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Students' Problem-Solving Ability in Pythagorean Theorem Word Problems Viewed from Spatial Visualization and Gender

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ABSTRACT: This study describes eighth-grade students' mathematical problem-solving performance on Pythagorean theorem word problems in relation to spatial visualization and gender. A qualitative descriptive case-study design was implemented at SMP Negeri 11 Pontianak during the 2025/2026 academic year. Twenty students completed a spatial-visualization test, after which eight participants were selected purposively: two male and two female students with high spatial visualization and two male and two female students with low spatial visualization. Data were collected through written problem-solving tests and in-depth interviews. The analysis followed Polya's four stages—understanding the problem, devising a plan, carrying out the plan, and looking back—and was interpreted alongside spatial perception, spatial relations, visualization, and spatial orientation. Technique triangulation was used to compare written and interview evidence. Students in the high spatial-visualization group, regardless of gender, completed all four stages, although looking back was generally limited to numerical re-substitution rather than contextual evaluation. Male participants tended to execute plans more consistently, whereas female participants produced more complete sketches; these differences reflected solution style rather than a consistent difference in overall capacity. Students in the low group encountered difficulties across nearly all stages. Spatial orientation had the lowest mean component score (5.60), corresponding to the weakness observed in looking back. The findings indicate that spatial visualization was more salient than gender in the observed problem-solving profiles and should be strengthened through visual representation and explicit verification activities.

KEY WORDS: mathematical problem solving, Pythagorean theorem, spatial visualization, gender

I. INTRODUCTION

Mathematics education is expected to develop more than computational fluency; it should also help students interpret situations, select appropriate concepts, and solve problems arising in academic and everyday contexts (Hermawati et al., 2018; Wahyuni, 2018). Problem solving is therefore one of the core standards of mathematical proficiency (Rosyidah et al., 2021) and is often described as central to doing mathematics because it integrates understanding, planning, execution, and evaluation (Darma et al., 2016). Nevertheless, Indonesian students continue to experience difficulty with non-routine mathematical tasks. The national mean in PISA mathematics declined from 379 points in 2018 to 366 points in 2022, compared with an OECD average of 472 points in 2022 (OECD, 2023), reinforcing earlier concerns about students' mathematical problem-solving performance (Darma & Sujadi, 2014).

Word problems involving the Pythagorean theorem are particularly demanding because students must identify a right-triangle structure within a verbal situation, represent the relevant lengths, choose the correct relationship among the sides, and interpret the numerical result in context (Wulandari & Riajanto, 2020). Polya's framework provides a useful lens for examining this process through four connected stages: understanding the problem, devising a plan, carrying out the plan, and looking back (Yuwono et al., 2018). A correct calculation alone does not demonstrate complete problem solving if the representation, strategy, or contextual interpretation remains unclear.

Spatial visualization is a relevant cognitive resource in this setting. It involves mentally representing, transforming, and relating spatial objects and supports the conversion of verbal information into geometric models (Van Garderen, 2006; Octaviani et al., 2021). Maier's framework, as presented by Lestari and Yudhanegara (2017), distinguishes spatial perception, spatial relations, visualization, and spatial orientation. These components can support different parts of a solution, from recognizing the geometric structure to checking whether an answer is reasonable from another orientation or point of view. Prior research reports a close relationship between spatial reasoning and geometry problem solving (Musriroh et al., 2021; Silitonga et al., 2024).

Gender has also been examined in relation to mathematical and visuospatial performance, but the evidence does not support a simple or universal advantage for one group. Studies have reported differences in some tasks and response patterns (Simanjuntak et al., 2019; Voyer et al., 2017), while other findings emphasize the effects of task characteristics, experience, and individual variation (Aini & Suryowati, 2022). Treating gender as an explanatory label without considering spatial proficiency may therefore obscure important differences within each group.

Preliminary observations at SMP Negeri 11 Pontianak indicated that many students had difficulty extracting known and required information, constructing a visual representation, and selecting a solution strategy. The pattern appeared to vary across levels of spatial visualization and, to a lesser extent, across male and female students. However, limited attention has been given to how gender-related solution patterns operate within contrasting spatial-visualization levels when each stage of Polya's process is examined. Accordingly, this study aims to describe: (1) the problem-solving performance of male and female students with high spatial visualization; (2) the performance of male and female students with low spatial visualization; and (3) the relationship between Polya's stages and the observed spatial-visualization components.

II. METHOD

Research design and setting

The study used a qualitative descriptive approach in the form of a case study. This design was selected to examine students' written work and explanations in depth within a bounded school context (Assyakurrohim et al., 2022). The research was conducted with Grade 8 students at SMP Negeri 11 Pontianak during the 2025/2026 academic year.

Participants and selection

All 20 students in the participating class completed a spatial-visualization test covering spatial perception, spatial relations, visualization, and spatial orientation. The scores were classified using the sample mean and standard deviation (Arikunto, 2018). With a mean of 30.65 and a standard deviation of 7.09, scores above 37.74 were categorized as high, scores from 23.56 to 37.74 as moderate, and scores below 23.56 as low. Eight students were then selected purposively: two male and two female students from the high category and two male and two female students from the low category. The moderate category was not included in the focal case analysis so that contrasts between the two selected levels could be examined more clearly.

Data collection and analysis

Data were obtained from a written problem-solving test containing Pythagorean theorem word problems and from in-depth interviews with the eight selected participants. Written responses were examined for evidence of understanding the problem, devising a plan, carrying out the plan, and looking back. The interview data were used to clarify the reasoning represented in the written work. For analytic interpretation, spatial perception was associated with recognizing the problem situation, spatial relations with organizing the geometric relationships, visualization with mentally representing and executing the plan, and spatial orientation with evaluating the result from the problem context.

The analysis proceeded by organizing the test and interview data for each participant, coding evidence for each Polya stage, comparing patterns within and across the high and low spatial-visualization groups, and then examining similarities and differences by gender. Credibility was strengthened through technique triangulation, in which written-test evidence was compared with interview evidence from the same participant (Sugiyono, 2018). Participant codes were used in reporting the findings.

III. RESULTS

Overall spatial-visualization profile

The spatial-visualization scores of the 20 students ranged from 18 to 42, with a mean of 30.65 and a standard deviation of 7.09. Table 1 presents the classification thresholds and the number of students in each category.

Table 1. Distribution of Students' Spatial-Visualization Categories

Category	Score interval	n	%
High	$X > 37.74$	5	25
Moderate	$23.56 \leq X \leq 37.74$	10	50
Low	$X < 23.56$	5	25
Total	—	**20**	**100**

Spatial perception had the highest mean component score (8.70), followed by visualization (8.50) and spatial relations (8.05). Spatial orientation had the lowest mean (5.60), and at least one student scored zero on this component. Thus, the students were generally more successful at recognizing forms and imagining geometric situations than at reasoning about direction or viewpoint.

Distribution by gender and focal participants

Table 2. Spatial-Visualization Categories by Gender

Category	Male	Female	Total
High	3	2	5
Moderate	4	6	10
Low	2	3	5
Total	**9**	**11**	**20**

Three of the nine male students and two of the eleven female students were in the high category. Two male students and three female students were in the low category. These descriptive counts characterize the participating class only and are not used to infer a population-level gender difference. The eight focal participants are listed in Table 3.

Table 3. Selected Participants

Participant code	Gender	Spatial-visualization category	Score
A13L	Male	High	42
A9L	Male	High	41
A3P	Female	High	39
A14P	Female	High	38
A5L	Male	Low	21
A15L	Male	Low	18
A19P	Female	Low	23
A8P	Female	Low	19

Problem-solving profiles in the high spatial-visualization group

The four high-category participants (A13L, A9L, A3P, and A14P) generally demonstrated evidence of all four Polya stages. They identified the known and required information, produced a relevant sketch, selected the Pythagorean relationship, and obtained an appropriate final result. Their representations made the connection between the verbal situation and the right triangle explicit, supporting the role of spatial visualization in geometry problem solving (Octaviani et al., 2021).

Some gender-related differences appeared in how solutions were expressed. The male participants were more consistent when carrying out their planned calculations, whereas the female participants tended to provide more complete sketches and more explicit statements of the problem information but showed occasional calculation inaccuracies. These were tendencies within the selected cases rather than evidence that one gender had greater overall problem-solving capacity. Across all four participants, looking back remained the weakest stage: checking was usually restricted to substituting numerical values again, without evaluating whether the answer was reasonable in the context of the word problem.

Problem-solving profiles in the low spatial-visualization group

The low-category participants (A5L, A15L, A19P, and A8P) experienced difficulties at nearly every stage. Their written work included incomplete identification of the requested information, inaccurate placement of side lengths, inappropriate substitution into the Pythagorean formula, and the absence of a meaningful checking process. Several participants moved directly to calculation before constructing a coherent visual model, a pattern consistent with the difficulty of solving contextual tasks when the situation has not first been represented clearly (Malik & Mas'ud, 2025). The difficulties were broadly similar for the male and female participants in this group.

IV. DISCUSSION

Spatial visualization across Polya's stages

The contrast between the two groups indicates that spatial visualization was closely associated with the quality and completeness of students' problem-solving processes. High-category participants translated the word problem into a geometric representation and maintained the relationships among its elements while executing the solution. In contrast, low-category participants often failed to stabilize the representation before applying a formula. This finding is consistent with research showing that spatial reasoning supports the representation and manipulation required in geometry problems (Musriroh et al., 2021; Van Garderen, 2006).

The component pattern also helps explain the stage-specific results. Spatial perception, visualization, and spatial relations had higher mean scores than spatial orientation, while looking back was the least developed problem-solving stage. Although the analytic alignment between spatial orientation and looking back should not be interpreted as a causal equivalence, both require students to reconsider a representation from an alternate perspective and judge whether the result is coherent. The mean spatial-orientation score of 5.60 therefore provides converging evidence for the observed weakness in contextual verification.

Gender-related patterns within spatial-visualization levels

Gender-related variation was visible mainly in the style and completeness of responses among the high-group cases. The male participants' greater consistency in calculation and the female participants' more complete sketches did not produce a uniform advantage across all stages. This nuanced pattern agrees with evidence that gender differences in mathematical problem solving may emerge in particular response processes without establishing that one gender is consistently superior (Simanjuntak et al., 2019). It also supports treating gender as one contextual factor among several rather than as a fixed predictor of performance (Risalah et al., 2019; Silitonga et al., 2024).

Among the low-group cases, the similarity of difficulties across male and female participants was more prominent than the differences between them. Within this bounded sample, spatial-visualization level was therefore more salient than gender for explaining whether students could construct a model, apply the Pythagorean relationship correctly, and verify the result. This interpretation is consistent with meta-analytic evidence that gender effects in visuospatial tasks vary across task type and individual experience (Voyer et al., 2017), and it cautions against designing instruction around gender stereotypes.

Pedagogical implications and limitations

Instruction on Pythagorean word problems should explicitly connect verbal information, diagrams, side relationships, calculations, and contextual interpretation. Teachers can model multiple representations, ask students to label and rotate or reorient diagrams, and require a final explanation of why an answer is reasonable. A structured looking-back prompt—checking units, comparing the result with the diagram, and interpreting the answer in the original situation—may help strengthen both verification and spatial orientation. These supports should be provided according to demonstrated learning needs rather than gender.

The findings should be interpreted within the study's qualitative scope. The focal analysis involved eight participants from one school, and the moderate spatial-visualization group was intentionally excluded. The results describe patterns in the selected cases and do not establish causal effects or population-level gender differences. Future studies should include moderate-category students, broader school contexts, and additional geometry topics, and may combine qualitative profiles with larger quantitative samples.

V. CONCLUSION

Students with high spatial visualization, both male and female, demonstrated all four stages of Polya's problem-solving process, although looking back remained limited and largely numerical. Male participants in this group tended to execute their plans more consistently, while female participants tended to construct more complete sketches; these differences reflected solution style rather than a consistent difference in overall capacity. Students with low spatial visualization, regardless of gender, experienced difficulties from understanding the problem through verification. Across the selected cases, spatial-visualization level was more salient than gender in the observed problem-solving profiles. The low spatial-orientation mean and the weak looking-back stage together indicate a need for systematic instruction in contextual verification.

Recommendations

Teachers are encouraged to integrate diagrams, manipulable geometric representations, and explicit checking prompts into Pythagorean theorem instruction, with additional scaffolding for students whose spatial visualization is still developing. Further research should involve more participants, include the moderate spatial-visualization category, and investigate whether targeted spatial-orientation activities improve the quality of students' looking-back processes.

VI. ACKNOWLEDGMENTS

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VII. DISCLOSURE

The authors declare no conflicts of interest related to this work.

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