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Examination of students' written mathematical communication skills in addressing gender-based open-ended problems

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ABSTRACT
Written mathematical communication skills are an important concern in mathematics education. One way to assess these skills is by presenting students with open-ended problems. This study examines differences in written mathematical communication skills based on gender. The purpose of this study is to describe students' written mathematical communication skills in solving open-ended problems from a gender perspective. The research employed a descriptive qualitative approach, with participants consisting of Grade VIII students from SMPN 2 Pamekasan, categorized into low, medium, and high levels of written mathematical communication skills. Data were collected through open-ended problem-solving tests to analyze students' written mathematical communication based on gender. The findings indicate that: (1) students in the low-ability category were unable to fully meet the indicators, with both males and females scoring 58; (2) students in the medium-ability category were moderately able to meet the indicators, with both males and females scoring 75; and (3) students in the high-ability category demonstrated strong performance in meeting the indicators, with males scoring 83 and females 100. These results suggest that high-ability students are more effective in meeting the indicators of written mathematical communication, with observable differences based on gender. Female students tend to excel in written narratives, whereas male students show greater strength in visualization. Students with low and medium abilities still require support in notation, image proportion, and written explanations.

KEYWORDS
Mathematical communication; open ended; gender

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INTRODUCTION

Humans are social beings who continuously interact with one another; one such form of interaction is the exchange of information, commonly referred to as communication. Communication is a multidirectional process involving the exchange of information or messages between individuals (Dewanti & Muna, 2023;Situmorang & Pandiangan, 2022). Classroom learning is an example of communication activity, as it involves the exchange of information in the form of messages, ideas, thoughts, understandings, and experiences about a topic studied together—particularly in mathematics education. Communication plays a crucial role in clarifying problem understanding, thereby facilitating problem-solving (Settiyani *et al*., 2020;Zetriuslite *et al.*, 2021).

Communication skills are essential in learning, especially in mathematics. Mathematical communication skills refer to the process by which students convey mathematical ideas clearly to others—peers, teachers, or broader audiences—either in written or oral form (Ikhtiar *et al*., 2021). These skills can be categorized into *written* and *oral* mathematical communication (Qurohman *et al.*, 2021). Written communication involves expressing ideas through written representations, while oral communication involves verbally conveying mathematical ideas during discussion or explanation (Maryati *et al*., 2022).

Mathematical communication skills, particularly in writing, are vital in mathematics learning. However, many students still struggle to express their mathematical ideas in written form. Previous studies indicate that students' mathematical communication skills remain relatively low. Research by Syafira and Zulkarnaen (2022) found that students often make errors in formulating problem-solving steps and have difficulty articulating the reasoning behind their answers. Many students also tend to write only the final results without presenting a logical and coherent mathematical thought process. Similarly, Hartini *et al.*, (2016) reported that the PISA study revealed a low level of mathematical communication proficiency among Indonesian students. These findings indicate the need for targeted interventions to enhance students' written mathematical communication skills.

To address this issue, clear reference indicators are needed to identify and assess students' mathematical communication abilities. Aini and Setianingsih, (2022) As follows: a) Using mathematical notation and structures to represent ideas in real-life contexts (Mathematical Expression); b) Interpreting mathematical ideas both verbally and visually through pictures or graphs (Drawing); and c) Expressing mathematical ideas in written and oral form (Written Text). This indicator reflects students' mathematical communication abilities, encompassing written, oral, and visual representations that emphasize the effective conveyance of mathematical concepts, with particular attention to the accurate use of mathematical notation.

These indicators reflect various modes of mathematical communication—written, oral, and visual—emphasizing the accurate and effective representation of mathematical concepts. Similarly, Rahmalia *et al.*, (2020) proposed related indicators: a) Expressing mathematical ideas orally, in writing, and visually; b) Interpreting and evaluating mathematical ideas from visual representations both verbally and in writing; and c) Using mathematical terms, symbols, and structures to model mathematical situations or problems. This indicator measures students' ability to communicate mathematically, both orally and in writing. Through the components of interpretation, evaluation, and mathematical modeling, students are expected to engage in a deeper exploration of the mathematical concepts they encounter.

These frameworks measure students' ability to communicate mathematically through interpretation, evaluation, and modeling—encouraging deeper exploration of mathematical concepts. This study adopts the indicators proposed by Aini and Setianingsih, (2022), as they encompass key components of mathematical communication, namely: (a) Mathematical Expression, (b) Drawing, and (c) Written Text.

One effective way to measure mathematical communication skills, particularly in writing, is through open-ended problems. Open-ended problems have multiple solutions and various approaches for reaching correct answers (Murtafiah *et al.*, 2023). Engaging with open-ended problems encourages students to think critically and creatively, as they are given the freedom to express their ideas, analyses, and reasoning processes in solving mathematical tasks (Hajar *et al*., 2021).

Another factor influencing students' ability to solve open-ended problems is gender. Gender plays a role in cognitive processing, particularly in decision-making and problem-solving (Izzah *et al*., 2022). In general, male students tend to employ more abstract and rational thinking patterns, while female students often rely on intuition and emotional aspects in their reasoning (Davita and H., 2020). These gender-based cognitive differences may affect how individuals understand and develop mathematical concepts (Risaldi *et al*., 2023). For example, female students are often observed at the stages of property noticing, observing, image making, and formalizing, whereas male students are more frequently found in the folding-back process at the image-having stage (Patmaniar *et al*., 2021).

This study differs from previous research such as that by Utami *et al.*, (2023), Baehaqi *et al.*, 2023) which examined mathematical communication and gender without incorporating open-ended problems. Similarly, studies by Raja *et al.*, (2020), Saragih *et al.*, (2021) ocused on mathematical communication in the context of open-ended problems but emphasized the senior high school level. Meanwhile, Ats-Tsauri *et al.*,(2021) explored mathematical communication in general without a specific focus on written communication. The present study specifically integrates written mathematical communication with open-ended problem solving, emphasizing gender aspects that have been rarely investigated comprehensively at the junior high school level.

The urgency of this research lies in the need to understand the relationship between mathematical communication skills and open-ended problem solving, particularly in relation to gender among junior high school students. Although prior studies have addressed mathematical communication and gender separately, few have explored their integration within open-ended problem contexts that allow for creative exploration of solutions.

Moreover, research on open-ended problem solving has primarily focused on senior high school students, leaving a gap at the junior high school level. This study is also significant because it explicitly examines written mathematical communication—an aspect often underexplored in previous studies. By combining these elements, the research aims to contribute to the development of more effective and contextual learning strategies for junior high school students and to deepen understanding of how gender influences mathematical communication and problem-solving processes. The findings of this study are expected to serve as a basis for implementing more responsive teaching approaches aligned with students' needs and the demands of modern education.

METHODS

This study employed a descriptive research method with a qualitative approach. The qualitative approach is characterized as a descriptive and analytical process through which the researcher seeks to understand the meaning, patterns, and context of the collected data in depth. Descriptive research with a qualitative orientation focuses not only on what happens but also on why and how a phenomenon occurs within a specific context (Creswell and Creswell, 2023). The aim of this study is to analyze students' written mathematical communication skills in solving open-ended problems based on gender.

The study involved 31 eighth-grade students. From this group, six students were randomly selected to represent three levels of written mathematical communication skills—low, medium, and high. The six subjects consisted of three male students and three female students. The research instrument was an open-ended essay-type question designed to assess how students formulate, organize, and convey mathematical ideas when faced with open-ended problems. Each student was presented with a mathematical problem to be solved according to their own understanding.

The data collected consisted of students' written responses to the open-ended test question, which aimed to measure written mathematical communication skills. Data were obtained by administering one descriptive question to Grade VIII-G students, to be completed within 60 minutes. Data analysis followed the interactive model developed by Miles *et al.*, (2014) which includes three main components: data condensation, data display, and drawing and verifying conclusions. Data condensation involved selecting, focusing, simplifying, and transforming raw data from students' answers and interviews into more meaningful forms. The data were then presented in a systematic narrative format to facilitate the identification of patterns and relationships. The final stage involved drawing conclusions based on a comprehensive interpretation of the condensed and displayed data. This process was conducted iteratively to ensure the validity of the findings.

Data analysis in this study was carried out using the indicators of written mathematical communication ability proposed by Aini and Setianingsih (2022) linked to the open-ended question indicators adapted from Solahudin (2022) to gain a deeper understanding of the relationship between students' written mathematical communication skills and the characteristics of the open-ended problems used. The indicators are presented in Table 1.

Table 1. Open-ended question indicators

No.	Open-ended questions	Open-ended Problem Indicator	Written Mathematical Communication Indicators
1a.	Create a precise sketch model of the carpenter and clearly and concisely describe the steps you took.	Variations in mathematical solutions and relationships; creativity in problem solving	Using mathematical notation and structure to present ideas in real-life situations (Mathematical Expression); interpreting mathematical ideas in visual form, such as drawings or graphs
1b.	Prove that the area of the sketch you drew meets the specified dimensions.	Classification and under-standing of concepts; data measurement and interpretation	Expressing mathematical ideas in written form (Written Text)

The formula used to determine the category of students' mathematical communication skills is shown in Equation (1).

$$Score = \frac{score\ obtained\ by\ the\ student}{total\ score} \times 100 \qquad (1)$$

The categories used in the research were adopted from the study by Febriana et al. (2024), as shown in Table 2.

Table 2. Categories of written mathematical communication skills test

Test Result Score (X)	Category: Student Written Communication Skills
$0 \leq X < 65$	Low
$65 \leq X < 80$	Medium
$80 \leq X \leq 100$	High

The results of the open-ended question test were compiled and analyzed to examine students' written mathematical communication skills. The data were organized according to predetermined indicators and categorized based on each student's level of achievement to illustrate the variation in written mathematical communication skills. The findings are presented in a narrative form to provide a clearer and more comprehensive picture of students' written communication patterns based on gender.

RESULT AND DISCUSSION

The results of the open-ended question test completed by the students were analyzed

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to determine their proficiency levels in mathematical communication. Based on the data obtained, each student's scores were categorized as low, medium, or high in mathematical communication skills, with consideration of gender.

The analysis focused on six subjects representing the low, medium, and high levels of written mathematical communication skills, with attention to gender. The selected subjects were S26 (male) and S13 (female) with low communication ability, S23 (male) and S14 (female) with medium communication ability, and S12 (male) and S16 (female) with high communication ability. The responses of each subject are analyzed and presented according to these categories as follows:

1. Test Results for Students with Low Communication Skills

The subjects in the low mathematical communication category were S26 (male) and S13 (female), each scoring 58. The analysis of their responses is presented in Figure 1 and Figure 2.

a. S26

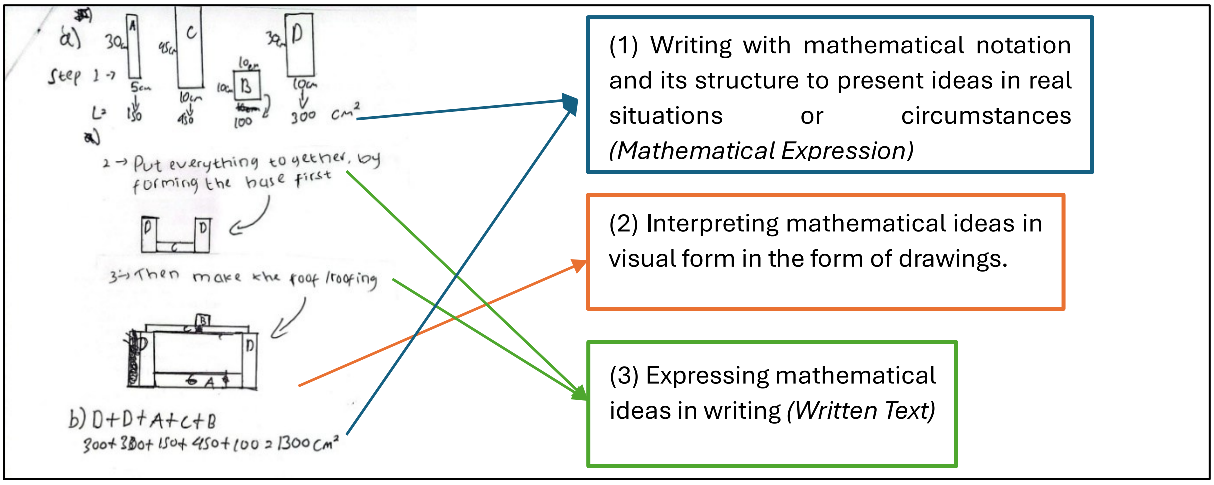

Figure 1. S26's response

Based on the analysis, S26's performance on each indicator is as follows: (1) Mathematical Expression Indicator**:** S26 used the same notation for all pieces of wood, which caused difficulty in identifying the area of each piece. In addition, inconsistent notation when calculating the total area led to confusion regarding the origin of the area values used in the design. (2) Drawing Indicator**:** S26 was able to produce a sketch that met the overall area requirement. However, the individual pieces of wood were not depicted concretely or proportionally according to the dimensions given in the problem. For example, piece C, which should have a width of 10 cm, was drawn smaller than piece A, which is only 5 cm wide. This discrepancy indicates that S26 struggled to accurately correlate numerical measurements with

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visual representations. (3) Written Text Indicator**:** S26 was unable to provide a coherent narrative explanation. The student primarily presented calculations without explaining why specific shapes were chosen or how the arrangement ensured the design met the required criteria.

b. S13

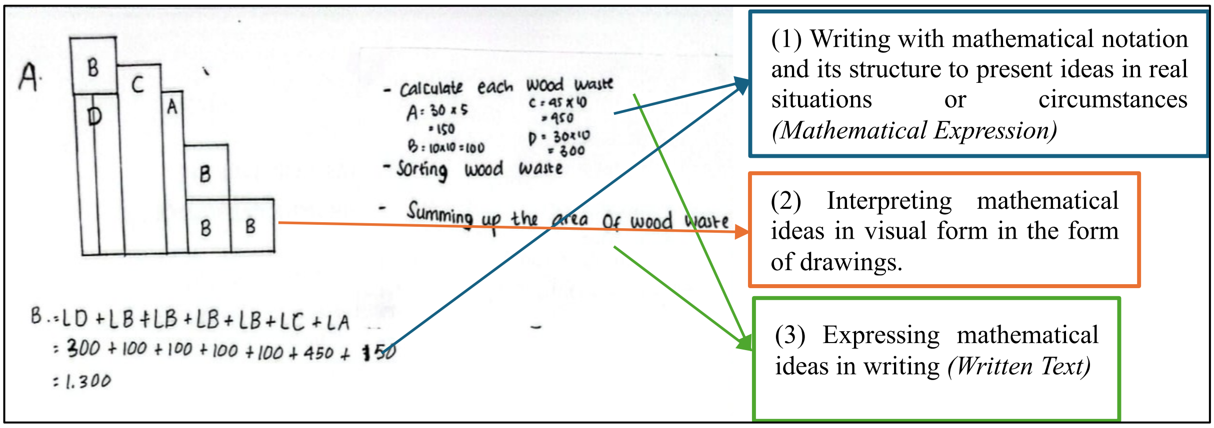

Figure 2. S13's response

The analysis results show S13's performance on each indicator as follows: (1) Mathematical Expression Indicator: S13 did not use notation consistently. The notation used to calculate the area of each piece differed from that used to calculate the total area, making the calculation process less clear. This inconsistency makes it difficult to trace the problem-solving steps and may lead to errors in interpreting the conveyed mathematical ideas. (2) Drawing Indicator: S13 was able to depict sketches that were concrete and proportional. (3) Written Text Indicator: S13 provided only brief descriptions of the solution steps without in-depth explanations. The work did not demonstrate a clear sequence of reasoning, making the communicated mathematical ideas unclear. This indicates that S13 still needs to develop the ability to effectively express their thoughts in writing.

2. Results of open-ended questions for students with moderate communication skills

The subjects in the moderate mathematical communication category were S23 (male) and S14 (female), each scoring 75. The analysis of their responses is presented in Figure 3 and Figure 4.

a. S23

Based on the analysis results, S23's performance on each indicator is as follows: (1) Mathematical Expression Indicator**:** S23 used the same notation for all pieces of wood, making it difficult to distinguish the area of each part. This resulted in a calculation process that was less organized and somewhat confusing. Additionally, the use of inconsistent

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notation when calculating the total area made it challenging to identify the contribution of each piece, potentially leading to misunderstandings of the intended mathematical ideas. (2) Drawing Indicator: S23 was unable to visualize the wood pieces accurately according to their actual dimensions. For example, in Figure A.1, the combined length of wood A and B should exceed the length of wood C, but the drawing shows the opposite. Moreover, the widths of wood A and B, which are supposed to differ, were depicted as the same. This indicates that S23 still struggles to represent numerical dimensions proportionally in visual form. (3) Written Text Indicator: S23 recorded the sequence of solution steps, but the accompanying explanations were limited and not fully structured. As a result, the student's thought process was not clearly communicated in writing.

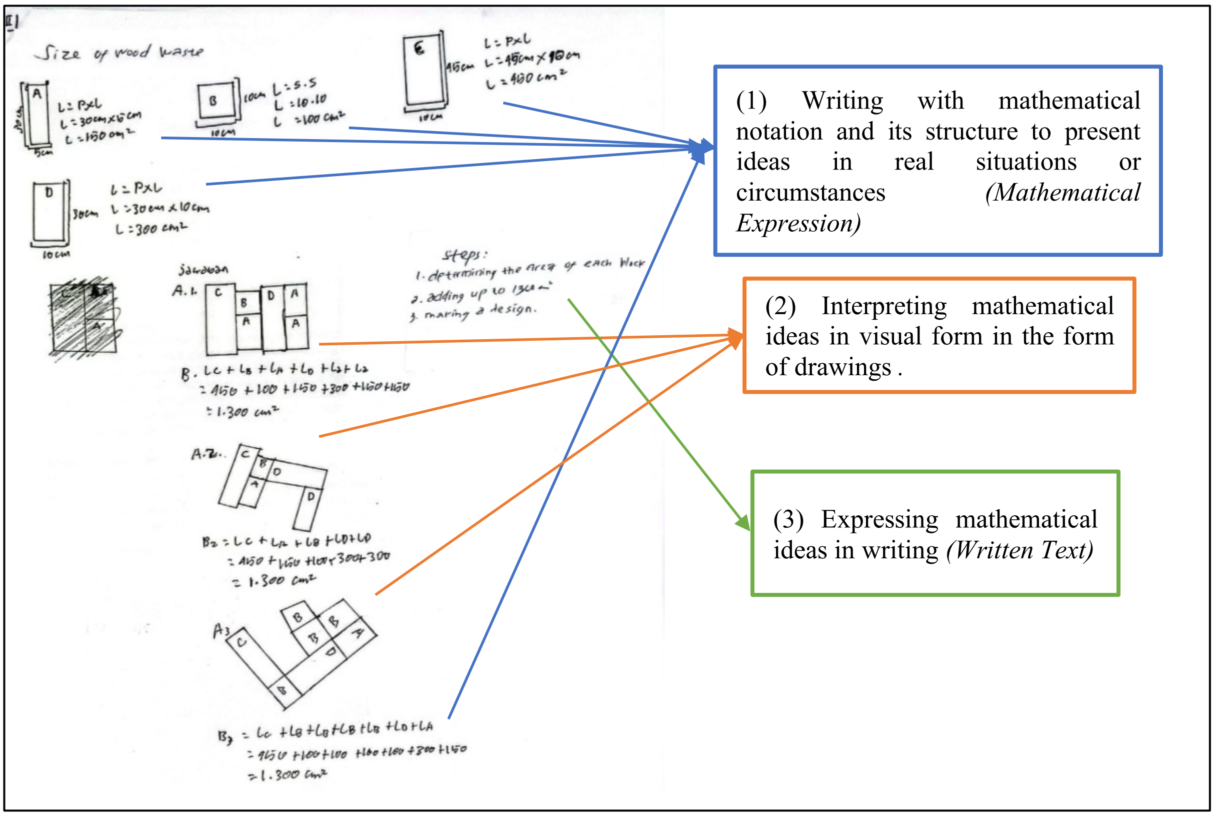

Figure 3. S23's response

b. S14

The analysis shows S14's performance on each indicator as follows: (1) *Mathematical Expression* Indicator: S14 consistently used mathematical notation when calculating the area of each piece of wood. However, when calculating the total area, S14 wrote only the final result without showing the addition of individual pieces. This made the calculation process less transparent and made it difficult to trace the origin of the final value. (2) *Drawing* Indicator: S14 was able to create visual sketches of the wood pieces, but the drawings did not

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reflect the actual dimensions. For example, wood piece B, which is only 10 cm long, appeared much larger than other pieces that should have been longer and wider. Similarly, in the second sketch, the size comparisons between pieces were inaccurate. This indicates that S14 still needs to practice drawing while paying closer attention to proportional dimensions. (3) *Written Text* Indicator**:** S14 provided only brief descriptions of the solution steps, which were not fully aligned with the actual calculation process. There was a discrepancy between what was written and the steps shown in the calculations, making the thought process unclear. This suggests that S14 needs to improve the ability to express mathematical ideas in writing in a coherent manner that accurately reflects the problem-solving process.

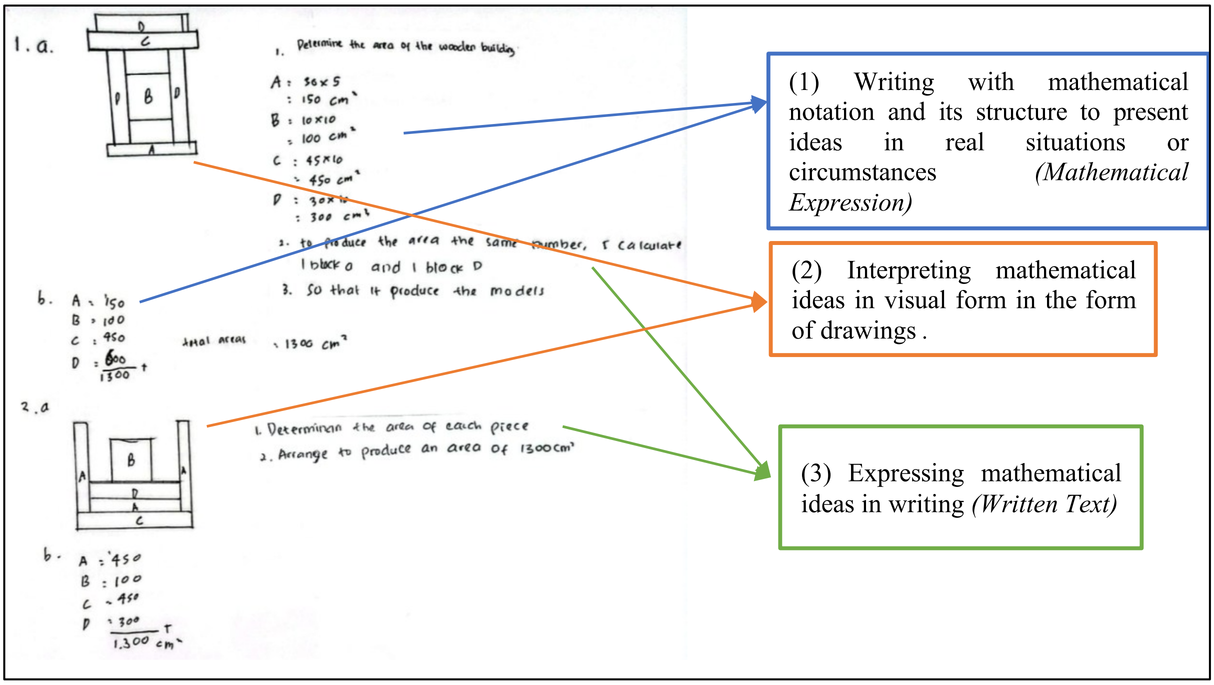

Figure 4. S14's response

2. Test results for open questions for students with high communication skills

The subjects in the high mathematical communication category were S16 (male, score 83) and S12 (female, score 100). The analysis of their responses is presented in Figure 5 and Figure 6.

a. S16

The analysis results show S16's performance on each indicator as follows: (1) Mathematical Expression Indicator: S16 used mathematical notation correctly and clearly when calculating the area of each piece of wood. However, when calculating the total area, S16 wrote only the final result without detailing the contribution of each piece. This made the calculation process less transparent and made it difficult to trace the steps thoroughly. (2)

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Drawing Indicator: S16 was able to depict sketches accurately and proportionally, paying close attention to size details. Each piece of wood was drawn according to the given length and width ratios, resulting in a neat and realistic visualization. This demonstrates that S16 has strong spatial understanding and can effectively translate numerical information into visual representations. (3) Written Text Indicator: S16 recorded the steps taken to solve the problem, but the explanations were general and did not fully detail the calculation process. The paper lacked a coherent line of reasoning, so the mathematical ideas were not fully conveyed. This suggests that S16 still needs to improve the ability to write more detailed and structured explanations.

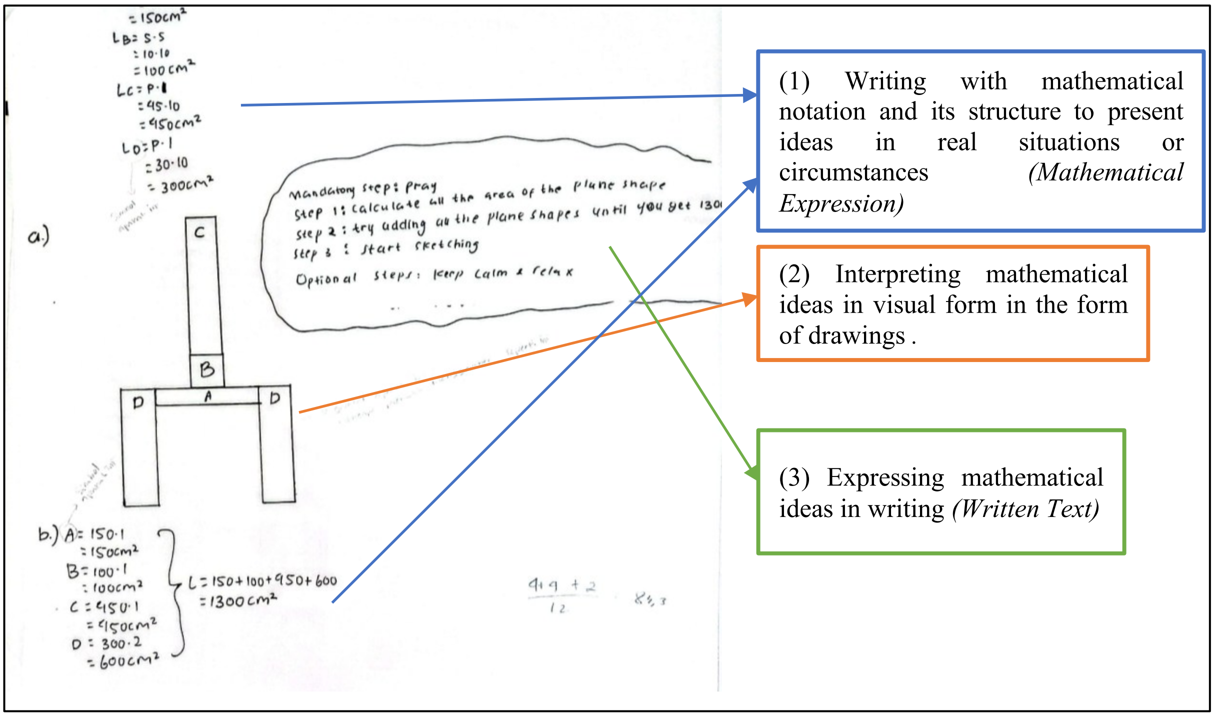

Figure 5. S16's response

b. S12

The analysis shows S12's performance on each indicator as follows: (1) Mathematical Expression Indicator: S12 consistently uses mathematical notation when calculating the area of each piece of wood. When calculating the total area, S12 demonstrates excellent proficiency in presenting answers mathematically. The notation is both diverse and consistent, with different symbols or labels assigned to each piece, making it easy to trace the ideas conveyed. S12 also calculates the area of each sketch accurately and completely, in accordance with the question's requirements. (2) Drawing Indicator: In terms of visualization, S12 depicts the sketches clearly and proportionally, following the given specifications. The drawings are accurate and varied, and S12 explores multiple possibilities for arranging the

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beams vertically and horizontally, demonstrating flexible and creative thinking. (3) Written Text Indicator: S12 provides a complete and concise written explanation of the solution steps. The explanation is easy to understand and demonstrates a strong grasp of the problem content. Additionally, S12 applies multiple approaches or concepts, including flat building area, algebra, and combinatorics, making the written solution unique and reflecting advanced, mature thinking. This demonstrates that S12 not only understands mathematical concepts but is also able to communicate them effectively in written form.

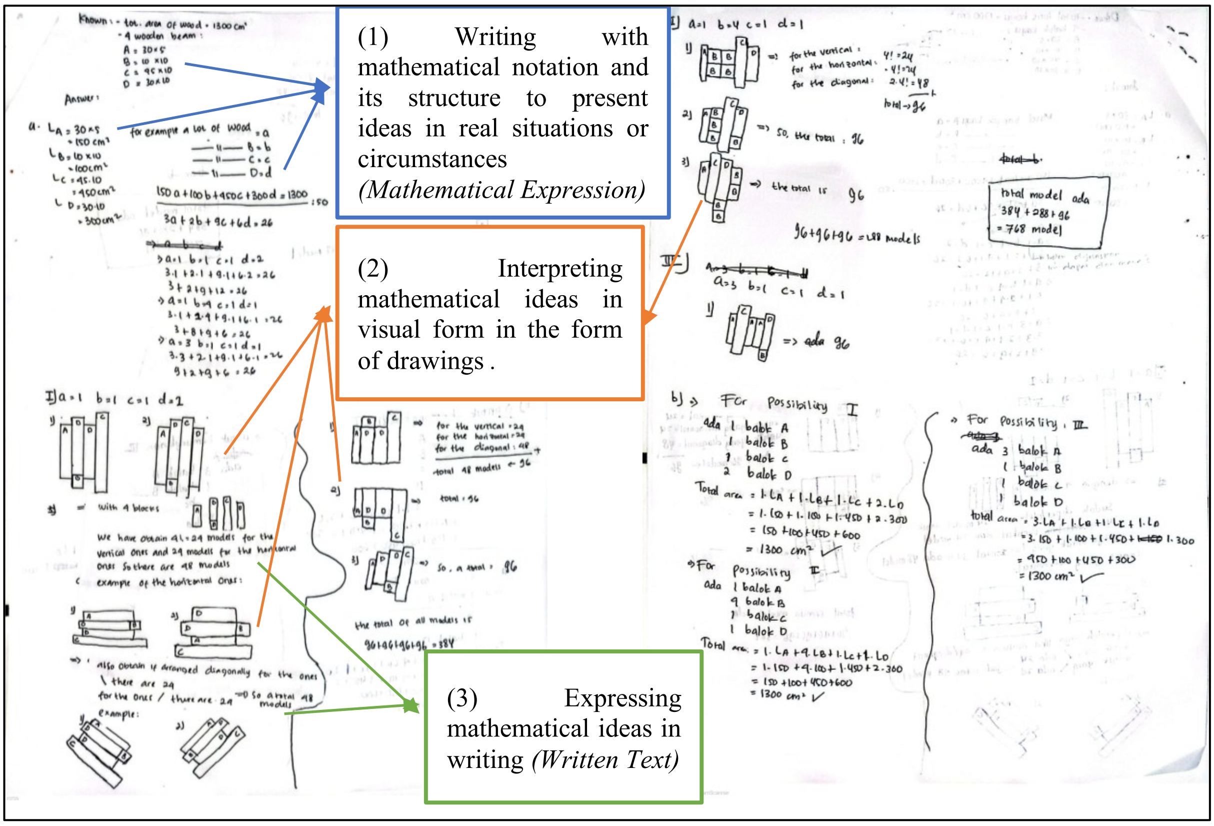

Figure 6. S12's response

After analyzing each student's responses according to the three indicators of written mathematical communication—mathematical expression, visualization, and written explanation—the results are summarized in Table 3 to facilitate comparisons among the subjects.

Analysis of students' written mathematical communication skills by gender revealed differences in how male and female students express their mathematical ideas. Female students tend to formulate answers more neatly and systematically, often including clear narratives. However, occasional errors still appear in strategy selection or inconsistencies in visual representations. This aligns with research by Qirom *et al.*, (2023) which found that female students are generally more proficient in using mathematical language to convey

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problem-solving strategies. In contrast, male students often display confidence in exploring ideas but are less consistent in documenting their steps in detail and tend to omit narrative explanations. Suprapto *et al.*, (2023), similarly reported that male students rely more on visual approaches and quick logic, whereas female students are more structured and careful in developing their answers. These differences also influence students' selection and application of mathematical concepts when solving problems.

Table 3. Summary of the results of the analysis of students' written mathematical communication skills

Student Code	Ability category	Gender	Indicator 1 (Mathematical Expression)	Indicator 2 (Visualization)	Indicator 3 (Written Text)	Score
S26	Low	Woman	Notation is the same for all parts, but inconsistent in calculating the total area	Disproportionate drawings; misalignment between pieces of wood	No narrative explanation; only calculations	58
S13	Low	Man	Inconsistent notation between parts and totals	Proportional and concrete sketches	Brief explanations; unclear order of thinking	58
S23	Medium	Man	Notation is the same for all parts, but inconsistent in total calculation	Visualization is disproportionate; length/width does not match reality	Steps are described but incomplete and unsystematic	75
S14	Medium	Woman	Consistent when counting parts, but does not list processes when totaling	Disproportionate images; inappropriate size	Short steps; not aligned with the actual process	75
S16	High	Man	Notation is clear and correct per section, but does not describe the total process	Sketches are neat, proportional, and attentive to size details	Explanations are general and not detailed	85
S12	High	Woman	Notation is consistent and varied, with complete justification for each part	Proportional, varied, and creative sketches (vertical and horizontal)	Clear, concise explanations using broad concepts, algebra, and combinatorics	100

In the context of open-ended problem-solving, students employ diverse approaches to using mathematical concepts. Many students rely on a single central concept, while others integrate multiple ideas, such as algebra and combinatorics, to develop more complex solutions (Karlimah *et al.*, 2020). Aulia *et al.*, (2024) further highlights that students with a stronger conceptual understanding are better able to combine strategies and knowledge from different domains. This demonstrates that mathematical communication skills and depth of conceptual understanding interact, enhancing the effectiveness of problem-solving (Umaratu *et al.*, 2022; Fitri & Darhim, 2023).

The analysis indicates a reciprocal relationship between mathematical communication and open-ended problem-solving. Engaging with questions that require explanation not only strengthens students' grasp of mathematical concepts but also develops their critical and creative thinking skills (Rahmawati et al., 2022). Therefore, integrating activities that promote communication, such as open-ended problems, is essential for improving students' overall academic understanding and skills (Mirna et al., 2023).

This study demonstrates that students' written mathematical communication skills vary according to ability level and gender. High-ability students tend to convey mathematical ideas more clearly and concisely, whereas students with medium and low abilities continue to struggle with notation, visualization, and written explanations. Limitations of this study include a small sample size and a limited number of questions. Future research should include more participants and diverse open-ended tasks that allow multiple solution strategies.

CONCLUSION

Students with low written mathematical communication skills, both male and female, generally struggle to meet the indicators optimally. Male students tend to use inconsistent notation and produce disproportionate drawings, while female students are neater but provide brief and incomplete steps. In the medium category, male students begin to explore visual representations, though not yet proportionally accurate, whereas female students demonstrate consistent notation but still lack detailed explanations. Among high-ability students, both genders meet all three indicators effectively; however, their strengths differ: female students excel in complete written narratives, while male students excel in proportionate and creative visual representations.

Future studies should involve larger samples and more varied learning contexts to enhance representativeness. Additionally, students should be given open-ended problems that encourage diverse solution strategies, proper use of notation, coherent answer structures, and reinforced explanations both orally and in writing. Such research will provide a more comprehensive understanding of the development of students' mathematical communication skills.

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