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STUDENTS' MATHEMATICAL REASONING BASED ON POLYA'S PROBLEM-SOLVING STAGES FROM A GENDER PERSPECTIVE

Sri Utari^{1*}, Dwi Rahmawati², Rahmat Bustanul Anwar³, Sutrisni Andayani⁴, Nego Sihaluhung⁵

^{1,2,3,4,5}Departement of Master of Mathematics Education, Pascasarjana Universitas Muhammadiyah Metro, West Lampung, Indonesia

*Correspondence: usri63009@gmail.com

ABSTRACT

This study aims to analyze the mathematical reasoning abilities of junior high school students through Polya's problem-solving stages, taking gender differences into account. A qualitative approach was employed within a descriptive research framework. Data collection was conducted at SMP Muhammadiyah 4 Metro, involving both male and female students. The data collection methods included tests, interviews, and documentation to ensure accurate recording of all activities. Data analysis was carried out through the stages of data reduction, data display, and conclusion drawing/verification. To ensure data validity, the triangulation method was applied by comparing the results of tests and interviews. The findings indicate that male students demonstrate superior mathematical reasoning skills compared to female students. Furthermore, female students tend to struggle with drawing conclusions when solving problems based on the processes they undertake.

Keywords: Analysis, Mathematical Reasoning, Problem Solving Stages Gender.

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PRELIMINARY

Thinking and mathematics are inherently interconnected; thinking skills can be developed through mathematics instruction. Abylkassymov et al.(2023) emphasizes that the primary goal of mathematics education, from elementary to senior secondary levels, is to develop essential competencies, mathematical reasoning, and creative thinking. Reasoning is defined as a cognitive process through which students utilize their knowledge to obtain solutions. Mathematical thinking itself constitutes a fundamental component of basic mathematical skills. Mathematical reasoning ability enables individuals to solve both mathematical and everyday problems, whether routine or non-routine in nature (Rohati et al., 2023b).

Therefore, mathematical proficiency is a crucial aspect of children's development. Direct experiences in students' daily lives play a significant role in enhancing their thinking abilities. Through such experiences, students can identify their surrounding environment and design solutions to the challenges they encounter. However, in practice, Indonesian students' mathematical thinking skills remain relatively low. According to PISA data, only 9% of Indonesian students reach levels 5 or 6, which indicate advanced mathematical thinking skills. In addition, the average mathematics score of Indonesian students is only 366 points, far below the OECD average of 472 points. The 2023 Education Report Card also reveals that numeracy skills, including reasoning competence, among public junior high schools in metropolitan areas remain inadequate. For example, at SMP Muhammadiyah 4 Metro, the education report indicates a decline in numeracy performance, with reasoning competence (L3) decreasing by 8.26% compared to the previous year.

Erickson,(2024) defines reasoning as a cognitive process that connects existing facts or evidence to arrive at a conclusion. Observations at SMP Muhammadiyah 4 Metro indicate that students experience difficulties in solving mathematical problems, particularly in linking relevant facts and information presented in word problems. Consequently, an examination of students' mathematical reasoning abilities in problem solving is necessary to identify existing weaknesses that may serve as a basis for instructional improvement. Mathematical reasoning ability is influenced by various factors, one of which is gender. In Latin, the term *gender* is derived from the word *genus*, meaning "type" or "kind." Kumar,(2024) defines gender as the characteristics and behaviors of males and females shaped by social and cultural factors. Kung, (2022) emphasizes that gender is an important factor influencing social development in early childhood. Geary et al.(2022) argues that differences in mathematics learning between males and females lie in males' stronger reasoning abilities, whereas females tend to demonstrate greater accuracy, precision, and more balanced thinking.

Various factors must be considered in mathematics instruction, including skills, competencies, intelligence, teacher readiness, student readiness, curriculum, and pedagogical methods. Another important factor is gender. Schlünssen & Jones,(2023) state that gender reflects differences in behavior between males. and females related to their roles and responsibilities, which are shaped by social and cultural dynamics. Females tend to exhibit dominance in right-brain development, while males are more dominant in left-brain development (Andrushko et al., 2023). These differences may result in variations in

students' approaches to problem solving. However, other studies indicate that female students demonstrate better mathematical problem-solving abilities than male students (Hidayati et al., 2019).

The relationship between reasoning and problem solving lies in the fact that engagement in problem-solving activities can enhance students' reasoning abilities. The problem-solving process allows students to identify and resolve difficulties in order to achieve learning objectives, including the development of thinking skills (Mayer, 2022). George Polya is a key figure in problem-solving theory (Toh et al., 2024). This study adopts Polya's framework, which includes four indicators of problem-solving ability: understanding the problem, devising a plan, carrying out the plan, and evaluating the solution (Loh, 2020). Polya asserts that during the problem-solving process, students can relate the difficulties they encounter to prior experiences, thereby engaging more than mere recall abilities (Keazer & Jung, 2020). The problem-solving steps proposed by Polya consist of: (1) understanding the problem; (2) formulating a solution plan; (3) implementing the plan; and (4) evaluating the results and drawing conclusions (Zamnah, 2021). This study aims to examine the mathematical reasoning abilities of students at SMP Muhammadiyah 4 Metro using Polya's problem-solving stages, with a particular focus on gender differences in the topic of plane geometry.

METHODS

The participants in this study were 30 eighth-grade students from SMP Muhammadiyah 4 Metro, consisting of 14 male students and 16 female students. This study employed a descriptive method with a qualitative approach. The objective of the research was to analyze the mathematical reasoning abilities of students at SMP Muhammadiyah 4 Metro from a gender perspective within the topic of plane geometry. The data sources used in this study comprised primary and secondary data. Primary data were obtained through problem-solving ability tests and interviews, while secondary data were collected from documentation generated during the research process (Velentgas, 2021). The data collection method that integrates primary and secondary data is known as triangulation (Park, 2024), which in this study was conducted by comparing students' written work with findings from the interviews.

The data analysis process consisted of three main stages: data reduction, data presentation, and conclusion drawing and verification. In addition, students' written work

was evaluated using a problem-solving assessment table designed to systematically measure their mathematical reasoning abilities.

Table 1. Stages of Problem Solving According to Polya

Understanding the Problem	Identifying the information that is known and determining what is being asked in the problem.
Devising a Problem-Solving Plan	Representing the problem using relevant forms such as tables, formulas, diagrams, or other appropriate mathematical models.
Carrying Out the Plan	Substituting the known values into the selected formulas and performing the necessary calculations to solve the problem..
Looking Back (Reviewing the Solution)	Drawing conclusions based on the results obtained and verifying the correctness of the solution.

In this study, mathematical reasoning is interpreted as the ability of students to identify facts and relationships between known information, formulate mathematical arguments logically, provide justification for each solution step, and draw coherent conclusions based on mathematical evidence (Bischofberger & Ragni, 2021; Rohati et al., 2023a). The reasoning indicators analyzed include: (1) the ability to recognize relevant facts and relationships in the problem; (2) the ability to construct logical mathematical models or representations; (3) the ability to provide reasons or justifications for the procedures used; and (4) the ability to evaluate and infer results appropriately. The problem-solving stages according to Polya are used in this study not as the main indicator measured, but as an analytical framework to identify how mathematical reasoning appears at each stage, namely at the stage of understanding the reasoning problem reflected in the ability to connect known and questioned information; at the stage of planning the solution can be seen from the preparation of strategies and the selection of formulas accompanied by reasons; at the stage of implementing the plan appears to be logical consistency and procedural precision; and at the review stage, it can be seen from the ability to verify and draw conclusions that are in accordance with the context of the problem. Thus, the main focus of this study is the quality of students' mathematical reasoning as analyzed through the lens of Polya stages. In this study, Polya's stages serve as an analytical framework, while the primary focus of analysis remains on students' mathematical reasoning indicators manifested within each stage.

RESULT AND DISCUSSION

This study began by presenting a narrative problem related to everyday issues involving two-dimensional surfaces. Based on the responses obtained, one male student and one female student with the most comprehensive and accurate answers were selected as research participants. Subsequently, in-depth interviews were conducted with both participants to further explore their responses and the reasoning underlying their approaches to solving the given problems. The results of the problem-solving tasks and the interviews were then analyzed to evaluate the students' reasoning abilities in mathematical problem solving. The selected male participant was the student with identification number 6, hereafter referred to as L6, while the selected female participant was the student with identification number 4, hereafter referred to as P4.

Analysis of Male Students' Mathematical Reasoning Ability

Diketahui: luas = 96 m^2 $p = 4 + l$

Ditanya: A. p & l?
B. keliling?

Dijawab:

A. luas = $p \cdot l$
 $96 = (4 + l) \cdot l$
 $96 = 4l + l^2$
 $0 = l^2 + 4l - 96$
 $0 = (l + 12)(l - 8)$
 $l + 12 = 0$ $l - 8 = 0$
 $l = -12$ $l = 8$

$l = -12$ tidak memenuhi, karena lebar tidak mungkin negatif

Maka, lebar = 8 cm
 Panjang = $4 + l$
 Panjang = $4 + 8$
 Panjang = 12 cm

B. keliling = $2(p + l)$
 $= 2(8 + 8)$
 $= 2(16)$
 $= 32 \text{ cm}$

Figure 1. Response of Subject L6

Based on the results of the written test, Subject L6 demonstrated a relatively strong level of mathematical reasoning ability. An analysis of Subject L6's reasoning skills based on Polya's problem-solving stages is presented as follows.

1. Understanding the Problem

At this stage, Subject L6 showed a clear understanding of the given problem. This was evident from the answer sheet, which explicitly identified the known information, such as the length, width, and area of the garden, as well as clarified what was being asked, namely the length and the perimeter of the garden. This finding is consistent with Atir et al.(2024), who stated that the ability to understand a situation is reflected in one's capacity to distinguish between known information and the required outcomes.

2. Formulating a Problem-Solving Plan

At this stage, Subject L6 successfully constructed relevant mathematical expressions based on the given information, such as the statement that "the length of the garden exceeds its width by 4 meters." Accordingly, Subject L6 formulated the equation $p = l + 4$, where p represents the length of the garden and l represents the width. In addition, the subject correctly expressed the formula for the area of the garden as $L = (l + 4) \times l$, where L denotes the area. This demonstrates that Subject L6 was able to develop an appropriate problem-solving strategy. These findings support Siregar & Banjarnahor(2019), view that mathematics is an abstract system constructed through deductive reasoning and organized in a systematic and logical manner.

3. Implementing the Problem-Solving Strategy

During the implementation stage, Subject L6 accurately substituted the known values into the formulas and performed the algebraic procedures carefully. The subject was able to obtain the correct results for both the length and the perimeter of the garden through systematic calculations.

4. Verifying the Solution

At this final stage, Subject L6 was able to draw conclusions that were generally consistent with the initial problem, correctly determining the length and area of the garden. However, an error was identified in the use of measurement units, as the subject used centimeters instead of meters. Based on the interview, this mistake occurred because the subject worked hastily and did not recheck the problem statement regarding units. Furthermore, in responding to the second question concerning the length of the fence, Subject L6 only stated the perimeter of the garden without explicitly specifying the fence length. During the interview, the subject explained that mentioning the perimeter was considered sufficient, as the

concept of fencing is directly associated with the perimeter of the garden in mathematical terms.

Analysis of Female Students' Mathematical Reasoning Ability

Diketahui: 1. $P = l + 4$ $96 = (l + 4) \times l$ $L = 96 \text{ meter}$ $96 = l^2 + 4l$ $L = P \times L$ $l^2 + 4l - 96 = 0$ $(x + 12)(x - 8)$
Ditanya: Panjang dan lebar taman
Dijawab: D) jadi $l = 8$ $= l + 4$ $= 8 + 4 = 12$ $K = 2 \times (P + l)$ $= 2 \times (12 + 8)$ $= 2 (20)$ $= 40$

Figure 2. Response of Subject P4

Based on the results of the written test, subject P4 demonstrated an adequate level of mathematical reasoning ability. The analysis of P4's reasoning skills according to Polya's problem-solving stages is presented as follows:

1. Understanding the Problem

At this stage, subject P4 was able to identify relevant data, such as the length, area, and width of the garden, appropriately. However, when recording information from the problem, the subject noted only partial data specifically the length and width of the garden without explicitly addressing information related to the second question, such as the length of the fence or the perimeter of the garden. This indicates that the subject's understanding of the problem was not yet fully comprehensive.

2. Devising a Plan

At this stage, subject P4 successfully articulated the required mathematical expressions. Based on the statement that "the length of the garden must be 4 meters longer than its width," the subject derived the equation $p=l+4$ $p = l + 4$, where

ppp represents the length and lll represents the width of the garden. In addition, the subject correctly formulated the area equation as $L=(1+4) \times IL = (1 + 4) \times IL=(1+4) \times l$, where LLL denotes the area of the garden. These responses indicate that subject P4 was able to formulate an appropriate problem-solving strategy.

3. Carrying Out the Plan

During the implementation stage, subject P4 did not complete the solution process fully and accurately. The subject successfully substituted the expression for length into the area formula and incorporated the given value of the garden's area. However, the algebraic process was halted at the factorization stage, and the resulting variable values were not explicitly documented or articulated. Interview data revealed that subject P4 experienced difficulty in continuing the algebraic procedures. Nevertheless, the subject understood that the width of the garden was 8 meters and the length was 12 meters, derived from the equation $p=1+4p = 1 + 4p=1+4$.

4. Verifying the Answer

At this stage, subject P4 provided correct answers regarding the width, length, and perimeter of the garden in accordance with the problem. However, a more explicit conclusion regarding the length of the fence that needed to be constructed by Dina was not clearly stated. During the interview, the subject explained that stating the perimeter of the garden was considered sufficient to answer the question, even though the length of the fence was not explicitly mentioned.

Differences in Mathematical Conceptual Understanding Between Male and Female Students

In this study, Polya's problem-solving stages function as an analytical framework to identify how mathematical reasoning is manifested in each phase of problem solving. The reasoning indicators examined include identifying relevant relationships, constructing logical arguments, justifying procedures, and drawing evidence-based conclusions. Therefore, the comparison presented in Table 2 does not merely describe differences in problem-solving steps, but highlights variations in the quality of reasoning demonstrated by male and female students within each stage. It is important to clarify that understanding, devising, implementing, and reviewing are not treated as reasoning indicators in this study; rather, they function as structural phases within which students' mathematical reasoning processes are observed and analyzed.

Table 2. Manifestation of Mathematical Reasoning Indicators within Polya's Problem-Solving Stages

Polya's Stage (Analytical Framework)	Male Students	Female Students
Understanding the Problem	Able to accurately and comprehensively identify the given information and the questions posed.	Less able to identify the given information and the questions posed.
Formulating a Solution Plan	Able to formulate and present the relevant formulas accurately and completely.	Demonstrates the ability to write relevant formulas completely and accurately
Implementing the Solution Plan	Able to substitute the given values into the relevant formulas and compute the solution in a detailed and systematic manner.	In contrast, shows limited ability to substitute the given values into the formulas and to carry out the calculations in a detailed and structured way, with noticeable shortcomings in the elaboration of algebraic procedures.
Reviewing and Verifying the Results	Able to draw partial conclusions based on the results obtained during the problem-solving process.	Conversely, not yet able to formulate conclusions that are consistent with the results obtained from the solution process.

The analysis indicates differences not merely in procedural performance but in the quality of mathematical reasoning demonstrated by male and female students. In the stage of understanding the problem, male students exhibited stronger relational reasoning, as evidenced by their ability to explicitly connect known information with the questions posed. Female students, however, showed partial identification of relevant elements, indicating less comprehensive relational reasoning. During the planning stage, both groups

were able to formulate mathematical models; however, differences emerged in argumentative reasoning. Male students provided clearer justification for formula selection, whereas female students tended to present symbolic expressions without fully articulating the logical basis of their strategy.

In the implementation stage, male students demonstrated greater procedural coherence and logical consistency in executing calculations. Their reasoning was evident in the systematic transformation of algebraic expressions. Female students, although arriving at correct answers, displayed less explicit justification in their computational steps, indicating weaker explanatory reasoning. At the verification stage, male students showed partial reflective reasoning by attempting to conclude their findings, while female students demonstrated limited evaluative reasoning, as conclusions were not consistently aligned with the solution process.

CONCLUSION

Based on the research objectives and the results of the analysis, it can be concluded that there are notable differences in the mathematical reasoning abilities of male and female students in the topic of plane geometry, as viewed through Polya's problem-solving stages. Male students demonstrated strong mathematical reasoning across all four stages: understanding the problem, devising a plan, carrying out the plan, and reviewing the solution. In contrast, female students exhibited comparatively lower levels of mathematical reasoning, with adequate performance observed only at the stage of devising a solution plan. At the stages of understanding the problem and implementing the plan, female students continued to show limitations, while the stage of reviewing the solution was not performed at all. These differences are particularly evident in the indicators of problem comprehension, execution of the solution plan, and verification of results, suggesting that male students outperformed female students in these aspects.

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