

Problem-based learning: Assessing students' mathematical communication in story problems

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Abstract

Students often have difficulty solving mathematical word problems because they must interpret contextual information, construct mathematical representations, and clearly communicate their reasoning. These challenges are closely related to students' mathematical communication skills, which play an important role in supporting conceptual understanding and problem solving. Therefore, this study aims to describe students' mathematical communication skills during the implementation of the Problem-Based Learning (PBL) model in solving word problems on lines and angles. This research employed a qualitative descriptive approach conducted at SMP Negeri 3 Plumpang, Tuban, involving seven seventh-grade students selected through purposive sampling based on different levels of academic ability. Data were collected through written tests, classroom observations, and documentation, and analyzed using an interactive qualitative analysis consisting of data reduction, data display, and conclusion drawing. The results show that students' mathematical communication skills vary across ability levels. Students in the high category were able to present accurate visual representations, use mathematical notation correctly, and explain solution steps clearly and coherently. Students in the medium category were able to use mathematical symbols and provide explanations but still showed limitations in constructing visual representations. Meanwhile, students in the low category had difficulty representing problems and expressing mathematical ideas systematically. These findings indicate that implementing PBL can support the development of students' mathematical communication skills through collaborative discussion and problem-solving activities. This study contributes to a deeper understanding of how mathematical communication skills emerge during PBL-based learning in mathematics classrooms.

Keywords: Problem-Based Learning, Mathematical Communication, Story Problem, Mathematics

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INTRODUCTION

Mathematics learning at various educational levels, both nationally and internationally, continues to reveal students' difficulties in solving word problems (Melinda & Zainil, 2020). Word problems require not only mastery of mathematical concepts but also the ability to interpret contextual information, transform narratives into mathematical representations, determine appropriate solution strategies, and communicate reasoning systematically (Utami et al., 2023). Many students experience obstacles in identifying relevant information, constructing mathematical models, and explaining solution processes clearly (Kusumah, 2020). These challenges are closely related to mathematical communication skills, which involve expressing ideas, interpreting symbols, constructing representations, and explaining reasoning both orally and in written form (Putri & Musdi, 2020). Mathematical communication plays a fundamental role in learning mathematics by supporting conceptual understanding and problem-solving.

Theoretically, mathematical communication includes the ability to represent ideas visually, use mathematical symbols and structures appropriately, and express reasoning coherently through written text and oral explanation (Maryati et al., 2022; Nugraha & Pujiastuti, 2019). Communication in mathematics occurs through discussion, presentation, and explanation, as well as through written representations such as diagrams, symbols, tables, and mathematical expressions (Sastradiharja & Febriani, 2022). In geometry, particularly on the topic of Lines and Angles, students are required to interpret relationships between lines, identify types of angles, construct appropriate representations, and explain reasoning logically (Anderha & Maskar, 2020). When such material is presented in the form of word problems, students must translate contextual situations into geometric models and communicate their thinking clearly (Siagian et al., 2023). Therefore, mathematical communication becomes central in understanding and solving contextual geometric problems.

One instructional approach considered capable of facilitating the development of mathematical communication skills is *Problem-Based Learning* (PBL). PBL emphasizes student-centered learning by engaging students in collaborative exploration of contextual problems (Wati & Yerizon, 2024). Through group discussion, investigation, and presentation, students are encouraged to articulate ideas, justify reasoning, and

reflect on problem-solving strategies. According to Andika & Hidayat, PBL promotes active participation and critical thinking by situating learning within real-life contexts. In addition, PBL supports the development of communication skills, as students are required to explain their reasoning processes both orally and in writing (Ramadhan et al., 2023).

Previous studies have examined the relationship between PBL and mathematical communication skills. Several findings indicate that the implementation of PBL contributes to improving students' mathematical communication outcomes (Mirna et al., 2023; Safitri et al., 2021). Other studies reveal differences in communication performance across ability levels, where high-ability students tend to fulfill communication indicators more completely than medium- and low-ability students (Dewanti & Muna, 2023; Ulymaz et al., 2022). These studies provide important evidence that PBL is associated with improved communication performance. However, most previous research has focused primarily on quantitative outcomes such as score improvement or categorical achievement levels. Limited attention has been given to examining in depth how mathematical communication processes unfold during classroom interactions, particularly when students interpret word problems, construct representations, discuss ideas, and express reasoning within PBL activities.

This gap indicates the need for a qualitative exploration that emphasizes the communication process rather than merely its measurable outcomes. Grounded in the theoretical framework of mathematical communication, which covers visual representation (drawing), mathematical expression, and written or oral explanation (Putri & Musdi, 2020), this study seeks to analyze how students' communication skills emerge and develop during PBL implementation in solving word problems on the topic of Lines and Angles. The difference between this study and previous research lies in its focus on process-oriented analysis of communication characteristics during learning activities, rather than on statistical comparison of achievement scores (Siswadi et al., 2023). This research employed a qualitative descriptive approach involving seven purposively selected seventh-grade students with varying levels of academic ability. Data were collected through written tests, classroom observations, and documentation, and analyzed using an interactive data analysis model consisting of data reduction, data display, and conclusion drawing. Coding procedures were applied to identify patterns of

mathematical communication across different ability levels.

Based on the issues and research gap described above, this study aims to describe how students' mathematical communication skills appear and develop during Problem Based Learning in solving word problems on Lines and Angles, to analyze the communication processes occurring during classroom interaction, and to identify the characteristics of mathematical communication across different levels of student ability. The novelty of this article lies in its emphasis on analyzing the dynamics and characteristics of mathematical communication processes within problem-based learning, thereby contributing to a deeper understanding of how communication unfolds in mathematics classrooms.

METHODS

The purpose of this study is to explain students' mathematical communication skills when solving word problems using the PBL model. Therefore, this research design was chosen as a qualitative, descriptive study. This study focuses on certain events, specifically students' written mathematical communication skills when solving word problems. This research was conducted at SMP Negeri 3 Plumpang, Tuban Regency, East Java, in the even semester of the 2024/2025 academic year. The research subjects consisted of 7 seventh-grade students selected through purposive sampling to reflect variation in academic ability. Data collection techniques included written tests, observation, and documentation. During the learning process, observations were used to track student activities, written tests were used to measure their mathematical communication skills, and documentation was used as supporting data. The research instruments consisted of observation sheets, essay test questions, and documentation of student work.

The research process consists of four main stages: preparation, planning, implementation, and data analysis (Faizah & Sugandi, 2022). In the preparation stage, the researcher conducted a literature review, formulated the research objectives, and developed the main instrument, a written test designed to measure students' mathematical communication skills. Developing a PBL-based teaching module for the learning of lines and angles was part of the planning stage. The authors also created

mathematical communication metrics to analyze student work. This study used indicators of mathematical communication ability, as presented in [Table 1](#).

Table 1. Indicators of Mathematical Communication Ability.

Written Mathematical Communication Indicators	Oral Mathematical Communication Indicators
Interpreting mathematical ideas into visual representations in the form of graphs or images (Drawing). This indicator reflects the ability to present mathematical concepts or data visually through relevant graphs or illustrations, making them easier to understand in a real-world context.	Interpreting mathematical ideas orally (Drawing). This indicator includes the ability to explain and describe mathematical concepts or ideas orally in a clear, structured, and accurate manner, particularly when interpreting images or graphs, making them easy to understand.
Writing mathematical ideas using appropriate mathematical notation and structures to represent situations or problems in a real-world context (Mathematical Expression). This indicator relates to the ability to present mathematical concepts symbolically, clearly, and in a structured manner so that they accurately depict real-world conditions.	Using mathematical notation and structures verbally to present ideas in real-world situations or contexts (Mathematical Expression). This indicator relates to the ability to verbally explain mathematical concepts or ideas by using relevant notation and structures accurately so that others can understand them.
Expressing mathematical ideas in written text (Written Text). This indicator emphasizes the ability to convey mathematical concepts or ideas through sentences that are systematic, clear, and easily understood by others.	Expressing mathematical ideas orally (Written Text). This indicator emphasizes the ability to convey and explain mathematical concepts or ideas orally clearly and coherently so that the listener can understand them.

The implementation phase was conducted through PBL-based learning consisting of two meetings. Students were divided into small groups to solve context-based story problems, then given individual written tests to evaluate their written mathematical communication skills. In the data analysis phase, students' answers were analyzed using a qualitative descriptive approach. Each indicator was scored on a scale of 1–4. The scores for each indicator were then converted into percentages using the following formula:

$$IK = \frac{n}{NM} \times 100$$

Description:

IK : Average score for each indicator.

N : Total scores obtained by all students for each indicator.

NM : Maximum score for each indicator.

The average score for each indicator is then converted into a quality category based on [Table 2](#).

Table 2. Conversion of Quality Categories by Percentage

Criteria	Information
$0 \leq X < 65$	Low
$65 \leq X < 80$	Medium
$80 \leq X \leq 100$	High

Adoption (Febriana et al., 2024)

Next, the following formula is used to determine the average mathematical communication ability:

$$RK = \frac{\text{sum of all students' scores}}{\text{number of students}}$$

Description:

RK: average mathematical communication ability of students.

RESULT AND DISCUSSION

Test Results (Written Mathematical Communication Skills)

This section describes students' mathematical communication skills in written form through the application of the PBL model to solving word problems. The analysis was based on three indicators: a. Interpreting mathematical ideas into visual representations in the form of pictures or graphs (Drawing), b. Writing mathematical ideas using appropriate mathematical notation and structures to represent situations or problems in real-world contexts (Mathematical Expression), and c. Expressing mathematical ideas in written text (Written Text). The study subjects consisted of seven students. The results for each student category are presented in [Table 3](#).

Table 3. Test Data Results

No.	Name	Average value	Category
1.	D	100	High
2.	F	100	High
3.	N	75	Medium
4.	J	75	Medium
5.	I	75	Medium
6.	E	33	Low
7.	Q	33	Low
Total		70,14	Medium

Students with High Ability

Soal

Rani memiliki dua buah batang kayu. Batang kayu pertama panjangnya 60 cm, dan batang kayu kedua panjangnya 40 cm. Kedua batang kayu tersebut dihubungkan dengan sebuah paku sehingga membentuk sudut = 90° . Kemudian, Rani mengikat seutas tali dari ujung batang kayu pertama ke ujung batang kayu kedua. Berapakah panjang tali yang menghubungkan kedua ujung batang kayu tersebut?

Jawaban :

Panjang batang kayu pertama = 60 cm
 Panjang batang kayu kedua = 40 cm
 Kedua batang kayu membentuk sudut = 90°
 Di tanya : Berapakah Panjang tali yg menghubungkan kedua ujung batang kayu tersebut ?

Rumus :
 $C^2 = a^2 + b^2$
 di mana : C = Panjang sisi miring
 a = Panjang sisi pertama
 b = Panjang sisi kedua

Menghitung Panjang tali (c) :
 $C^2 = 60^2 + 40^2$
 $C^2 = 3.600 + 1.600$
 $C^2 = 5.200$
 $C = \sqrt{5.200} = \sqrt{400 \times 13} = 20\sqrt{13}$

Jadi, Panjang tali yg menghubungkan kedua ujung batang tali tersebut adalah $20\sqrt{13}$

Total : 12

1K = $\frac{n}{NM} \times 100$
 $= \frac{12}{12} \times 100$
 $= 100$

Indicator 3 points to the final answer 12.

Indicator 2 points to the calculation of C.

Indicator 1 points to the diagram of the right-angled triangle.

Figure 1. Students with High Ability

Students D and F demonstrated exceptional written mathematical communication skills. Indicator 1 demonstrated the ability to produce a complete right-angled triangle diagram with labels for side lengths and angles that correspond to the given data. In Indicator 2, they used mathematical symbols and notation correctly, with no errors, particularly in applying the Pythagorean theorem. In Indicator 3, they wrote the solution steps very clearly and coherently, using their own language and in an easy-to-understand way. These results are shown in [Figure 1](#), which effectively demonstrates their ability to connect visualization, symbolization, and mathematical explanation.

Students with Medium Ability

Students N, J, and I demonstrated fairly good written mathematical communication skills, but still needed improvement. In indicator 1, they failed to create a right-angled triangle, thus failing to meet indicator 1. In indicator 2, they used mathematical symbols and notation correctly. In indicator 3, they clearly explained the solution to the problem. Overall, they understood the basic concepts but needed to

improve the accuracy and neatness of their presentation, as seen in [Figure 2](#).

The image shows a student's handwritten solution to a math problem. The problem is in Indonesian and asks for the length of a string connecting two wooden poles of different heights. The student's work includes several indicators of mathematical communication skills:

- Indicator 3:** Points to the student's identification of knowns and unknowns. The student lists:
 - Diket: c = Panjang sisi miring = I_3
 - a = Panjang sisi Pertama = 60 cm
 - b = Panjang sisi Kedua = 40 cm
- Indicator 2:** Points to the student's final answer and reasoning. The student concludes:
 - Jadi, tali yang menghubungkan kedua batang bambu adalah $20\sqrt{13}$ cm

The student also uses the Pythagorean theorem formula: $Rumus = c^2 = a^2 + b^2$ and calculates $c^2 = 60^2 + 40^2 = 3600 + 1600 = 5200$, leading to $c = \sqrt{5200} = \sqrt{400 \times 13} = 20\sqrt{13}$. There is also a small calculation on the right: $\frac{9}{12} \times 100 = 75$.

Figure 2. Students with Medium Ability

Students with Low Ability

Students E and Q still lack written mathematical communication skills. They lack conceptual visualization in indicator 1 because they do not create a picture or a triangle. In indicator 2, they do not write mathematical symbols and notation. In indicator 3, they provide unclear and disjointed explanations, and the main idea is difficult to grasp; it can be seen in [Figure 3](#). As shown in [Table 4](#), they still have difficulty connecting problem information to mathematical representations and organizing information systematically.

The image shows a student's handwritten solution to the same math problem. The student's work includes several indicators of mathematical communication skills:

- Indicator 3:** Points to the student's identification of knowns and unknowns. The student lists:
 - Panjang batang kayu pertama = 60 cm
 - Panjang batang kayu kedua = 40 cm
 - Panjang sisi $\approx 90^\circ$

The student also includes a small calculation on the right: $\frac{9}{12} \times 100 = 75$. The student's work is less organized and lacks mathematical symbols and notation compared to Figure 2.

Figure 3. Students with Low Ability

Table 4. Representation of Students' Written Mathematical Communication Skills

Indicator	Students D and F (Category High)	Students N, J, and I (Category Medium)	Students E and Q (Category Low)
Interpreting mathematical ideas into visual representations in the form of graphs or images (Drawing).	Complete image with proper labels	Does not create an image	Does not create an image
Writing mathematical ideas using appropriate mathematical notation and structures to represent situations or problems in a real-world context (Mathematical Expression).	Exact symbols and notation	Writing symbols and notations	Do not write symbols and notations
Expressing mathematical ideas in written text (Written Text).	Very clear and coherent	Quite clear but not coherent	Unclear and not coherent

Observation Results (Oral Mathematical Communication Skills)

Based on observations during the learning process using the PBL model, some students still experienced difficulty understanding the problems presented. This was evident in their low participation in group discussions and their lack of initiative in asking questions or responding to peers' ideas. However, student engagement increased during the presentation stage, with students in the high category showing greater confidence in conveying their mathematical ideas. Conversely, students in the low category tended to be passive and less confident in expressing their opinions.

[Table 5](#) presents observations of student activity during the learning process, organized by grade and category.

Table 5. Observation Data

Nama	D	F	N	J	I	E	Q
Average	100	100	75	75	75	33	33
Category	High	High	Medium	Medium	Medium	Low	Low
Understanding the Problem	Y	Y	Y	Y	Y	N	N
Discussion Activity	Y	Y	Y	Y	Y	N	N
Visual Interpretation	Y	Y	N	N	N	N	
Solution Evaluation	Y	Y	Y	Y	Y	N	N
Collaborate	Y	Y	Y	Y	Y	N	N
Independence	Y	Y	Y	Y	Y	N	N

Presentation	Y	Y	Y	Y	Y	N	N
Logical Answers & Reasons	Y	Y	Y	Y	Y	N	N
Confident	Y	Y	Y	Y	Y	N	N

Noted: Y = YES, N = NO

The conclusion from [Table 5](#) shows that students F and D in the high category were very active in discussions, able to express opinions clearly, understand concepts well, and have high self-confidence. Both were able to provide appropriate solutions and explain the steps for solving them coherently. Students N, J, and I, in the medium category, were quite active in discussions, understood the concepts being studied, and conveyed answers orally quite clearly. However, they did not present visualizations when solving the problems. Meanwhile, students E and Q in the low category showed limited understanding of the problem, were less active in discussions, and lacked independence and confidence in conveying their answers. Observations show that problem-solving abilities differ across categories. High-skill students accurately identified known and requested information, while medium-skill students still needed time to understand the problem, and low-skill students struggled, resulting in less precise solutions. During discussions, high-skill and medium-skill students were more active in asking questions, responding, and expressing ideas, while low-skill students tended to be passive. Differences were also evident in visual interpretation and solution evaluation skills, as shown in [Table 6](#). High-skill students were able to use visual representations to aid problem solving, while medium- and low-skill students did not. In the solution evaluation, high- and medium-skill students provided fairly logical reasoning, while low-skill students still struggled. Group collaboration, independence, and self-confidence were more evident among high- and medium-skill students than among low-skill students.

Table 6. Representation of Students' Oral Mathematical Communication Skills

Indicator	High Category (D and F)	Medium Category (N, J, and I)	Low Category (E and Q)
Interpreting mathematical ideas verbally (Drawing)	Very active in expressing opinions, asking questions, and responding to friends' ideas, providing coherent and clear oral explanations, being able to follow the flow of discussion well, and	Quite active in discussions and able to convey ideas orally quite clearly, independently, and confidently when speaking, even though not presenting or referring to	Very passive in discussions, rarely expresses opinions, is unable to explain the solution steps verbally, and shows a low level of self-confidence.

Indicator	High Category (D and F)	Medium Category (N, J, and I)	Low Category (E and Q)
	showing self-confidence during presentations.	visualizations in the explanation.	
Using mathematical notation and structures verbally to present ideas in real situations or contexts (Mathematical Expression)	Able to explain concepts and solution steps orally using appropriate mathematical terms, able to evaluate their own solutions and friends' solutions logically.	Able to explain the solution steps verbally and use several relevant mathematical terms, but does not link the explanation with visual representation, and the evaluation of the solution is not yet in-depth.	Unable to explain concepts or solution steps precisely, they use mathematical terms very sparingly and are unable to provide a logical evaluation of the solution.
Expressing mathematical ideas orally (Written Text)	Using clear and structured mathematical language in discussions, explanations are coherent and easy for others to understand.	Able to convey ideas verbally quite clearly and coherently, the structure of the explanation is still simple and not yet fully systematic.	Oral explanations are incoherent and unclear; they are unable to model problem situations verbally using appropriate mathematical language.

Discussion

The findings of this study indicate that students' mathematical communication skills during Problem-Based Learning (PBL) vary across ability levels. Students in the high category demonstrated more complete communication skills. In contrast, students in the medium and low categories showed several limitations in expressing mathematical ideas both in written and oral forms. High-ability students were able to present visual representations, use mathematical symbols correctly, and explain solution steps clearly, indicating their ability to integrate visualization, symbolic representation, and written explanations in problem solving. This finding supports the theory of Putri & Musdi, which states that mathematical communication involves visual representation, mathematical expression, and clear explanation. Students in the medium category were able to use mathematical notation and explain their reasoning. However, they did not provide visual representations, suggesting they still had difficulty translating contextual problems into visual mathematical models. According to Maryati et al. (2022), visual representation plays an important role in understanding mathematical relationships. Meanwhile, students in the low category showed difficulties in most communication indicators, as they did not construct visual representations, rarely used mathematical notation, and produced unclear explanations, indicating difficulties in interpreting problem information and organizing mathematical ideas systematically. Similar findings were

reported by Dewanti & Muna (2023), who found that students with lower ability levels often struggle to connect contextual information to mathematical representations. Observation results also showed differences in oral communication, with students in the high and medium categories more active in discussions and more confident in presenting ideas. In contrast, students in the low category tended to be passive. This supports the view that PBL encourages student participation and communication during learning (Andika & Hidayat, 2023). Overall, these findings are consistent with previous studies showing that PBL can support the development of students' mathematical communication skills (Mirna et al., 2023; Safitri et al., 2021), while this study provides a qualitative description of how these communication skills appear across different ability levels during classroom interactions.

CONCLUSION

This study concludes that students' mathematical communication skills when implementing Problem-Based Learning (PBL) to solve word problems on lines and angles vary across ability levels. Students in the high category demonstrated more complete communication skills through accurate visual representations, correct use of mathematical notation, and clear explanations of solution steps. Students in the medium category were able to explain their reasoning and use mathematical symbols but still had limitations in creating visual representations. In contrast, students in the low category had difficulty representing problems and expressing mathematical ideas clearly. These findings indicate that PBL can support the development of students' mathematical communication skills through discussion and collaborative problem solving. This study contributes to understanding how mathematical communication skills emerge across different levels of student ability in PBL-based learning. Future research is recommended to involve larger samples, explore additional mathematical topics, and include additional instruments, such as interviews, to analyze students' mathematical communication processes in greater depth.

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AUTHOR CONTRIBUTIONS

The following are the contributions made by each author in this research:

Yus Mochamad Cholily: Leading the development of research ideas, media development, designing research methodologies, and providing supervision throughout the research process;

Makrifatul Khoiriyah: Primarily responsible for data collection, analysis, and making significant contributions to the preparation of results and discussions;

Alfiani Athma Putri Rosyadi: Focuses on conducting literature reviews, creating theoretical frameworks, and plays an important role in writing background and conclusions;

Akhsanul In'am: Focus on results and discussions.

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