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Analyzing Cognitive Styles and Spatial Abilities in Geometry Transformations through the Problem-Based Learning Approach

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Abstract: Analyzing Cognitive Styles and Spatial Ability in Geometry Transformations Learning through PBL Approach. Objective: This study aims to investigate the spatial abilities of grade IX junior high school students using the Problem- Based Learning (PBL) approach, considering their cognitive styles: Field Independent (FI) and Field Dependent (FD). **Methods:** Using a descriptive qualitative approach, six students were selected based on their cognitive styles and spatial ability. Data were collected through spatial ability tests, interviews, and classroom observations. **Findings:** The findings highlight notable differences in spatial abilities between FI and FD students. FI students displayed strengths in spatial visualization, perception, and orientation, excelling in tasks that required analytical problem-solving and independent work. However, they faced challenges in mental rotation and proportional scaling during dilation, often struggling with complex transformations due to limited exposure and insufficient time management. FD students performed better in structured tasks, particularly spatial perception and orientation, benefiting from guided instructions and peer support. Nevertheless, FD students encountered significant difficulties in mental rotation and spatial relations, particularly in tasks requiring independent conceptual understanding. Group dynamics played a crucial role in the effectiveness of PBL. Balanced groups, consisting of both cognitive styles, fostered collaboration and improved learning outcomes. In contrast, homogeneous or imbalanced groups often resulted in reduced engagement and lower performance.**Conclusion:** This study underscores the necessity of adapting PBL strategies to align with the distinct needs of cognitive styles. FI students thrive with opportunities for independent exploration and structured individual feedback, while FD students require collaborative, guided discussions and supportive group settings. By integrating differentiated instructional strategies, educators can optimize spatial ability development and ensure equitable learning opportunities for all students. These insights provide a framework for enhancing geometry education through targeted, inclusive approaches.

Keywords: fcognitive styles, field dependent, field independent, problem-based learning, spatial ability.

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INTRODUCTION

Spatial ability is an important aspect of mathematics learning, especially in understanding concepts involving position, shape, and relationships between objects in space. This ability has a positive correlation with mathematics learning achievement (Tambunan, 2006). In the context of geometry, spatial abilities allow students to imagine, manipulate, and understand the shape and orientation of an object from a variety of perspectives. This ability is essential in studying geometric transformations, such as reflection, rotation, translation, and dilation, which require good visualization and spatial orientation skills.

Lohman (1996) defines spatial ability as the ability to generate, maintain, remember, and transform a well-structured visual image. As can be understood from the definition, spatial ability is a complex structure that embodies many skills at the same time. There are different classifications regarding the components of spatial abilities in literature (Yýldýzhan & Ertekin, 2024).

According to Maier (1994) in (Subroto, 2012), spatial ability consists of five important dimensions, namely the perceptual, visual, rotational, relative, and orientation dimensions, all of which support the understanding of geometric concepts and play a role in different mental processes in understanding spatial objects visually and cognitively.

Since 2000, research on spatial abilities in education has increased, mainly due to its relevance in STEM (Science, Technology, Engineering, and Mathematics) fields as well as medical and technological education (Yýldýzhan & Ertekin, 2024). Spatial skills help students understand abstract concepts and apply logical reasoning in problem-solving (Bufasi et al., 2023).

Previous research concluded that students' spatial abilities, particularly in visualization and mental rotation, need to be improved to support the understanding of geometry (Khofifah et al., 2022). In addition, there is a significant influence between spatial ability and student learning outcomes, especially in three-dimensional lessons (Inuhan & Rupilele, 2022).

The results of the spatial skills analysis of grade IX junior high school students based on Peter Hubert Maier's theory found that the general spatial skills of students were quite weak. The majority of students are more able to explain in more detail their answers to the visualization element, while in other elements students are less able to explain it well (Teapon & Kusumah, 2023). Spatial ability is influenced by various factors, including innate factors such as inherited genetic differences, environmental factors such as a lack of experience in three-dimensional thinking that can hinder its development, and psychological factors, such as low learning motivation and fatigue, which also negatively affect spatial ability (Rahman et al., 2022).

Geometry and spatial ability are two interrelated components because this lesson requires the ability of students to visualize certain objects. In the process of learning geometry topics, spatial visualization is an important component that must be utilized. This means that spatial thinking skills are a crucial element that should be integrated into the educational curriculum (Febrianti et al., 2024).

Spatial skills are very important for students in learning geometry, because they relate to aspects such as colors, lines, shapes, spaces, as well as the relationships in between, including the skills of visualizing, drawing, and describing spatial arrangements accurately (Rizqa et al., 2024). By studying geometry, students can connect abstract mathematical concepts with concrete concepts, making it easier to understand more deeply. However, in reality, geometry is still difficult for most students to master, and geometric transformations are often considered one of the most difficult to understand (Zanthy & Maulani, 2020).

The results of Zanthy and Maulani's (2020) research show that the most errors occur in dilation materials, with only 10% of students able to answer correctly. Meanwhile, the least mistakes occurred in translation, where 40% of students answered correctly (Zanthy & Maulani, 2020).

Another study shows that grade XI students of State Vocational Schools in Cimahi City experience many mistakes in solving geometric transformation problems. The average percentage of correct answers was only 3%, which means that only 1 in 32 students managed to answer correctly, while most students had difficulty doing the questions (Maulani & Setiawan, 2021).

At the junior high level, geometry transformation lesson is one of the important topics that challenge students. Grade IX students who have strong spatial abilities tend to understand the change in shape and orientation of objects in geometric transformation. However, not all students have the same spatial abilities. Several studies have shown that differences in cognitive styles, especially field independent (FI) and field dependent (FD), play an important role in influencing students' spatial abilities.

Messick (1982) defined cognitive style as an individual's consistent pattern of thinking in processing and organizing information. Cognitive styles include individual preferences in how they manage attention, solve problems, and interact with information and the environment (Messick, 1982). Cognitive style is not just intellectual ability or intelligence, but rather the way a person likes to use those abilities (Sternberg & Grigorenko, 1997).

Witkin et al. (1977) developed the concepts of Field-Dependent (FD) and Field- Independent (FI) as two different cognitive styles, which are used to understand how individuals interact with information and the environment. Individuals with the FD style tend to see things as a whole, are more dependent on the context of the environment, are sensitive to social cues, and are easily influenced by others. In contrast, individuals with the FI style are more analytical, able to separate details from the setting or context, independent in thinking, less influenced by the social environment, and more focused on tasks (Witkin et al., 1977). To identify these cognitive styles, Witkin et al. developed the Embedded Figures Test (EFT) which was later refined into the Group Embedded Figure Test (GEFT), a more efficient tool for group administration (Mykytyn, 1989).

In a previous study on spatial ability reviewed from the cognitive style of FI and FD using realistic mathematics learning, results were obtained that showed that students with a field-independent cognitive style had high spatial abilities compared to students with a field-dependent cognitive style (Sinurat & Fauzi, 2022).

Ibrahim and Nur stated that Problem-Based Learning or PBL is one of the learning approaches used to stimulate students' higher-level thinking in situations oriented to real-world problems, including learning how to learn (Rusman, 2012).

PBL has proven to be effective in improving student learning outcomes, The implementation of the Augmented Reality-assisted PBL learning model significantly improves students' spatial abilities compared to the direct learning method. This model provides a more realistic and contextual learning experience, thereby improving students' spatial visualization skills (Nurwijaya, 2022).

However, research that specifically analyzes the effectiveness of PBL in developing students' spatial abilities by considering the differences in the cognitive styles of FI and FD using geometric transformation materials is still very limited. Therefore, this study aims to analyze the spatial ability of grade IX students on geometric transformation materials through problem-based learning (PBL), taking into account the cognitive styles of Field independent (FI) and Field dependent (FD).

■ METHOD

This study employs a descriptive qualitative approach to analyze students' spatial abilities in relation to their cognitive styles, namely Field Independent (FI) and Field Dependent (FD), during the implementation of Problem-Based Learning (PBL). The study explores how these cognitive styles influence students' performance on spatial indicators and provides a deeper understanding of the unique characteristics and challenges faced by FI and FD students within a PBL-based learning environment.

Participants

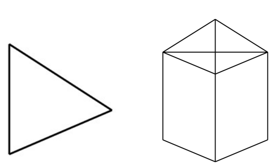
This study involved six ninth-grade students from class IX A at Kartika XIX-2 Junior High School, Bandung, selected from a total of 34 students. Using purposive sampling, the participants were categorized into Field Independent (FI) and Field Dependent (FD) cognitive styles, with each group stratified into high, medium, and low spatial ability levels based on the Group Embedded Figures Test (GEFT) and spatial ability assessments. The selected participants were: S-FI1: FI, medium spatial ability, S-FI2: FI, low spatial ability, and S-FI3: FI, high spatial ability. S-FD1: FD, medium spatial ability, and S-FD2: FD, low spatial ability. No FD students with high spatial ability were identified in this study. This sample facilitated an in-depth analysis of the interplay between cognitive styles and spatial abilities within the Problem-Based Learning (PBL) framework.

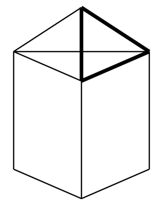
Instruments

Group Embedded Figures Test (GEFT)

GEFT was a test tool developed by Witkin et al. as an enhancement of the Embedded Figures Test (EFT) (Mykytyn, 1989). GEFT was used to identify the cognitive styles of FD and FI, consists of 25 items divided into three sections. The first section serves as a practice, while the other two sections are scored. Each correct answer is awarded one point, with a maximum score of 25, and the total time allocated is 20 minutes. Higher scores indicate a tendency towards Field Independence, while lower scores suggest Field Dependence. Example Question for GEFT: The image below shows a simple triangle shape named 'X'. This shape, 'X', is hidden within a more complex image beside it.

Try to find the simple shape "X" in the complex image and trace it using a pencil. The shape you find must have the same size, proportion, and orientation as the simple shape "X."





Spatial Ability Test

The spatial ability test consisted of 5 questions based on the five spatial ability elements defined by Maier (Subroto, 2012): spatial visualization, spatial perception, spatial orientation, mental rotation, and spatial relations. These questions were contextualized within geometric transformation materials. Each question assessed specific indicators and was equally weighted in scoring. The indicators of elements are listed in the table 1 and the test of spatial ability in figure 1.

Interviews

Semi-structured interviews were conducted to explore students' experiences in answering geometric transformation problems, learning in groups, and the alignment of their cognitive styles with the PBL approach. These questions aimed to understand their problem-solving processes, interactions within groups, and how well the PBL method supported their learning preferences.

Classroom Observations

Observations were carried out to document group interactions, problem-solving strategies, and levels of engagement during PBL sessions. These observations complemented data from tests and interviews

Research Design and Procedures

The research procedures began with administering the GEFT (Group Embedded Figures Test) to all students in class IX A to categorize them into Field Independent (FI) and Field Dependent (FD) groups. Following this, spatial ability tests were conducted, and students' scores were used to classify them into high,

Table 1. Indicators of elements

Element	Indicator
(a) Spatial visualization	Students can determine and imagine the result of a shape's translation without detailed coordinate calculations.
(b) Spatial perception	Students can construct the result of a shape's translation on a coordinate plane based on a specific direction and distance.
(c) Spatial orientation	Students can understand the exact position of objects after reflection over an axis or a specific line.
(d) Mental rotation	Students can determine the result of an image rotation, including the coordinates of its vertices.
(e) Spatial relation	Students can express proportional relationships between elements of a shape after dilation, such as enlarging shapes with a scale factor and analyzing the transformed image relationship.

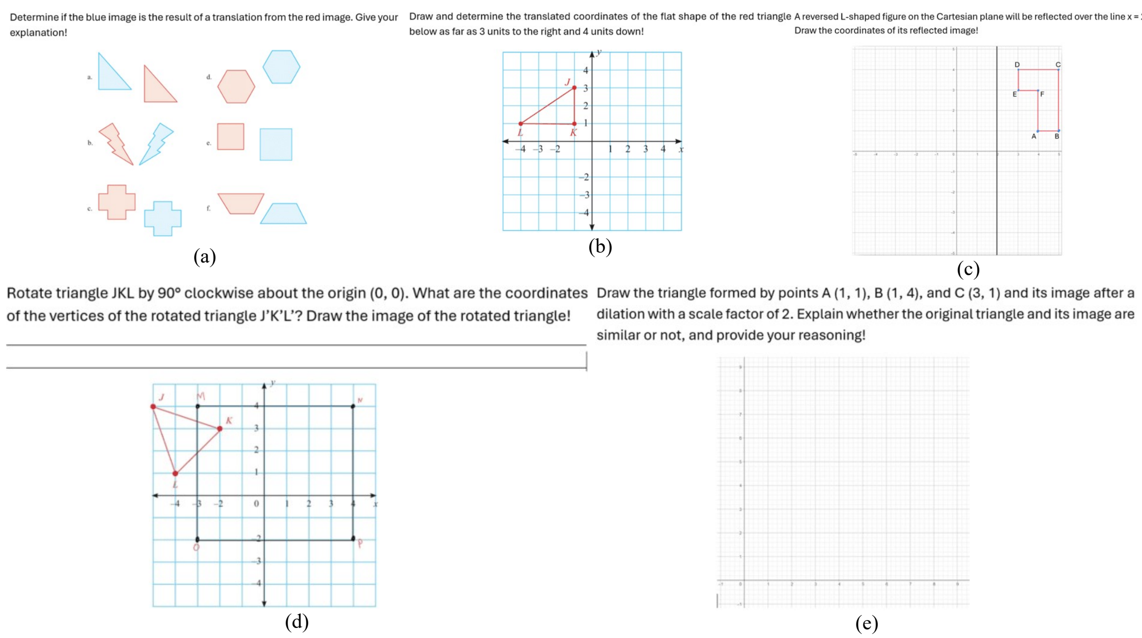


Figure 1. Spatial ability test

medium, or low levels of spatial ability. The students then participated in Problem-Based Learning (PBL) sessions centered on geometric transformations over a two-week period. During this time, data were collected through spatial ability tests, interviews, and classroom observations.

Data Analysis

Data collected from the GEFT test, spatial ability test, interviews, and observations were analyzed using a qualitative approach. Triangulation of data from various sources was conducted alongside the analysis to ensure the validity and reliability of the findings. The data were reduced by selecting relevant information and categorizing it into key themes related to spatial abilities and cognitive styles. The reduced data were then organized into tables and narratives to identify patterns and relationships. Finally, conclusions were drawn by analyzing the patterns, cross-verifying findings through

Figure 2. Learning process using PBL

triangulation across multiple sources and methods, and refining the results to ensure alignment with the research context. This process provided a reliable basis for understanding the relationship between cognitive styles (FI and FD) and spatial abilities in the context of Problem-Based Learning (PBL).

■ RESULT AND DISCUSSION

The GEFT test given to 34 students was carried out at the beginning of learning to determine the cognitive style of each student. After the GEFT test, students are taught Geometric Transformation material using the PBL method for 2 weeks. In PBL learning, students are required to create groups with 5 to 6 students each. At the end of the lesson, students were given questions about geometric transformation material by referring to spatial ability indicators. From the results of the students' answers, 5 students with extreme cognitive styles FI and FD were taken. These 5 students also represent the results of high, medium and low spatial ability.

Table 2. GEFT and spatial ability tes result

Student Initials	Cognitive Style	Spatial Abilities	Element Of Spatial Abilities				
			Spatial Visualization	Spatial Perception	Spatial Orientation	Mental Rotation	Spatial Relations
S-FI1	FI	Medium	ü	ü	ü		
S-FI2	FI	Low	ü				
S-FI3	FI	High	ü	ü	ü	ü	ü
S-FD1	FD	Medium		ü	ü		
S-FD2	FD	Low					

From the students' answers, no FD students with high spatial ability were found, so the researcher only took data from FD students with medium and low spatial ability.

Field Independent Cognitive Style

S-FI1's spatial ability

S-FI1 demonstrates a good understanding of spatial visualization, as shown by her ability to recognize that translation moves objects without changing their shape or size, effectively distinguishing different types of transformations. Her spatial orientation is also commendable, as she understands the concept of reflection and can imagine how an object changes orientation while maintaining equal distances from the mirror line. However, S-FI1 faces challenges in mental rotation, admitting difficulty in understanding the

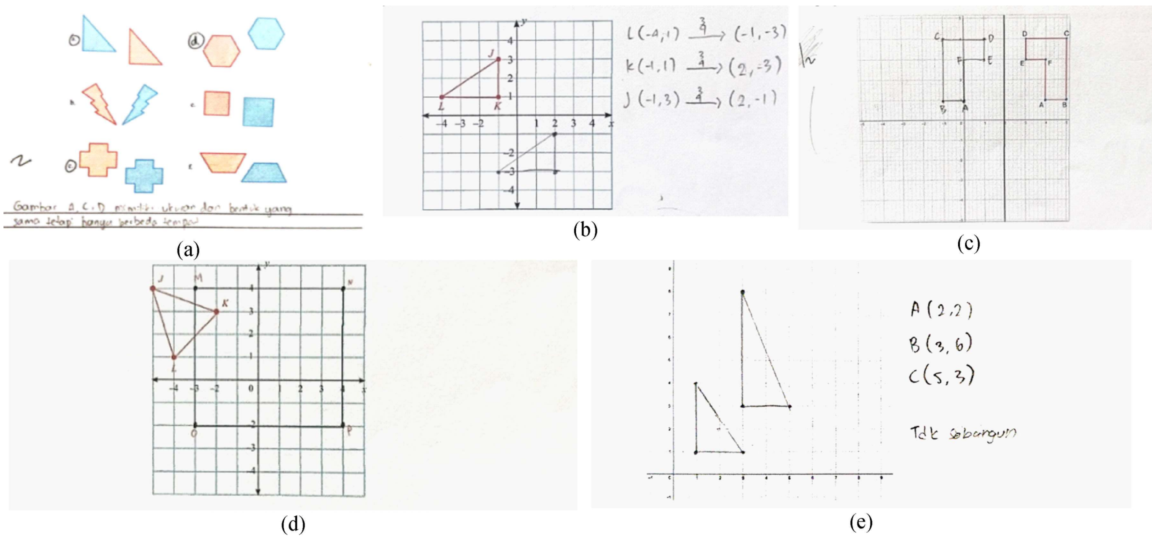


Figure 3. Spatial ability test S-FI1

concept and visualizing the form of an object after rotation, indicating a need for more practice with complex rotational tasks. In terms of spatial relations, S-FI1 struggles with the concept of dilation, particularly in determining the correct scale, which leads to inaccuracies in maintaining proportional changes between points. Lastly, her spatial perception is strong, as she understands how to move each point of an object accurately according to the translation formula, demonstrating clarity in perceiving direction and distance.

S-FI1's PBL learning experience

S-FI1 : "*Most of the time, I end up doing it by myself. Sometimes the group members aren't very active, so I feel it's easier to work on my own*."

S-FI1 feels that PBL doesn't help her much, especially since she often does his own assignments in groups. She usually acts as the facilitator of the discussion, but this role depends on the group members. Group discussions in PBL are rare, which according to her is not very helpful in understanding the material of geometric transformations. S-FI1 feels more comfortable if they can work independently or in a small group effectively.

As a student with a Field Independent (FI) cognitive style, S-FI1 prefers to study on their own, especially if there are many tasks to complete. However, in some situations, she will ask his group mate if he experiences confusion, then try to solve it on his own. FI's cognitive style makes her more comfortable working independently and relying on her own understanding before asking for help.

S-FI2's spatial ability

S-FI2 demonstrates some ability in spatial visualization, as she can recognize the correct image resulting from a shift, but she is unable to explain the reasoning behind her answer, indicating a limited understanding problems related to definition of translation. In terms of spatial perception, S-FI2 struggles to understand tasks requiring the transfer of points during translation, particularly the direction and position of displacement. Her spatial orientation also shows weaknesses, as she fails to grasp the concept of changing an object's orientation with respect to the mirror line in reflection problems. Similarly, S-FI2 faces significant challenges in mental rotation, unable to imagine changes in the orientation of objects after rotation around a central point. Lastly, S-FI2 encounters difficulties

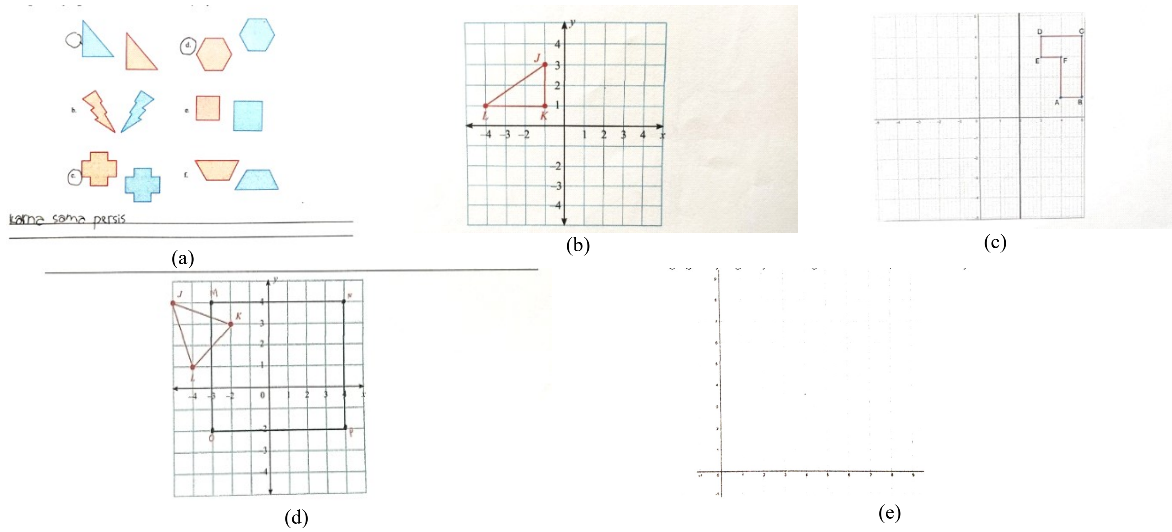


Figure 4. Spatial ability test S-FI2

in spatial relations, particularly with dilation tasks, where she struggles to comprehend the proportional changes between points after a scale transformation, highlighting limitations in her understanding of size and proportion changes.

S-FI2's PBL learning experience

S-FI2 : " *learning in a group with PBL didn't help much, Sir. I still felt confused about the material, and my group mates didn't discuss much, so I didn't get a clear explanation*."

S-FI2 felt that studying in the PBL group did not significantly help her understand the material. She considers the method to be unremarkable and finds the presentations in PBL to make her nervous. While learning geometry in a group, she prefers to work independently but will listen to discussions if invited to join. S-FI2 mentioned that her group rarely engaged in discussions, leading her to feel that the assistance provided was not optimal. However, she believes that peer explanations can be beneficial if group members are willing to help clarify the material.

S-FI2 prefers to study with friends only if they are willing to assist in explaining the material. If not, she opts to study alone. When facing challenges, S-FI2 typically attempts to resolve them independently, as she is concerned about burdening her peers. Her inclination toward self-study, coupled with selective reliance on peer assistance, reflects a characteristic of FI's cognitive style. This suggests that S-FI2 is more comfortable working independently and only seeks help when absolutely necessary.

S-FI3's spatial ability

S-FI3 demonstrates strong spatial visualization skills, as evidenced by his understanding that translation moves an object to a new position without changing its shape or size. His spatial perception is equally commendable, as he accurately moves each point in the correct direction and distance before connecting them, showing a clear grasp of the fundamentals of translation. In terms of spatial orientation, S-FI3 understands the concept of reflection well, recognizing that objects are "inverted" against the mirror line and accurately calculating the relative distances of points from the line. While S-FI3 faced challenges in solving mental rotation problems during the test, this was due to time constraints rather than a lack of conceptual understanding, as he was able to provide the correct answers during the interview.

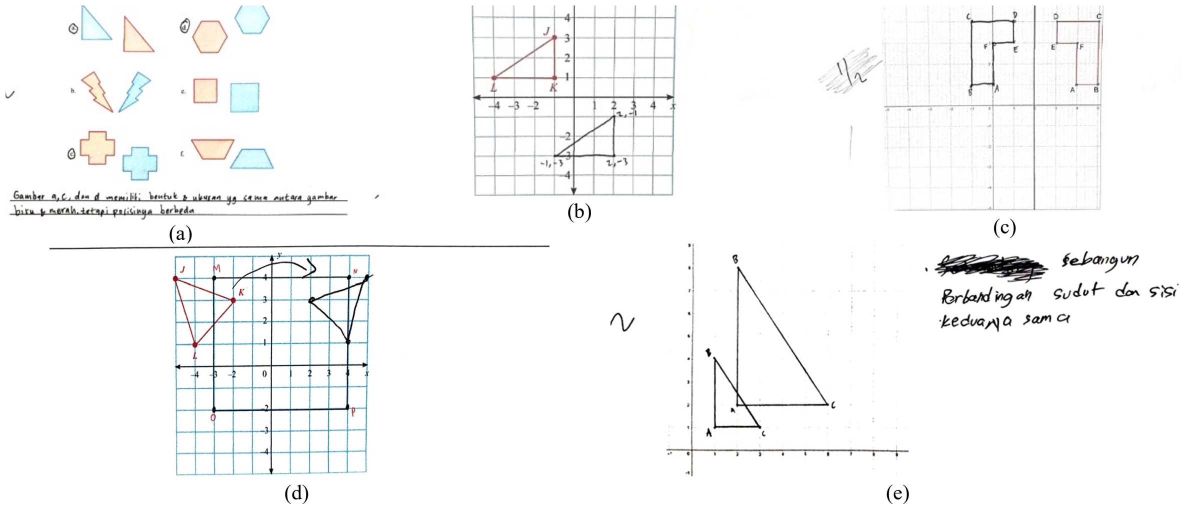


Figure 5. Spatial ability Test S-FI3

Lastly, S-FI3 exhibits a solid understanding of spatial relations, particularly in dilation, by correctly applying the scale factor to adjust the size of objects while maintaining their shape. This demonstrates his ability to comprehend proportional changes and maintain structural integrity during transformations.

S-FI3's PBL learning experience

S-FI3 : "*learning with PBL is helpful, Sir, but it really depends on the group. If my group mates are active and willing to collaborate, the discussions are engaging, and it's easier to understand. But if someone doesn't want to join the discussion, it feels better to work alone.*"

S-FI3 feels that studying in a group with the PBL method can help if the group members support each other, but often he feels more comfortable working alone. In a group, S-FI3 usually works independently, although sometimes he will ask if he encounters difficulties. According to him, group discussions are useful, but he feels more free to study independently.

S-FI3 prefers to study alone because it feels easier and more flexible in understanding the material without depending on the group. If he has difficulties, he prefers to find his own answers first and will only ask for help from friends if he really needs clarification.

Field Dependent Cognitive Style

S-FD1's spatial ability

S-FD1 demonstrates a good understanding of spatial visualization in recognizing that translation moves objects without altering their shape or size. However, she mistakenly identifies one of the shapes as a translation, revealing difficulty in perceiving size differences and limitations in deeply visualizing transformations. In terms of spatial perception, S-FD1 performs well by accurately moving and connecting points during translation, showcasing a clear understanding of direction and displacement. Her spatial orientation is also strong, as evidenced by her ability to describe reflection as maintaining a "face-to-face" relationship, correctly identifying the relative positions of objects after reflection. Despite these strengths, S-FD1 struggles with mental rotation, making errors in determining the direction and position of points after rotation, indicating difficulty in handling complex rotational tasks. Lastly, while she accurately calculates the coordinates of points during dilation, S-FD1 faces

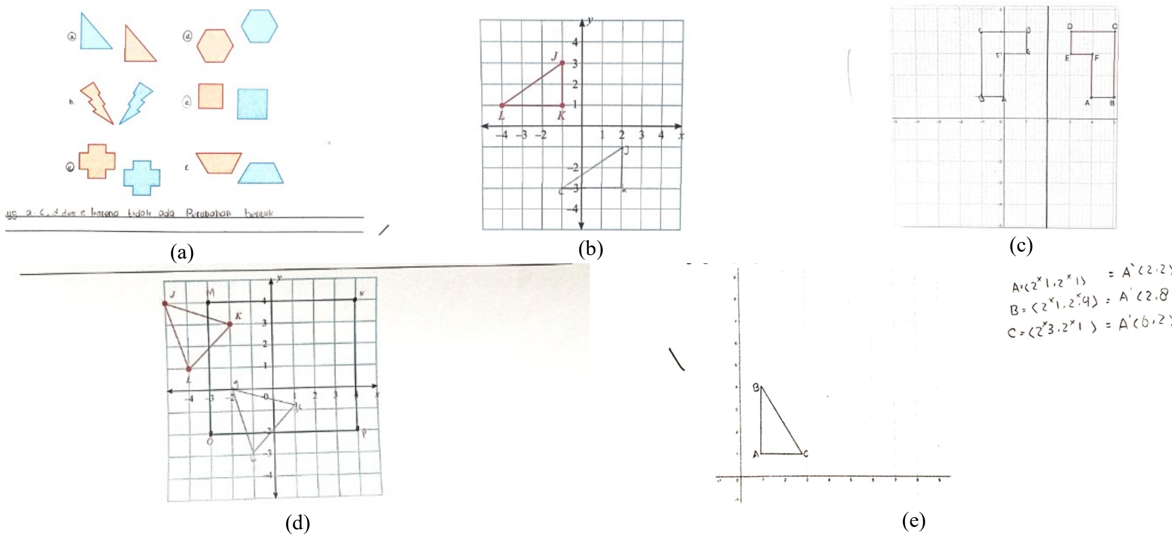


Figure 6. Spatial ability test S-FD1

challenges in grasping the proportional relationships and the overall concept of dilation, highlighting weaknesses in spatial relations.

S-FD1's PBL learning experience

S-FD1: "*learning in a group with PBL is helpful, Sir, because if I'm confused, I can immediately ask my group mates. But if the group has too many people, it sometimes becomes less effective*."

S-FD1 felt that the PBL method helped her understanding because it allowed her to ask questions to her friends in the group. This method facilitates understanding through cooperation in groups. In the group, S-FD1 felt helped when her friends' explained concepts that she did not understand. However, she prefers to study in small groups because she feels that groups that are too large tend to be ineffective. S-FD1 tends to follow group discussions without taking a dominant role, which indicates FD's learning style of preferring to learn through the help of others in a social context.

S-FD1 prefers to study in groups because she finds it easier to understand the material when she can ask questions directly to friends. When faced with difficulties, she tends to ask friends for help rather than trying to solve them on his own first. This preference is consistent with FD's cognitive style which relies more on external sources in understanding new concepts.

S-FD2's spatial ability

S-FD2 demonstrates a basic level of spatial visualization, as she can identify shifts in three flat planes but mistakenly classifies one plane as a shift and struggles to explain her reasoning. This indicates her ability to recognize position changes without altering shapes but highlights difficulty in visualizing transformations involving size differences. In terms of spatial perception, S-FD2 faces significant challenges, as she is unable to understand the direction and position of point displacement during translation. Similarly, her spatial orientation is limited, as she incorrectly assumes objects need to be moved before reflection, indicating a lack of understanding of how an object's position changes after reflection. Mental rotation poses a significant obstacle for S-FD2, as she admits to guessing answers and is unable to comprehend the degree of rotation, reflecting a difficulty in imagining the orientation of objects after rotation. Lastly, her spatial

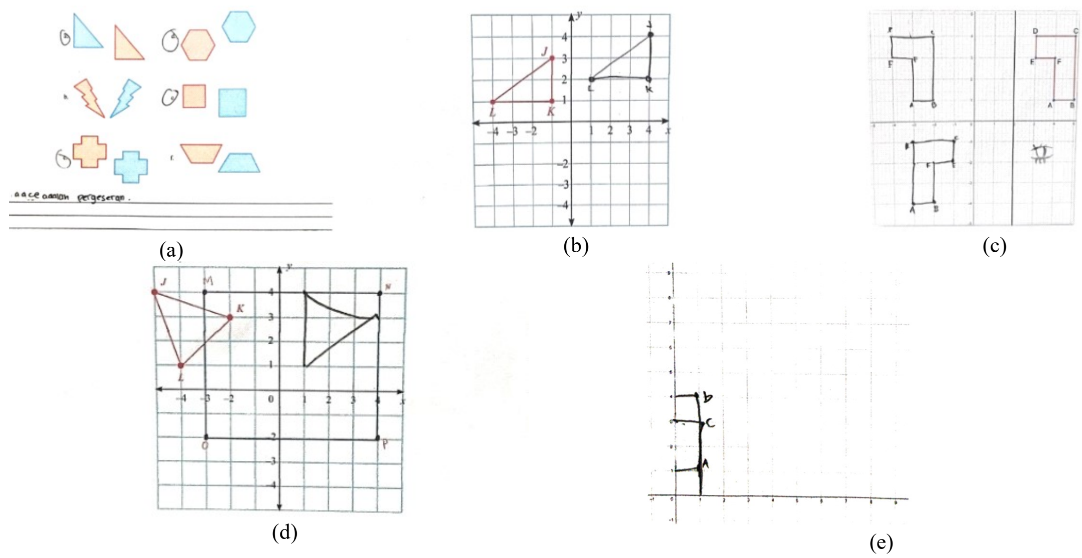


Figure 7. Spatial ability test S-FD2

relations are also weak, as evidenced by errors in reading coordinates and an inability to perform dilation tasks correctly, particularly in applying scale factors and understanding proportional changes in object sizes.

S-FD2's PBL learning experience

S-FD2 **:** "*Learning in a group with PBL is helpful, Sir, because we can discuss and help each other. Sometimes it's even more enjoyable because we work on it together as a team.*"

S-FD2 finds studying in PBL groups quite helpful and more fun than studying alone, especially because she can get input from friends during discussions. However, when studying in a certain group, although the discussion is helpful, she often feels confused by the discussions of her friends, which makes it difficult to understand more deeply. She felt that group discussions helped reduce the worry of making mistakes, which was consistent with FD's cognitive style of tending to feel more comfortable in a social learning environment.

S-FD2 prefers to learn by discussing with friends because she feels more helped by social interaction in the group. When experiencing difficulties, S-FD2 prefers to find answers on their own if they feel that the problem is simple but will ask friends if they experience greater difficulties. This choice reflects FD's cognitive style of tending to rely on the help of others to understand more complex material and is more comfortable learning collaboratively.

Effectiveness of PBL

Previous studies have stated that PBL is proven effective in developing secondary school students' understanding of geometric concepts by integrating theoretical and practical elements. This approach also significantly improves students' spatial abilities (Tanjung et al., 2021). In the context of cognitive styles, FI students benefit from their analytical nature in addressing the challenges offered by PBL, while FD students gain advantages from the social support provided through group work and discussions. Therefore, PBL is effective for both cognitive styles when implemented with an appropriate approach.

During classroom observations, it was noted that FI students tend to achieve better spatial abilities when grouped together. Their ability to analyze problems effectively, even with minimal social interaction, allows them to focus on solving tasks independently within the group. In contrast, FD students who worked in groups composed solely of their peers produced lower outcomes. Their tendency to rely heavily on each other led to difficulty in analyzing problems, resulting in less effective solutions. This highlights the importance of balanced group composition in PBL to maximize the strengths of both cognitive styles.

Students with a FI cognitive style tend to have higher spatial abilities compared to those with a FD cognitive style (Sinurat & Fauzi, 2022). However, previous studies often employed a realistic mathematics learning approach that did not emphasize group dynamics an essential factor considering the differing learning tendencies of FI and FD students. This study, using a PBL approach, revealed slightly different results, indicating that students' spatial abilities varied more depending on the context of group learning.

Group dynamics in PBL play a crucial role in supporting learning. Balanced groups consisting of both FI and FD students create mutually beneficial collaboration. However, FI-dominated groups may leave FD students feeling marginalized, while small groups are more effective in maintaining focused discussions compared to larger ones. FD students, who rely heavily on peer support, may struggle when group members are inactive or disengaged. Conversely, FI students may become frustrated in groups with slower members and prefer working independently to maintain their learning rhythm.

The preferences and characteristics of cognitive styles influence how students learn. FI students excel in individual exploration, as they quickly grasp material when given the freedom to analyze problems independently. On the other hand, FD students require guidance from peers or teachers to comprehend material effectively. Without adequate support, FD students often experience uncertainty and struggle to complete tasks.

In previous research, FD students relied heavily on external guidance, such as teachers or peers, which influenced how they applied geometric concepts. They demonstrated weaknesses in understanding problems and planning solutions, which often led to errors during the execution stage. Social assistance was crucial for FD students at all stages of problem-solving (Hidayat et al., 2019). These findings align with this study, which shows that FD students benefit greatly from social interactions during group discussions. These discussions provide opportunities to hear various perspectives and explanations, helping FD students understand challenging concepts. However, the effectiveness of these discussions depends on structured group dynamics. In large, unstructured groups, FD students may lose focus and feel overwhelmed, making small, structured groups more effective.

To address these challenges, teachers can structure PBL activities to support both cognitive styles simultaneously. Starting with individual exploration allows FI students to delve into tasks independently, while FD students can later rely on group discussions to reinforce their understanding. Problems designed with increasing levels of difficulty—from simple to complex—can cater to both FI and FD students. Additionally, structured and regular feedback from teachers is critical to ensuring both groups receive the necessary support.

By understanding the unique needs of FI and FD students, teachers can modify the PBL approach to create an inclusive and effective learning experience. A tailored approach not only supports the strengths of each cognitive style but also addresses their weaknesses, enabling all students to achieve optimal learning outcomes.

CONCLUSION

The findings of this study emphasize the importance of aligning PBL strategies with cognitive styles to enhance spatial abilities.

Students with FI cognitive styles tend to have higher spatial abilities, with high-ability FI students excelling in visualization, orientation, and spatial relations, though facing challenges in mental rotation. Medium-ability FI students demonstrate good understanding in visualization and orientation but struggle with proportional relationships and scaling, while low-ability FI students encounter significant difficulties in almost all elements. Conversely, students with FD cognitive styles rely heavily on external guidance and perform better in structured tasks. Medium-ability FD students excel in visualization and orientation but struggle with spatial relations, while low-ability FD students face significant challenges across all spatial ability elements.

The study revealed that group dynamics significantly influenced the effectiveness of PBL in fostering spatial abilities for both cognitive styles. Balanced groups that included both FI and FD students created an environment conducive to mutual learning, enabling FD students to benefit from analytical insights and FI students to refine their communication skills. Conversely, homogeneous groups of FD students often struggled with problem analysis, while FI-dominated groups could inadvertently marginalize FD students. These findings highlight the need for carefully planned group compositions and structured discussions to ensure all students benefit equally.

Spatial abilities, encompassing skills like visualization, mental rotation, and spatial relations, are crucial for understanding geometric transformations. This study demonstrated that PBL, when tailored appropriately, is effective in enhancing these abilities. Strategies such as starting with individual exploration, integrating tiered problem difficulty, and fostering collaborative group discussions helped cater to the diverse needs of FI and FD students. Regular feedback and scaffolding further supported the development of spatial skills, particularly for students with weaker cognitive abilities.

The study underscores the importance of integrating spatial ability development within PBL frameworks while accommodating cognitive style differences. Future research should focus on scaling these approaches to larger student populations, exploring how spatial abilities evolve across different levels of cognitive engagement, and designing interventions to support students with varying levels of spatial proficiency. By doing so, educators can better equip students to navigate the complexities of geometric transformations and other STEM-related challenges.

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