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Problem-based learning to improve students' mathematical communication skills and learning motivation

Anny Cahyani Dyah Ekowati[1], Masrukan[2]

[12]FMIPA, Universitas Negeri Semarang, Jawa Tengah, Indonesia
Correspondence: anny_cahyani@students.unnes.ac.id

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Abstract

This study aims to analyze the implementation of Problem-Based Learning (PBL) in improving students' mathematical communication skills and learning motivation. The method employed was a Systematic Literature Review (SLR), which analyzed ten published articles from 2019 to 2024. The results indicate that PBL is effective in enhancing students' mathematical communication skills, with 75% of the reviewed articles reporting significant improvements. These improvements were primarily achieved through discussion activities, problem-solving, and collaboration. Furthermore, learning motivation exhibits a positive correlation with mathematical communication ability, as students with higher motivation tend to demonstrate better communication skills. The findings of this study confirm that PBL can serve as an innovative solution to improve students' mathematical communication skills and learning motivation.

Keywords: problem-based learning; mathematical communication skills; learning motivation

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INTRODUCTION

Current educational development requires students not only to understand mathematical concepts procedurally but also to communicate their ideas clearly. Mathematical communication skills are essential for conveying understanding, explaining problem-solving strategies, and collaborating in classroom discussions (NCTM, 2000). According to the Programme for International Student Assessment (PISA), seven fundamental mathematical competencies underpin mathematical processes: mathematical communication, mathematical representation, reasoning and formulating problem-solving strategies, using symbolic, formal, and technical language and operations, and utilizing mathematics teaching aids (OECD, 2023).

Sumayanti and Siswanto (2021) define mathematical communication as a bidirectional process in which students actively construct understanding through various forms of expression, ranging from abstract representations (such as symbols and formulas) to concrete ones (including demonstrations and diagrams), while

simultaneously interpreting the mathematical meaning of these representations. The ability to communicate during mathematics learning plays a crucial role, necessitating the enhancement of students' mathematical communication skills (Anim et al., 2022). Sharing ideas and articulating understanding of mathematical concepts are communicative strategies employed in the learning process (Yunita & Siswanto, 2023).

Students who are proficient in mathematical communication will be skilled in applying mathematical ideas (Yuliani et al., 2022). Possessing strong verbal and written mathematical communication abilities facilitates their organization and interpretation of thoughts to solve problems (Noer et al., 2022). Mathematical communication skills refer to the ability to express solutions to specific scenarios or issues based on information obtained through oral and written communication using graphs, symbols, or diagrams (Nufus, 2022).

Research by Marniati et al. (2021) reveals that increased learning motivation significantly contributes to better learning achievement. Furthermore, their findings affirm the crucial role of motivation as a determining factor in developing students' mathematical communication competencies. A related study by Nofrianto et al. (2017) reinforces these findings by demonstrating a clear positive correlation between learning motivation levels and mathematical communication mastery, where decreased learning motivation is directly proportional to decreased mathematical communication abilities. A comparative analysis by Marniati et al. (2021) further categorizes students' mathematical communication abilities into three categories based on their motivation levels, revealing significant disparities among student groups with high, moderate, and low motivation.

Problem-Based Learning (PBL) is an instructional learning approach that encourages students to engage with various challenges designed to focus on the learning process (Husna & Kurniasih, 2023). This learning model can enhance students' conceptual exchange by implementing Problem-Based Learning (Lubis & Dewi, 2023). PBL is a teaching model that places focus on students and enables them to take responsibility for their learning process (Navarro-Durán et al., 2023). They are encouraged to determine the knowledge required to understand and address problems that arise during learning (Orfan et al., 2021). The PBL approach is an effective way to improve students' mathematical communication skills (Mirna et al., 2023). The PBL model is a problem-solving-based learning approach that can train students' independence

and communication skills in group settings (Kanah & Mardiani, 2022). PBL can maximize students' mathematical communication abilities and foster more positive student attitudes, enabling them to communicate their ideas when solving problems (Sitopu et al., 2022).

Based on the description above, this research was conducted by reviewing the literature on the PBL learning model to enhance students' mathematical communication abilities in mathematics learning and to improve students' learning motivation. This research aims to answer the following questions: "How is PBL implemented to improve students' mathematical communication skills?" and "What is the influence of learning motivation on the effectiveness of problem-based learning in improving students' mathematical communication skills?" Through the research findings, it is expected that this contribution will enhance education by developing more effective learning models to improve students' communication abilities and learning motivation.

METHODS

This research employs a Systematic Literature Review (SLR); therefore, data collection must adhere to established procedures. According to Zawacki-Richter et al. (2020), the SLR research procedure design is illustrated in Figure 1.

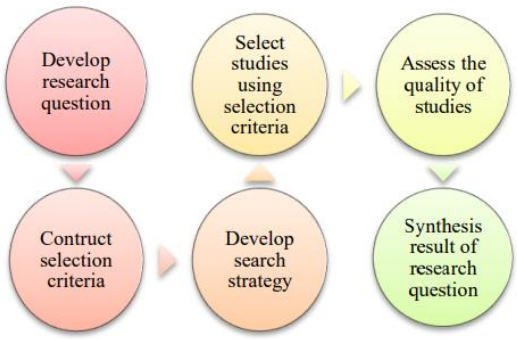

Figure 1. (SLR Procedure Diagram (Zawacki et al., 2020))

The detailed explanation is as follows.

Develop Research Question

Research Questions (RQ) are developed according to the selected topic. The research questions in this study are as follows.

RQ1: How is PBL implemented to improve students' mathematical communication skills?

RQ2: What is the influence of learning motivation on the effectiveness of problem-based learning in improving students' mathematical communication skills?

Construct Selection Criteria

The decision regarding whether the obtained data can be used in the study or not is made at this stage. Therefore, the inclusion and exclusion criteria are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Articles relevant to students' mathematical communication skills, learning motivation, and the PBL learning model	Articles that do not contain analysis related to students' mathematical communication skills, learning motivation, and the PBL learning model
Articles published in reputable scientific journals, both national and international	Articles with limited access or that cannot be fully accessed
Articles published between 2019 and 2024 to maintain data currency	Articles published before 2019

Develop Search Strategy

In the article search process, the Publish or Perish application was utilized. The selection of Google Scholar, Crossref, and Scopus databases was conducted within this application to ensure that the articles found were appropriate and relevant to the research topic. Search keywords included mathematical communication skills, learning motivation, and the problem-based learning approach, also known as PBL.

Select Studies Using Selection Criteria

The article screening process was conducted through stages of inclusion and exclusion criteria to ensure alignment with the research focus. The first step involved reviewing titles and abstracts, followed by examination of the entire article content for screening finalization (Zawacki et al., 2020).

Assess the Quality of Studies

Data obtained from the previous stage were evaluated using Quality Assessment (QA) criteria as follows.

QA1: Does the article state a research problem relevant to this study?

QA2: Is there a relationship between the PBL learning model and students' mathematical communication skills and learning motivation?

Each QA criterion was assigned a "yes" or "no" response.

Synthesis Result of Research Question

The final stage involved synthesizing the collected data to obtain answers to the research questions.

RESULTS AND DISCUSSION

In the Develop Search Strategy stage, 205 articles were successfully identified; however, upon examination, 41 duplicate articles were found based on title and author. Thus, the number of articles that passed initial screening was 164.

In the Select Studies Using Selection Criteria stage, of the 164 articles evaluated using the selection criteria, 37 articles met the requirements (inclusion) and 127 articles did not meet the criteria (exclusion). The next step involved reviewing the titles and abstracts of these 37 selected articles to assess their relevance to the research focus. As a result, 20 relevant articles and 17 irrelevant articles were identified.

In the "Assess the Quality of Studies" stage, 10 journal articles met the criteria, as evidenced by affirmative responses to all questions (QA1 and QA2). This means these journal articles describe the relationship between the PBL learning model and students' mathematical communication skills and learning motivation.

In the final stage, Synthesis Result of Research Question, data synthesis was conducted to obtain answers to research questions RQ1 and RQ2. A comprehensive summary of the 10 articles is presented in Table 2.

Table 2. Summary of Article Review

No	Author	Title	Results
1.	(Eka et al., 2020)	Meta-Analysis of Improving Learning Motivation and Mathematical Communication Using the PBL Model	Research results indicate that implementing the Problem-Based Learning model can increase students' learning motivation by an average of 0.35, which falls into the moderate category. Additionally, the PBL model has also been proven to improve mathematical communication skills. These findings suggest that the Problem-Based Learning (PBL) model is effective in enhancing learning motivation

			and mathematical communication skills in elementary school students.
2.	(Hidayati et al., 2020)	Improving students' mathematical communication skills and learning interest through problem-based learning model.	Research results demonstrate an improvement in students' mathematical communication skills through the PBL model. Students' interest in learning mathematics through PBL, particularly in statistics, also increased. The results of this research can serve as a reference for enhancing students' mathematical communication skills through the PBL model. The PBL model also has a positive influence on students' interest in learning mathematics and can help students achieve mastery of statistics learning.
3.	(Marniati et al., 2021)	Analysis of Students' Mathematical Communication Skills in Solving Problems Based on Student Learning Motivation	In highly motivated students, their mathematical communication abilities develop optimally, characterized by proficiency in presenting mathematical arguments logically . On the other hand, students with moderate motivation show varied results. Students with low motivation often struggle to express their mathematical thinking, despite having very basic communication skills.
4.	(Sumayanti & Siswanto, 2021)	Analysis of Mathematical Communication Abilities Viewed from Learning Motivation During the Covid-19 Pandemic and Gender	Both male and female students with moderate and low learning motivation demonstrate a better ability to communicate mathematics orally and in writing compared to their peers with high learning motivation.
5.	(Rahayu et al., 2022)	Analysis of Mathematical Communication Abilities Viewed from Mathematics Learning Motivation in Grade VII D Students of SMPN 2 Campalagian	The research results show that students met only 3-4 indicators of mathematical communication. Students with intermediate-level mathematical communication

			skills demonstrated the ability to connect mathematical ideas but struggled to relate them to everyday situations. In expressing ideas using mathematical symbols, students achieved varying levels. Students who demonstrated high-level communication skills showed the ability to explain mathematical concepts, ideas, and daily situations through sentences and diagrams, meeting all indicators of mathematical communication.
6.	(Sitopu et al., 2022)	Students' Mathematical Communication Through the Problem-Based Learning (PBL) Model	Based on research data analysis, it can be concluded that the use of the PBL model has a positive impact on students' mathematical communication . Specifically, the research found that the mathematical communication of students taught with the PBL model is better than that of those taught with conventional methods. There is an improvement in mathematical communication abilities after PBL implementation, and students show positive attitudes toward this learning model.
7.	(Susanti et al., 2023)	Problem-based learning through lesson study learning community to enhance students' mathematical communication skills	Students' mathematical communication abilities after learning using the problem-based learning model and integrating information technology through lesson study learning community are categorized as fairly good.
8.	(Fitri & Darhi, 2023)	Analysis of Junior High School Students' Mathematical Communication Abilities Based on Learning Motivation	Students' ability to communicate mathematical ideas, especially in explaining problems in their own language, varies according to their level of learning motivation. Students with high

			motivation demonstrate this ability nicely. Students with moderate motivation are also capable, although they may not fully understand the purpose of the problem. However, students with low motivation are not yet able to use their own language to communicate mathematical ideas and often make mistakes in understanding problems.
9.	(Ningrum et al., 2024)	The Effect of the PBL Model on Learning Outcomes Viewed from Mathematical Communication Ability of Students	Research results indicate a relationship between learning models and mathematical communication abilities in student learning outcomes. Students who received PBL learning have higher average learning outcomes than students who received conventional learning. Additionally, students with high mathematical communication abilities achieve the highest average learning outcomes compared to those who received conventional learning.
10.	(Robi et al., 2024)	Improving cognitive learning outcomes and communication skills through problem-based learning with lesson study	Research results indicate that PBL learning syntax has been effectively implemented, with significant differences in learning outcomes. Furthermore, students' communication skills also experienced a 0.5% increase in score. This suggests that the PBL model, combined with lesson study activities, can effectively enhance students' communication skills and is recommended for learning purposes.

RQ1. How is Problem-Based Learning implemented to improve students' mathematical communication skills?

Problem-based learning has proven to be a practical approach for enhancing students' mathematical communication skills. Through analysis of various studies, it was found that PBL creates a learning environment that encourages students to actively participate in discussions, collaborate, and express mathematical ideas clearly. One of PBL's strengths is its ability to engage students in contextual problem-solving, where they not only learn mathematical concepts but also how to communicate them through symbols, graphs, or diagrams.

Several studies in Table 2 demonstrate that collaborative activities in PBL, such as group discussions and presentations, significantly enhance students' oral and written communication abilities. For instance, students learning with the PBL model are proven to be more capable of explaining problem solutions in their own language compared to conventional learning methods. The teacher's role as a facilitator is also crucial in guiding students to articulate mathematical thinking systematically. Findings from various studies, including research by Sitopu et al. (2022) and Susanti et al. (2023), reinforce that PBL not only improves conceptual understanding but also communication skills that are essential in mathematics.

RQ2. What is the influence of learning motivation on the effectiveness of problem-based learning in improving students' mathematical communication skills?

Learning motivation plays an essential role in determining the success of PBL implementation. Students with high learning motivation tend to be more actively involved in the learning process, including in discussion and problem-solving activities. This has a positive impact on their mathematical communication abilities, as high motivation fosters confidence and willingness to convey mathematical ideas clearly.

Research by Marniati et al. (2021) and Fitri & Darhi (2023) reveals significant differences in mathematical communication abilities among students with high, moderate, and low motivation. Highly motivated students are not only more capable of communicating mathematical ideas but are also better at connecting mathematical concepts with real-world situations. Conversely, students with low motivation often struggle to understand problems and express solutions effectively. These findings confirm that learning motivation is a key factor that requires attention in PBL implementation.

To optimize the effectiveness of PBL, educators need to create a supportive and motivating learning environment. Providing positive feedback, concept reinforcement,

and integrating technology or methods, such as lesson study, can help increase students' learning motivation, especially for those with moderate or low motivation. Thus, the combination of PBL and learning motivation enhancement strategies can produce greater improvements in students' mathematical communication skills.

CONCLUSION

Based on the analysis and discussion results, it can be concluded that Problem-Based Learning is an effective learning model for enhancing students' mathematical communication skills. The strength of PBL lies in its collaborative and problem-based approach, where students are not only invited to understand mathematical concepts but also develop the ability to express mathematical ideas both orally and in writing. Through discussion activities, problem-solving exercises, and presentations, students are trained to think critically and communicate their thoughts more systematically. Furthermore, learning motivation is an essential factor that influences the success of PBL implementation. Students with high learning motivation tend to be more actively involved in the learning process, thus showing more significant improvements in mathematical communication abilities. This confirms that motivation not only encourages student participation but also strengthens the positive impact of PBL on communication skill development.

Educators can take several practical steps to optimize PBL: 1) design contextual problems relevant to students' lives to make learning more meaningful, 2) provide support and encouragement to increase learning motivation, especially for students who are still less motivated, and 3) integrate technology or methods such as lesson study to enrich the learning experience and ensure more optimal results. Through the application of these strategies, PBL can not only improve students' mathematical communication skills but also create a more dynamic and effective learning environment.

These findings strengthen the recommendations for educators and researchers to continue developing PBL implementation by considering aspects of motivation and learning contexts. Thus, PBL can become an innovative solution in addressing mathematics learning challenges in the modern era, while preparing students with skills essential for the future.

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