3	$0 \leq skor < 60$	Low

The triangulation method was applied to ensure data validity, combining test results, interviews, and documentation. Member checking was used during interviews to confirm the accuracy of students' statements. The operational stages of the research included: (1) designing and validating instruments, (2) administering tests, (3) conducting interviews, and (4) analyzing and interpreting the results. Figures and tables illustrating sample test items and student responses are included in the Results section and are followed by analytical discussions to clarify the meaning and implications of students' performance on each spatial indicator.

RESULT AND DISCUSSION

The mathematical spatial ability test results from 24 vocational high school students were classified into three levels high, medium, and low based on assessment criteria. This classification aimed to provide a detailed analysis of student abilities in

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Email: yusfita@unsap.ac.id

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solving geometric transformation problems. Table 3 presents the distribution of students according to the scoring criteria.

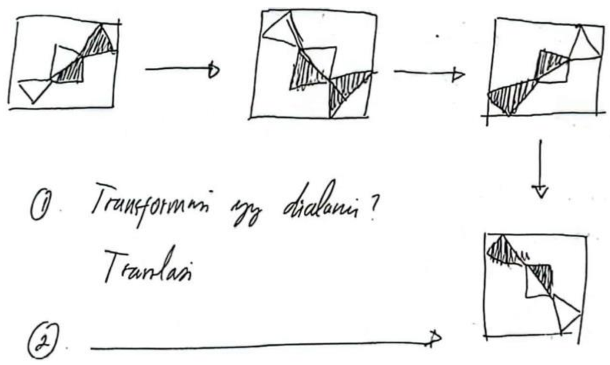
Table 3. Criteria for the assessment of the results of the mathematical spatial ability test

Criterion	Score Range	Number of Students
Tall	$75 \leq skor \leq 100$	7
Keep	$60 \leq skor < 75$	11
Low	$0 \leq skor < 60$	6

From this classification, one representative student from each ability level was selected for in-depth analysis: Student 1 (S1 - high), Student 2 (S2 - medium), and Student 3 (S3 - low). The analysis below presents their performance and responses related to the three spatial ability indicators.

Student 1 (S1) can solve the first indicator problem, namely mental rotation correctly. The problem of this mental rotation indicator is simple because the pattern is "the image is rotated 90° clockwise". Student 1 (S1) is able to rotate objects mentally well, but there is a slight error in determining what transformation the image undergoes, this can be seen from the results of the interview that S1 still does not know the concept of rotation. The answer sheet and the results of the S1 interview are presented in Table 4.

Table 4. Student Answer Result Sheet and S1 Interview Results Mental Rotation Indicators

<table>
<tr><th>S1 answer sheet</th><th colspan="3">Interview Results</th></tr>
<tr><td rowspan="4">
</td><td>P</td><td>:</td><td>How did you get the pattern of the image?</td></tr>
<tr><td>S1</td><td>:</td><td>I saw from the slope of the image, the first image was tilted to the right, the second image was tilted to the left, and the black color followed the slope pattern</td></tr>
<tr><td>P</td><td>:</td><td>You know what kind of transformation the change is?</td></tr>
<tr><td>S1</td><td>:</td><td>Translation, bu</td></tr>
</table>

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Based on Table 4. student 1 (S1) also answered correctly on the spatial orientation indicator. The results of this study are in line with research conducted by (Anissa et al., 2022) which stated that students with high abilities was obtained that the subject had good abilities in rotating a spatial shape and imagining the rotation of the spatial shape correctly. Student 1 (S1) is able to imagine the orientation effect of the transformation, but S1 has not been able to change the answer to the mathematical model, that what shifts up/down is the result of shadows y, and what shifts to right/left is the result of shadows x. This occurs because S1 understanding is still focused on visual spatial reasoning rather than formal mathematical reasoning. Although able to mentally rotate objects and recognize orientation changes, S1 has not yet mastered the relationship between movement direction and coordinate changes (vertical shifts affecting y, horizontal shifts affecting x) or the formal rule for rotation such as $(x,y)\rightarrow(y,-x)$ for a 90° clockwise rotation. Similar findings were reported by (Sudirman & Alghadari, 2020), which showed that students with good spatial ability can visualize transformations correctly but often struggle to translate them into accurate mathematical models. This challenge is further emphasized in studies where students' spatial intelligence in solving problems aligns with Hass’s theory, indicating difficulties in integrating visual-spatial thinking with procedural knowledge (Rohmah et al., 2021).

The answers and results of S1 interviews on spatial orientation indicators are presented in Table 5.

Table 5. Student Answer Result Sheet and S1 Interview Results Spatial Orientation Indicator

S1 answer sheet	Interview Results		
	P	:	*How did you get the answer?*
	S1	:	*I count each square from point A to point A, I count vertically up and horizontally to the right.*
	P	:	*You know what kind of transformation the change is?*
	S1	:	*Translation, ma'am, shift*

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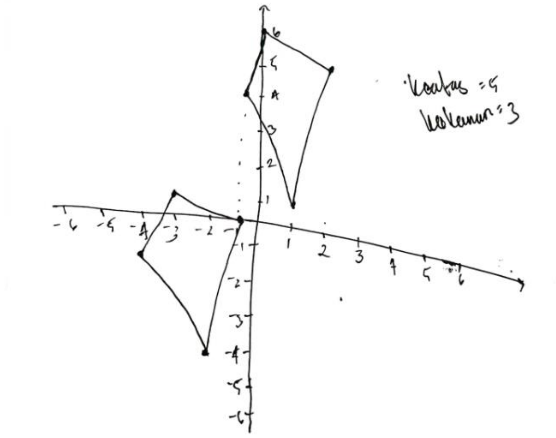

(own authorship, 2024)

Based On table 5., S1 is able to rotate objects mentally well, which is reflected in the correct answer. However, S1 has not been able to provide a solution using the concept of geometric transformation precisely, as seen from the interview. This is in line with the statement (Sholihah et al., 2019), which mentions that even though students have a good understanding, they still sometimes have difficulty providing appropriate solutions to solve problems. Such difficulties are often linked to errors in Van Hiele levels, where students fail to advance from informal deduction to rigor in geometric reasoning (Mawarsari et al., 2023).

In the third indicator, namely spatial visualization, student 1 (S1) also answered correctly. However, the student solves it in his own way. S1 is able to determine the shadow of an object after it has been transformed correctly, but it does not use a reflection formula. The answer sheet and the results of the S1 interview on the spatial visualization indicator can be seen in Table 6.

Table 6. Student Answer Result Sheet and S1 Interview Results Spatial Visualization Indicator

S1 answer sheet	Interview Results
	P : *How did you get the answer?* *S1* : *I mirror a flat build to the axis and then proceed to mirror to the axis.yx*

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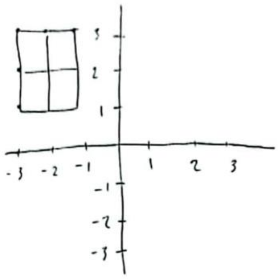	*P : How about using the concept of mirroring?* *S1 : I forgot the formula again.*

(own authorship, 2024)

Based on Tabel 6., S1 successfully mirrors objects correctly on the indicator Spatial visualization, particularly in reflecting against lines $y = x$. S1 does it by reflecting first to the axis x and then to the axis y, although it is not accompanied by the use of explicit formulas. So in other words, S1 can manipulate an object into other visual settings. This discovery is supported by research $y = xxy$ (Subakti & Listiani, 2022), which states that spatial visualization skills help students relate objects with mathematical positions and symbols resulting in logical conclusions. However, on the indicator spatial orientation, although S1 is able to understand object shifts and visualize orientation well, S1 has not been able to translate the results of its visualization into mathematical representations in the form of coordinates $x\ and\ y$. These findings are in line with the results of the study (Subakti & Listiani, 2022), which reveals that students often have trouble turning geometric visualizations into accurate mathematical representations. The overall findings show that although S1 has high mathematical spatial ability, the main challenge lies in the integration between spatial visualization ability, spatial orientation, and spatial representation in mathematical form. The main cause is the lack of habituation in connecting intuitive spatial abilities with the application of formal spatial concepts and mathematical procedures in the context of geometric transformations. This integration is crucial, as evidenced by studies showing that spatial visualization supports mathematical performance through mechanisms like transfer to symbolic representation (Lowrie & Logan, 2023). Moreover, research on the development of Android-based learning media designed to enhance spatial ability supports instructional strategies that address these gaps by utilizing interactive technology as a means to strengthen students' spatial visualization and intelligence (Fahmi et al., 2022).

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Email: yusfita@unsap.ac.id

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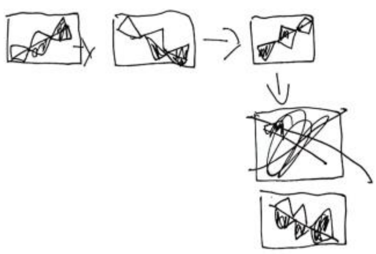
The results of the research of S2 students, who are in the category of medium spatial ability, show several errors in each indicator. Meanwhile, for student 2 (S2) in solving problems on the mental rotation indicator, the student used a strategy to observe the similarities and differences in the position of the image and the location of the shade on each object that constitutes the image. It appears that the students have difficulty in mentally changing the position of the objects in the image and recognizing changes in the arrangement of the objects in the image. This results in the resulting image being incorrect and can be seen from the shape of the upper and lower triangles. The results of the answers and the results of the S2 interview on the mental rotation indicator can be seen in Table 7.

Table 7. Student Answer Result Sheet and S2 Interview Results Mental Rotation Indicator

S2 answer sheet	Interview Results		
	P	:	*How did you get the pattern of the image?*
	S1	:	*I observed the similarities and differences in the position and location of the shade*
	P	:	*You know what kind of transformation the change is?*
	S1	:	*I don't know, ma'am.*

(own authorship, 2024)

Based on Tabel 7., student 2 (S2) also made a mistake in solving the geometric problem of the transformation of the spatial orientation indicator. S2 does not know the concept of translation, S2 only writes down the change of points or changes in the shadow one by one, but S2 already understands the axis of coordinates, so S2 writes the answer from the axis coordinates x and axis coordinates y. It can be seen from the results of the S2 interview that they do not know what transformation occurs, so they do not know the concept of translation.

The results of the answers and the results of the S2 interview on the spatial orientation indicator can be seen in Table 8.

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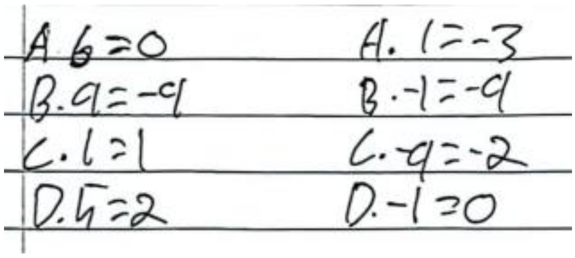
Table 8. Student Answer Result Sheet and S2 Interview Results Spatial Orientation Indicator

S2 answer sheet	Interview Results
 	*P : How did you get the answer?* *S1 : Point A changes from point 6 to point 0. And so on* *P : You know what kind of transformation the change is?* *S1 : Transformation, ma'am, because there is a change.*

(own authorship, 2024)

Based on Table 8., S2 made an error in determining the image of the rotation result. The strategy used by S2 is to observe the shading pattern, but students fail to understand the change in position due to rotation. This is in accordance with research (Trisna, et al., 2022), which found that students often had trouble distinguishing changes in the position of objects after undergoing rotation. Such errors align with Newman's error hierarchy, where comprehension and transformation errors prevail in geometry problems at van Hiele levels (Mawarsari et al., 2023).

Student 2 (S2) also made a mistake in solving the geometric problem of spatial visual indicator transformation. S2 is wrong in interpreting the axis $y = x$, so that S2's answer is wrong, then the reflection of the shaded image is also wrong, meaning that students do not understand the concept of reflection. The results of the answers and the results of the S2 interview on spatial visualization indicators can be seen in Table 9.

Table 9. Student Answer Results Sheet and S2 Interview Results Spatial Visualization Indicators

S2 answer sheet	Interview Results
	P : How did you get the answer? *S1 : I mirror a flat build to the axis.$y = x$* *P : What kind of axis?$y = x$* *S1 : Flat axis x*

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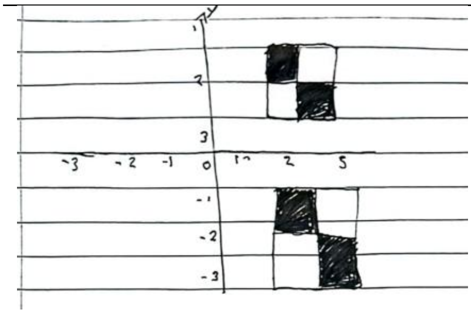

(own authorship, 2024)

Based on the table 9., S2 uses a nonspatial strategy to solve a problem of reflection on a line $y = x$. S2 does not understand the concept of lines, so the answers given are wrong. This discovery is in line with research $y = x$ (Tunnisa et al., 2018), which states that students often have difficulty determining the reflection on a particular line. Overall, these S2 students showed inconsistent performance in solving geometric transformation problems. Errors in mental rotation hinder their ability to understand the transformation of the object's position, while errors in spatial visualization lead to errors in reflection. This indicates that students in the intermediate ability category need reinforcement of basic spatial concepts, as well as further training to relate spatial strategies to formal mathematical understanding. Reinforcement could include augmented reality tools, which have been shown to improve geometry concept problem-solving through STEAM approaches by enhancing visualization (Nindiasari et al., 2024). Additionally, mobile augmented reality-based games can facilitate spatial reasoning by providing interactive visualizations, helping to address such inconsistencies (Chang et al., 2022).

Student 3 (S3) had difficulty in solving all transformation geometry problems in all I indicators. Even in the mental rotation indicator, the student does not understand the concept of rotation. The student instead made a fourth image based on the results of changing the shade from the second image. The results of the answers and the results of the S3 interview on the mental rotation indicator can be seen in Table 10.

Table 10 Student Answer Results Sheet and S3 Interview Results Mental Rotation Indicators

S3 answer sheet	Interview Results

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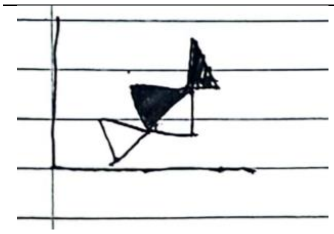
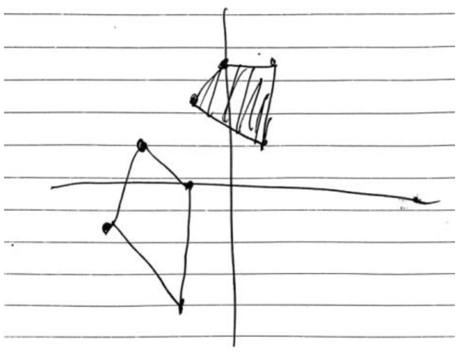
	*P : How did you get the pattern of the image?* *S1 : Looking at the pattern, so the next pattern is in the upper right.* *P : You know what kind of transformation the change is?* *S1 : I don't know, ma'am.*

(own authorship, 2024)

Based on the Table 10., S3 has not understood the basic concept of rotation or the questions on the questions. Students are unable to relate the requested changes to the concept of rotation itself. This is supported by Piaget's view (Utami, 2020), which states that a good understanding of concepts stored in long-term memory allows students to remember and apply those concepts even though time has passed. hese fundamental gaps are consistent with findings on students' spatial reasoning in geometrical transformations, where low performers struggle with basic mental manipulations (Evidiasari et al., 2019).

The results of S3 students, which are in the category of low spatial ability, show the dominant error in each indicator. Student 3 (S3) also made a mistake in solving the geometric problem of spatial orientation indicator transformation. S3 did not know the concept of translation, S3 only rewrote the question, and shaded the shadow image. The results of the answers and the results of the S3 interview on the spatial orientation indicator can be seen in Table 11.

Table 11. Student Answer Results Sheet and S3 Interview Results Spatial Orientation Indicators

S3 answer sheet	Interview Results
	*P : How did you get the answer?* *S1 : There are two flat buildings, so there are results of the change, I shade the change.* *P : You know what kind of transformation the change is?* *S1 : I don't know, ma'am.*

(own authorship, 2024)

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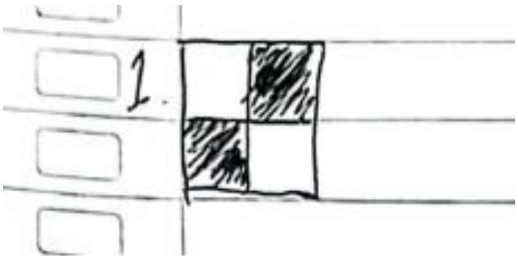
Based on the Table 11., S3 also shows very low comprehension. Students only copy the questions and shade the shadows of the images without knowing the correct steps to complete them. These findings are in line with research (Suryani et al., 2021) which states that students who do not understand concepts tend to only copy the elements of the problem without applying problem-solving strategies. This superficial approach is further illuminated by explorations of visual-spatial thinking in transformation geometry, revealing that low-ability students fail to map mental images effectively (Dwirahayu et al., 2025).

S3 also does not understand the concept of spatial visuals. The student does not understand the question given, so he just writes a flat figure without using the coordinate axis. The results of the answers and the results of the S3 interview on spatial visual indicators can be seen in Table 12.

Table 12. Student Answer Results Sheet and S3 Interview Results Spatial Visualization Indicators

S3 answer sheet	Interview Results
	*P* : *How did you get the answer?* *S1* : *By looking at the image, so that it has a different shadow* *P* : *Do you understand what is being asked?* *S1* : *No, ma'am, I forgot again*

(own authorship, 2024)

Based on Table 12, S3 again demonstrates the same pattern, namely copying the given image or rewriting information from the problem without understanding the fundamental steps of spatial visualization. This inability reflects a lack of understanding of spatial concepts in students within the low-ability category. This occurs because S3 is unable to mentally manipulate objects and fails to connect visual representations with the coordinate system, resulting in a superficial approach to completing the task. The findings of (Perangin-angin & Khayroiyah, 2021) indicate that students with low spatial ability tend to experience difficulties in spatial visualization due to their inability to construct complete

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mental images of geometric objects. This is consistent with the results of (Husni Sabil et al., 2024), who found that students with a Field Dependence (FD) cognitive style often struggle to meet indicators of spatial visualization, mental rotation, and spatial orientation, partly due to reliance on provided information, lack of self-confidence, and limited mastery of prerequisite material Furthermore, (Pradana & Sholikhah, 2023) emphasized that the aspects of visualization, spatial orientation, and mental rotation are strongly interconnected in the process of solving geometric problems; thus, a weakness in one aspect can affect performance in the others. Therefore, S3 low ability to understand and visualize spatial objects is not merely a result of insufficient practice but also stems from limitations in building connections between visual perception, mental manipulation, and the mathematical representation of those objects. These interconnections are supported by research on the impact of presentation modes on mental rotation, showing that different visual stimuli affect processing efficiency and accuracy (Stark et al., 2024). Embodied learning in augmented reality aids in learning spatial transformations and their math representations, offering potential solutions for low-ability students (Shaghaghian et al., 2022).

This study reveals that students' mathematical spatial abilities significantly influence their performance in solving transformation geometry problems. Students with high spatial ability show stronger visualization and manipulation skills but may lack formal expression. Medium level students have partial understanding, while low level students demonstrate limited comprehension across all indicators. The difficulties observed may be influenced by limited exposure to spatial based tasks and the lack of instructional strategies emphasizing spatial reasoning. These findings align with previous studies (Mananeke et al., 2017; Putra et al., 2022; Teapon et al., 2023) that highlight the importance of spatial ability in geometry learning and the challenges students face in connecting intuitive visualization to formal methods. This study highlights the critical role of spatial abilities in enhancing vocational high school students' performance in solving transformation geometry problems. The findings underscore the need for instructional strategies that integrate spatial reasoning to bridge the gap between intuitive visualization and formal mathematical representation. Dynamic geometry software, such as GeoGebra, has been shown to support students in connecting visual-spatial thinking

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with precise mathematical models, fostering deeper understanding of geometric transformations (Marasabessy & Helsa, 2024). Similarly, technology-enhanced environments, including dynamic geometry and 3D printing, demonstrate significant potential for facilitating far transfer to broader mathematical skills, enhancing students' ability to apply spatial reasoning across various contexts (Gilligan et al., 2020; Ng et al., 2020). Projective geometry further provides innovative avenues for developing spatial reasoning, particularly in STEM learning, by encouraging students to explore complex spatial relationships (Thom et al., 2024). Bibliometric analyses indicate a growing research focus on spatial ability within mathematics education, reflecting its increasing recognition as a vital component of geometric learning (Teapon et al., 2023). Additionally, cooperative learning models, such as the STAD approach, have proven effective in improving Grade 12 students' comprehension of geometric transformations by promoting collaborative problem-solving and conceptual clarity (Mukuka & Tatira, 2024). Comprehensive reviews offer valuable roadmaps for integrating spatial ability into mathematics education, emphasizing the need for curricula that prioritize spatial reasoning to enhance mathematical literacy (Schenck & Nathan, 2024). The use of spatial visualization tools is also critical for fostering mathematical success, as they help students translate visual insights into formal representations (Medina Herrera et al., 2024). Moreover, spatial ability and geometric thinking are essential for teacher training, as educators with strong spatial skills can better guide students in mastering complex geometric concepts (Pavlovičová et al., 2022). Correlation studies further confirm that spatial ability is closely linked to learning achievement in transformation geometry, highlighting its importance in both academic and professional contexts (Rumanov, 2024). The relationship between spatial and geometric reasoning in teachers also underscores the need for targeted professional development to equip educators with the skills to foster students' spatial competencies (Pradana & Sholikhah, 2023). In conclusion, this study wreinforces the pivotal role of spatial abilities in students' success with transformation geometry and advocates for the integration of spatially-oriented instructional strategies and tools into the curriculum to enhance mathematical literacy and problem-solving skills.

CONCLUSION

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This study concludes that vocational high school students' mathematical spatial abilities in solving geometric transformation problems vary significantly across ability levels and indicators. Students with high spatial ability demonstrated proficiency in mental rotation and spatial visualization, although they still experienced difficulty translating visual reasoning into formal mathematical representations such as coordinates. Students with moderate spatial ability displayed inconsistent understanding, often relying on superficial visual cues without fully grasping transformation concepts, especially rotation and reflection. Meanwhile, students with low spatial ability struggled with all indicators, indicating a fundamental lack of comprehension of spatial and geometric transformation principles. These findings highlight that students' spatial reasoning gaps are primarily due to limited mastery of basic geometric concepts and insufficient exposure to spatial based learning. Therefore, the study emphasizes the need for interactive and spatial oriented instructional strategies to enhance students' spatial understanding. Reinforcing foundational geometric concepts through appropriate pedagogical tools is essential for developing the spatial competencies required in academic and professional contexts.

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