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Analysis of students' mathematical communication ability in solving problems on the Pythagorean theorem

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Abstract

Mathematical communication skills are essential for learning mathematics. Nevertheless, many students still demonstrate low proficiency, particularly among junior high school students. This study aimed to describe and analyze students' mathematical communication abilities regarding the Pythagorean theorem. The research employed a descriptive qualitative approach with a sample of 20 eighth-grade students at SMPN 2 Pekanbaru. Data were collected using a mathematical communication ability test in problem-solving. The test consisted of three essay questions based on indicators of mathematical communication skills. Data analysis techniques included data reduction, data presentation, and concluding. The results indicate that the mathematical communication ability of eighth-grade students at SMPN 2 Pekanbaru on the Pythagorean theorem topic falls into the low category, with an average score of 32.91. Based on the test indicators, the ability to represent everyday problems using mathematical language was categorized as low (26%). Interpreting images into mathematical symbols and language was moderate (43%), while presenting statements into mathematical models was also low (28%). These findings indicate that students are not yet able to communicate their mathematical thinking processes in a coherent manner. The implication is that instructional practices should provide opportunities for students to explain their problem solving steps and consistently engage in mathematical communication during classroom activities.

Keywords: mathematical communication; problem solving; Pythagorean theorem; junior high school students

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I. Introduction

Mathematical communication ability is a fundamental skill for students to possess (Hendriana, Rohaeti, & Sumarmo, 2021). This ability plays a central role in mathematics learning, as it is essential for conveying mathematical ideas among individuals to facilitate understanding of mathematical concepts (Ahmad, Rohani, Siregar, & Sabri, 2022). Mathematical communication refers to an individual's capacity to express mathematical ideas and concepts both orally and in writing, as well as to understand, analyze, and critically evaluate mathematical ideas presented by others in a careful, logical manner, with the aim of deepening understanding (Lestari & Yudhanegara, 2017). This ability is explicitly stated as a learning objective in the Merdeka curriculum, where students are expected to communicate situations mathematically using models or symbols and explain their reasoning through words, tables, diagrams, or other media (Wanabuliandari, Junaedi, & Mulyono, 2024).

The interrelation among these perspectives suggests that mathematical communication functions not merely as a medium for conveying results but also as a cognitive process that facilitates students in constructing and negotiating mathematical meaning. Through communication, students articulate not only their answers but also their reasoning and thought processes. Consequently, mathematical communication is a bridge linking students' conceptual understanding and logical thinking skills in solving mathematical problems.

The importance of mathematical communication skills is also reflected in the Merdeka Curriculum, in which students are expected to communicate situations mathematically through the use of models or symbols and to articulate their thinking using words, tables, diagrams, or other representational media (Noviyana, Dewi, & Rochmad, 2019; Wanabuliandari et al., 2024). This case was also explained by Sumarmo et al. as cited in (Nuraini, Yuanita, Murni, & Roza, 2023), there are several important reasons why students need mathematical communication skills: (1) this ability is part of the learning goals and is included in the curriculum; (2) fundamentally, mathematics is a symbolic language that is practical, logically structured, and capable of quantitative analysis; (3) communication serves as a foundation for mathematics learning; (4) it is a key element in designing and developing mathematical concepts; (5) it equips students to solve, examine, and express mathematical concepts, and serves as a medium for social activities such as exchanging ideas and opinions, emphasizing the presentation of ideas to persuade others; and (6) it can be applied in various contexts, both within mathematics and other disciplines.

However, reality shows that students' mathematical communication skills remain low. Research by Ahid, Waluya, & Kharisudin (2019) revealed that only 11% of students were able to solve word problems by meeting all indicators of mathematical communication skills. The percentage data further indicate that the level of students' underachievement in solving problems, as measured by these indicators, remains considerably high. Another study by Marniati, Jahring, & Jumriani (2021) revealed that students often hesitate to express mathematical opinions or ideas during the learning process. They struggle to solve story problems, both when using mathematical language and when using their own words, and have difficulty correctly using mathematical symbols. The study conducted at SMP Negeri 32 Pekanbaru by Yuliani & Vioskha (2022) also reinforces these findings, reporting an average mathematical communication score of 66.67 out of the maximum score, which is categorized as low.

The low level of students' mathematical communication skills cannot be separated from classroom learning practices that still focus primarily on obtaining the final answer rather than on the reasoning process and the way students communicate their solution steps (Hariati, Sinaga, & Mukhtar, 2022; Utami, Suarsana, Ardana, & Sugiarta, 2022). Lestari (2018) emphasizes that such instructional practices do not optimally support the development of mathematical communication skills. In fact, mathematical communication plays a crucial role in fostering systematic and structured thinking (Rasyid, 2019) and encouraging students to connect mathematical ideas with everyday contexts (Robiana & Handoko, 2020; Widayanti & Anggraeni, 2019). Therefore, strengthening mathematical communication skills has become essential to the learning process.

Based on an interview with the mathematics teacher at SMP Negeri 2 Pekanbaru, it was found that students still experience difficulties in creating sketches, translating real-life situations into mathematical symbols, and explaining their problem-solving processes logically and coherently when working on context-based problems related to the Pythagorean Theorem. Each mathematical topic, therefore, requires more in depth analysis (Ningrum & Hw, 2022). The Pythagorean Theorem is one such topic that demands strong mathematical communication skills (Wardana & Amidi, 2022).

Previous studies have revealed the low level of students' mathematical communication skills (Ahid et al., 2019; Marniati et al., 2021; Yuliani & Vioskha, 2022). However, prior research has not extensively focused on the Pythagorean Theorem, which requires strong representational and visual explanatory abilities, nor has it been conducted in the context of SMP Negeri 2 Pekanbaru.

This condition highlights a gap between the expectations of the curriculum and the realities observed in the field. Theoretically, mathematical communication is recognized as an essential aspect of learning; however, empirically, students' abilities remain low and have not been thoroughly examined, particularly within the context of the Pythagorean Theorem topic at SMP Negeri 2 Pekanbaru.

The novelty of this study lies in its context and analytical focus: identifying students' mathematical communication abilities through three key indicators in the Pythagorean Theorem topic within the framework of the Merdeka Curriculum. This analysis is expected to provide a more specific description of the types of difficulties students encounter when communicating their mathematical ideas, as well as serve as a foundation for developing more effective instructional strategies in the future.

Based on the aforementioned discussion and research gap, this study focuses on analyzing junior high school students' mathematical communication skills on the Pythagorean Theorem by examining three main indicators: (1) expressing everyday problems in mathematical models or language, (2) interpreting images into mathematical symbols or language, and (3) presenting statements in mathematical models or language.

II. Research Method

This study employed a descriptive qualitative design to analyze students' mathematical communication skills in solving problems related to the Pythagorean Theorem. The research was conducted during the even semester of the 2024/2025 academic year, involving 20 eighth grade students from SMP Negeri 2 Pekanbaru as participants. The participants were selected purposively, as the class represented a regular mathematics group following the Merdeka Curriculum and consisted of students with diverse ability levels. Furthermore, based on interviews with the mathematics teacher, students in this class still had difficulty explaining problem-solving steps coherently, making them appropriate subjects for analyzing mathematical communication skills related to the Pythagorean Theorem. Only students who actively participated in the learning process and completed the assigned test were included in the study. The research was conducted with the school's permission, and all participants' identities were kept confidential. Data were collected using a test instrument comprising open-ended questions developed based on indicators of mathematical communication skills.

The indicators of mathematical communication used in this study were: (1) expressing everyday problems as mathematical models or language; (2) interpreting images into mathematical symbols or language; and (3) presenting statements in the form of mathematical models or language. Scoring was conducted according to the mathematical communication skill assessment rubric proposed by Cai, Lane, and Jacobsen (Ahmad et al., 2022).

For the calculation and categorization of students' mathematical communication skills, the following formula was employed:

$$x = \frac{Skor\ diperoleh}{Skor\ maksimum} \times 100\%$$

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Based on the calculated percentage scores, students' mathematical communication skills were classified into three proficiency levels: high, moderate, and low (Andini & Marlina, 2021). Table 1 presents the categorization of mathematical communication skill levels.

Table 1. Categories of mathematical communication skill achievement percentages

Achievement Level of Mathematical Communication Skills	Category
$x > 66\%$	High
$33\% < x \leq 66\%$	Moderate
$x \leq 33\%$	Low

III. Results and Discussion

The test instrument used to measure students' mathematical communication skills consisted of three essay questions, as illustrated in Figures 1–3.

1. Seorang siswa mengikuti lomba orientering di area sekolah. Dari pos pertama, ia berjalan ke arah Timur sejauh 60 meter menuju pos kedua. Ia melanjutkan perjalanan ke arah Utara sejauh 45 meter menuju pos ketiga. Setelah itu, siswa tersebut berjalan ke arah Barat sejauh 100 meter menuju pos terakhir.
   a) Buatlah sketsa lintasan perjalanan siswa tersebut dari pos pertama hingga pos terakhir, serta tuliskan informasi yang diketahui dari soal!
   b) Berapakah jarak terdekat yang ditempuh siswa jika siswa langsung pergi dari pos kedua menuju pos terakhir? (tanpa melewati pos lainnya)
   c) Berapakah jarak terdekat yang ditempuh siswa jika siswa langsung pergi dari pos pertama menuju pos terakhir? (tanpa melewati pos lainnya)

Figure 1. Question 1

Figure 1 presents a question based on Indicator 1, which asks students to express everyday problems in mathematical models or language. Students were asked to write down the given information and depict the situation. They were also required to solve the problem using the concept of the Pythagorean Theorem.

2. Sebidang tanah berbentuk trapesium seperti pada gambar di bawah ini. Tentukan tinggi dan luas dari trapesium dengan menuliskan model matematikanya terlebih dahulu!

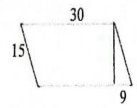

Figure 2. Question 2

Figure 2 shows a question aligned with Indicator 2, which focuses on interpreting images into mathematical symbols or language. Students were asked to interpret the given image, then apply the Pythagorean Theorem to determine the height and area of a trapezoid. They were also required to formulate the corresponding mathematical model prior to solving the problem.

3. Diketahui sebuah segitiga ABC dengan siku-siku di B. Jika diketahui panjang sisi AB 3x, BC 2x + 6, dan AC 5x.
   a) Gambarlah sketsa segitiga tersebut
   b) Tentukan nilai x tersebut
   c) Tentukan panjang sisi AB, BC, dan AC

Figure 3. Question 3

Figure 3 contains a question corresponding to Indicator 3, which entails presenting statements in the form of mathematical models or language. Students were instructed to create a sketch, comprehensively write down the given information, and then solve the problem.The data analysis results based on students' answers to the essay questions are summarized in Table 2 below.

Table 2. Statistical summary of mathematical communication skills

Statistical Measures	Mathematical Communication Ability Scores
Sample Size	20
Mean	32,91
Maximum Score	91,67
Minimum Score	16,67
Standard Deviation	24,55
Median	20,83
Mode	16,67

The results of the mathematical communication skills test on the Pythagorean Theorem topic indicated a generally low level of achievement, with an average class score of

32,91. The score range of 16,67-91,67 revealed that most students faced difficulties: some did not understand the problems, others only wrote down the given information without solving them, and some completed only part of the problems. The standard deviation of 24,55 reflects a wide variation in students' abilities; however, overall, these findings suggest that mathematical communication instruction, particularly within the topic of the Pythagorean Theorem, requires serious attention and improvement. This indicates that students' mathematical communication skills have not yet developed optimally, as instruction continues to emphasize final results rather than the mathematical thinking processes that represent idea communication (Hermawati & Amelia, 2024). The low achievement scores also signify that students have not yet developed the ability to connect visual and symbolic representations, as explained in the theory of mathematical communication (Sopari, Daniarsa, & Ulfatushiyam, 2022).

The percentage of students' achievement in mathematical communication skills based on each indicator is presented in Table 3.

Table 3. Percentage results of mathematical communication skills

Test Item	Indicator	Percentage of Achievement in Communication Skills	Criteria
1	Expressing everyday problems in mathematical models or language	26%	High
2	Interpreting images into mathematical symbols or language	43%	Moderate
3	Presenting statements in mathematical models or language	28%	Low

The research findings indicated that students' achievement in mathematical communication skills on question number 1 obtained the lowest percentage compared to the other items. Question number 2 showed the highest percentage; however, it still fell within the moderate category. The results suggest that most students were unable to complete the problems successfully and did not achieve maximum scores for each indicator of mathematical communication skills. The overall average achievement percentage was 32%, indicating that students' mathematical communication skills were classified as low.

These results demonstrate that indicator 1, namely the ability to translate real-life problems into mathematical models, was the most challenging aspect. According to Qonaah, Pujiastuti, & Fatah (2019), this skill requires abstract thinking and a strong command of mathematical language. Meanwhile, the relatively higher score for indicator 2 may be attributed to students' reliance on visual representations, even though they were still unable to connect symbols to their corresponding mathematical meanings fully.

After obtaining processed data for each indicator across the test items, further analysis and discussion were conducted to interpret students' responses in terms of indicators of mathematical communication skills in the Pythagorean Theorem topic. The analysis of students' responses to question number 1 is presented as follows.

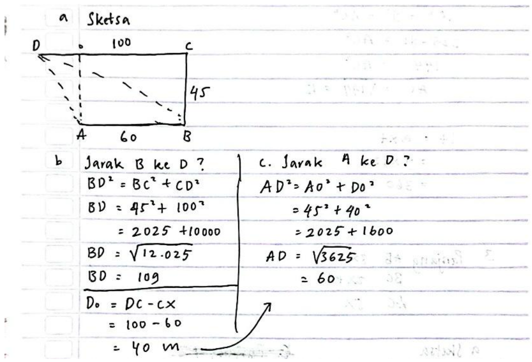

Figure 4. The answer provided by student S1 to question 1

Figure 4 shows that student S1 was able to connect mathematical ideas to the diagram and correctly solved the problem using the Pythagorean Theorem. The student successfully determined the distance traveled from the second point to the final point, as well as the distance from the first point to the last point, without passing through any intermediate points. However, the student did not write down the information provided in the problem statement, resulting in an incomplete solution. This finding aligns with the study by Nuraini et al. (2023), which reported that students often omit writing the known information and the questions asked in the problem. Writing down both elements is crucial for solving problems because written responses not only emphasize the correct answer but also highlight how students express their reasoning in problem-solving. This aligns with the view of Qodariyah & Hendriana (2015), who assert that mathematical communication encompasses not only the ability to produce correct answers but also the process of transforming ideas and reasoning into written forms that are logical and understandable to others.

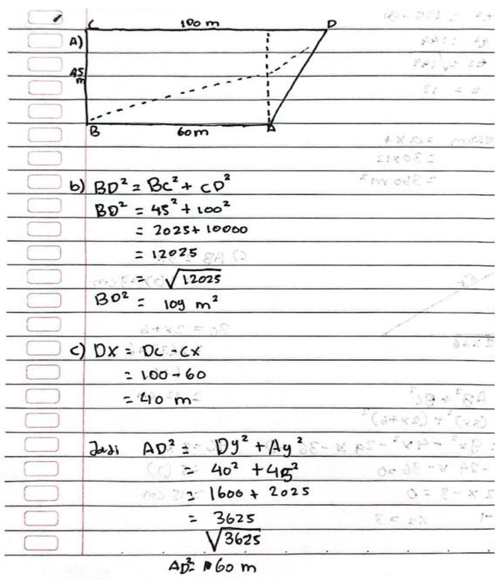

Figure 5. The answer provided by student S2 to question 1

Figure 5 shows that student S2 did not include the initial information or the problem-solving task objective. As a result, the student was unable to connect mathematical ideas to the diagram, leading to inaccurate and inconsistent work that did not align with the information provided in the problem. Although the student arrived at the correct final answer, the problem-solving process was flawed. This finding is consistent with the study by Hikmawati, Nurcahyono, & Balkist (2019), which revealed that students are often unable to fully utilize all the information given in the problem with appropriate understanding, negatively affecting the problem-solving process.

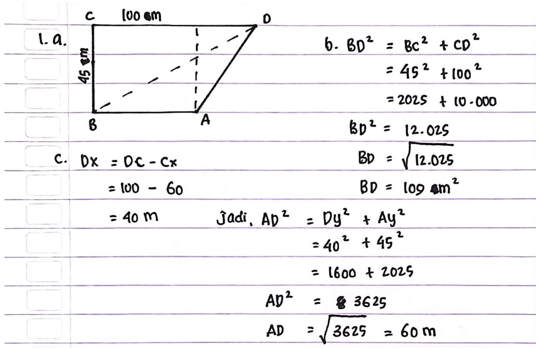

Figure 6. The answer provided by student S3 to question 1

Figure 6 illustrates that student S3 neglected to present the initial information and the problem-solving objectives. Consequently, the student was unable to relate the mathematical ideas to the diagram, resulting in inaccurate, inconsistent work that did not align with the information provided in the problem. Although the student arrived at the correct final answer, the problem-solving process was incorrect.

Both students S2 and S3 were able to identify real-life situations in the diagrams; however, they inaccurately represented the problem's scenario. The problem stated that the movement from the first position was to the east, meaning from the starting point to the right. However, based on their answers, the students misunderstood the problem, as they depicted the movement from the starting point towards the left. This initial error in sketching the travel path led to inaccuracies throughout the sketching process. This indicates that students still struggle with translating everyday life problems into accurate diagrams. This finding is supported by the study by Fiyah & Shodikin (2021), which found that students' errors in mathematical modeling stem from their inability to identify critical information or key statements in the problem, leading to difficulties with solving the given tasks.

From Figures 4, 5, and 6, it is evident that some students are still unable to express everyday problems using mathematical models or language. For question 1, only one student answered correctly and achieved the maximum score. Ten students attempted the question; however, several did not write down the initial information and the objective of the problem, while others did so inaccurately. Some students completed the problem and provided the correct final answer, but their problem-solving process was incorrect. Additionally, nine students left the question unanswered. The following section presents the analysis and discussion of students' responses to question 2.

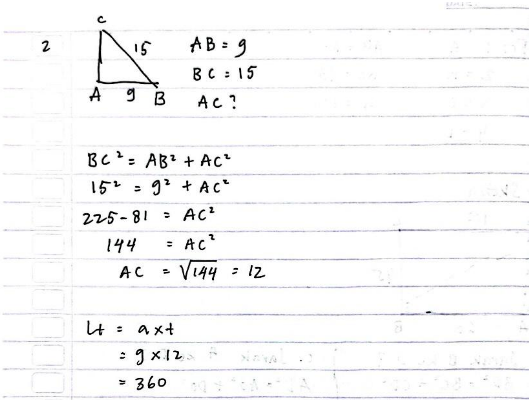

Figure 7. The answer provided by student S1 to question 2

Figure 7 shows that student S1 was able to interpret the diagram into mathematical symbols or language. Student S1 presented the initial information and the problem-solving objective comprehensively and correctly solved the problem. The student followed the appropriate steps, calculating side AC using the Pythagorean Theorem to determine the height and, thus, the area of the trapezoid, and successfully completed the problem.

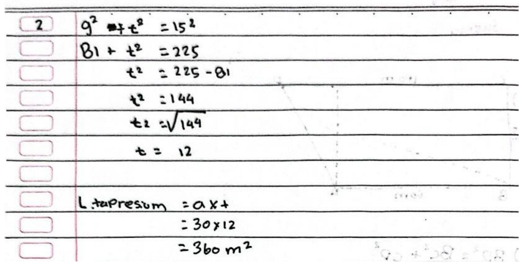

Figure 8. The answer provided by student S2 to question 2

Figure 8 shows that student S2 answered question 2 correctly but still neglected to present the initial information and the problem-solving objective, resulting in an incomplete response.

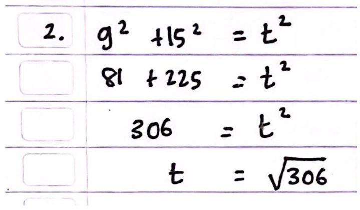

Figure 9. The answer provided by student S3 to question 2

As shown in Figure 9, student S3 responded only by writing what they already knew, without seeking or constructing a solution. The student did not fully understand the diagram's meaning or the appropriate steps for solving the problem. Moreover, the student incorrectly substituted 15^2 in an inappropriate place, resulting in an inaccurate answer. Consistent with this, Ramadhan & Minarti (2018) stated that students who experience difficulties in solving problems involving figures or diagrams generally do so because of insufficient comprehension of the problems, which leads to a lack of confidence when responding. According to the theory of mathematical communication, such difficulties arise because students are not yet accustomed to connecting visual representations with mathematical symbols (Asih, Isnarto, & Wardono, 2019). Consequently, their conceptual understanding and spatial reasoning skills have not developed adequately.

Figures 8 and 9 indicate that some students still have difficulty interpreting diagrams

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into mathematical symbols or language. For question 2, two students answered correctly. Seventeen students attempted the question but did not provide complete answers. Several students still did not write down the initial information and problem-solving objectives; some wrote these, but inaccurately. Some students provided accurate information but made errors during the problem-solving process, and one student left the question unanswered. The following section presents the analysis and discussion of students' responses to question 3.

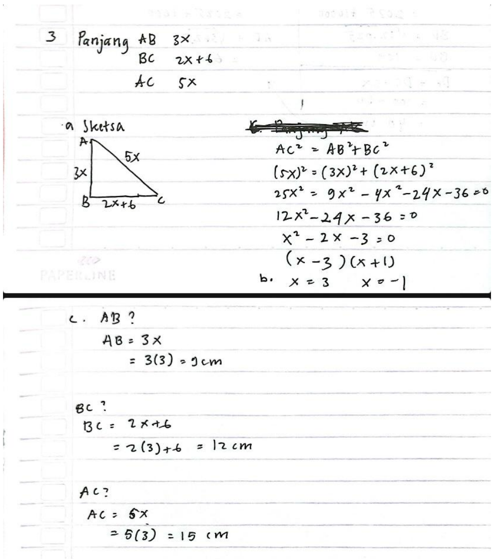

Figure 10. The answer provided by student S1 to question 3

Figure 10 shows that student S1 has written down all the information provided in the problem and has related the mathematical ideas to the diagram, thereby successfully solving the problem. The student determined the value of x, which was used to find the lengths of all triangle sides, and completed the problem accurately.

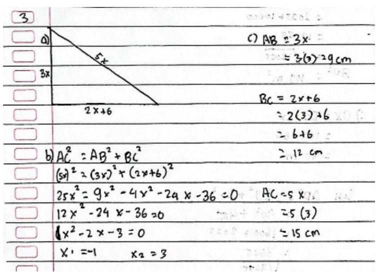

Figure 11. The answer provided by student S2 to question 3

Figure 11 shows that student S2 did not write down the initial information and problem-solving objectives, but was able to relate the mathematical ideas to the diagram accurately. The student successfully solved the problem by finding the value of x to determine the lengths of all triangle sides.

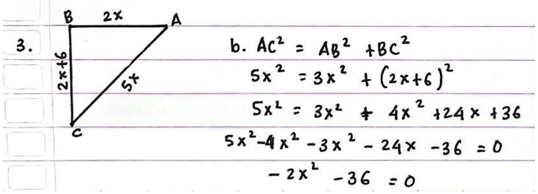

Figure 12. The answer provided by student S3 to question 3

Figure 12 shows that student S3 did not write down the initial information and the problem-solving objectives but was able to relate the mathematical ideas to the diagram. However, student S3 only responded based on what they knew, without continuing to look for a solution. It can be observed that the student wrote $5x^2$ instead of $(5x)^2$ and $3x^2$ instead of $(3x)^2$. These two expressions clearly have different meanings and results, which prevented the student from progressing further in solving the problem. This issue likely arose due to a lack of careful understanding and attention when interpreting and working through the problem.

This finding aligns with the view of Sulastri & Sofyan (2022), who stated that students often lack understanding in the problem-solving process and tend to be inaccurate when interpreting questions. Furthermore, from a computational perspective, Ahmad & Nasution (2018) found that students frequently made calculation errors, suggesting they had not yet mastered basic arithmetic operations. These findings support the concept of mathematical communication, which emphasizes conceptual understanding, the use of symbols, and the ability to create appropriate representations (Aini & Setianingsih, 2022; Andini & Marlina, 2021). Students who have not yet mastered mathematical symbols and operations often struggle to express their ideas in mathematical models.

Figures 11 and 12 show that some students are still unable to present statements in mathematical models or language. For question 3, two students answered correctly, and ten attempted it. Among them, some neglected to present the initial information and the problem-solving objectives. Some students were accurate in the initial steps but made errors during the problem-solving process, and eight students left the question unanswered. Based on an analysis of unanswered questions, Ahmad & Nasution (2018) found that students who struggle to understand the stages of problem-solving are unable to fully comprehend the problem, resulting in incorrect or incomplete answers.

The diverse levels of students' mathematical communication skills influence the variation in their understanding. Students' comprehension and mastery of mathematical concepts are fundamental components (Nasrullah, 2022). The underdevelopment of mathematical communication skills is also influenced by non-cognitive factors, such as students' tendencies to be shy or reserved, or to lack confidence in expressing ideas or opinions, whether orally or in writing (Ahmad & Nasution, 2018). Furthermore, regular practice through consistent problem assignments is necessary to assess and improve mathematical communication skills (Hikmawati et al., 2019). Based on the findings presented, mathematical communication skills need to be developed as optimally and comprehensively as possible. Overall, this study's findings indicate that mathematical communication skills encompass conceptual understanding, problem-solving procedures, and the ability to present mathematical ideas effectively (Fahmi, Sutiarso, & Coesamin, 2019). These results underscore the importance of instructional practices that provide students with opportunities to engage in discussion, use visual models, and articulate mathematical explanations in writing.

This study acknowledges several limitations. The sample was limited to 20 students from a single class, limiting the generalizability of the findings to a broader population. Moreover, the research focused exclusively on the Pythagorean Theorem and relied solely on written tests, thereby failing to fully represent students' mathematical communication skills in authentic classroom interactions or oral contexts. The study also did not account for other potential factors influencing mathematical communication, such as learning motivation, self-confidence, and teachers' instructional strategies.

In light of these limitations, future research is encouraged to involve a larger and more diverse sample across multiple schools to ensure greater representativeness. Subsequent studies may also employ complementary data-collection methods, such as interviews and classroom observations, to obtain a more holistic understanding of students' mathematical communication skills. Furthermore, future investigations could explore the application of specific instructional models designed to enhance students' mathematical communication, particularly in problem-solving situations.

IV. Conclusion

Based on the results and discussion presented, it is evident that the level of mathematical communication skills among eighth-grade students in Class VIII.2 at SMP Negeri 2 Pekanbaru, particularly regarding the Pythagorean Theorem, generally falls into the low category with an average score of 32,91. Regarding specific indicators, the mathematical communication skill for question 1, which involved writing everyday problems in mathematical models or language, did not meet the indicator and was classified as low (26%). For question 2, interpreting images into mathematical symbols or language was categorized as moderate, with a 43% score. For question 3, presenting statements in mathematical models or language did not meet the indicator, and it remained in the low category, with a 28% score. These findings suggest that mathematical communication skills need to be developed optimally and evenly among students, which requires habitual practice through consistent assignment of related problems.

For teachers and prospective teachers, it is essential to strengthen both the instruction of the Pythagorean Theorem and students' mathematical communication skills. Teachers should pay greater attention to students' problem-solving processes and provide adequate facilities and learning resources to support effective instruction. For students, engage more consistently in practice and deepen their conceptual understanding so that their mathematical communication skills can develop more effectively.

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