

## Original Article

# Application of The Problem-Based Learning Model to Improve Mathematical Communication Ability of Senior High School Students

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### Abstract:

Mathematical communicative competence constitutes a pivotal pillar within the architecture of mathematics education. Nevertheless, empirical realities across Indonesian classrooms disclose a disquieting deficit in learners' capacity to articulate mathematical reasoning with clarity and precision. This inquiry is undertaken to ascertain whether the attainment and progressive enhancement of students' mathematical communication proficiency, when cultivated through a Problem-Based Learning paradigm, surpass those fostered under conventional instructional approaches. Anchored in a quantitative framework, the study employs a quasi-experimental methodology, operationalized through a pretest–posttest non-equivalent group design to capture comparative developmental trajectories between cohorts. The participants were tenth-grade students from a senior high school in Bandung City, with two classes deliberately designated as samples through purposive selection. Data collection relied on written assessments targeting mathematical communicative competence and observational checklists as supporting instruments. The findings disclosed that: (1) learners immersed in the Problem-Based Learning approach attained a more elevated level of mathematical communicative performance than those instructed conventionally; and (2) the extent of their developmental gain likewise outstripped that of their peers in the traditional classroom context.

**Keywords:** Problem-Based Learning, Mathematical Communication, Mathematics Education, Learning Achievement, Secondary School Student.

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## Introduction

Mathematics is an essential discipline in school learning and has broad applications in everyday life ([Fitriani & Pujiastuti, 2021](#); [Ginting & Sutirna, 2021](#); [Lea et al., 2022](#); [Oktoviani et al., 2019](#); [Siswadi et al., 2023](#); [Suhenda & Munandar, 2023](#);

[Sumartini & Safitri, 2022](#); [Zanthy & Suswigi, 2019](#)). There are five standards of mathematical ability that students must possess, namely problem-solving aptitude, communicative mathematical proficiency, relational (interconnected) competence, inferential reasoning capacity, and representational dexterity ([NCTM, 2000](#)). These five abilities complement the others and help to create a comprehensive understanding of mathematics. Students will be encouraged to become active, reflective learners and be able to apply mathematics in various contexts if they master these five standards.

One of the main components and very important to have in within the domain of mathematical proficiency, the focal dimension is communicative mathematical competence ([Sari et al., 2022](#); [Suhenda & Munandar, 2023](#)) because it is useful in terms of organising and consolidating students' mathematical thinking and can help students in conveying their mathematical ideas or thoughts using appropriate mathematical language ([Sari et al., 2022](#); [Siswadi et al., 2023](#)). This ability shows how well students can comprehend and communicate mathematical ideas logically. Additionally, mathematical communication is a valuable tool for evaluating students' thinking processes and providing teachers with a foundation for relevant feedback.

In line with this, [Kemendikbudristek \(2022\)](#) stated that communicating mathematically in solving problems is one of the mathematics learning objectives at the Senior High School level. Therefore, every plan and execution of mathematics instruction in schools must carefully consider the development of this ability. However, field implementation reveals a discrepancy between student accomplishment and learning objectives.

However, various previous studies have shown that students' mathematical communication ability in Indonesia is still relatively low ([Aminah et al., 2018](#); [Dina et al., 2019](#); [Elfareta & Murtiyasa, 2022](#); [Refwalu et al., 2022](#); [Suryawati et al., 2023](#)), supported by the fact that students cannot connect the ideas that have been obtained to find solutions to problems ([Suharno et al., 2019](#)). Many students still struggle with mathematical communication ability questions in both written and oral forms ([Ningsih et al., 2021](#)). These problems can be caused by students' lack of response to mathematical communication questions ([Hariati et al., 2022](#)) and conventional teacher-centred learning ([Hariati et al., 2022](#); [Ningsih et al., 2021](#); [Suharno et al., 2019](#)). This condition indicates that ongoing learning has not fully supported the optimal development of students' communication abilities. This is a challenge for teachers and educators in developing effective learning strategies to improve these abilities.

The government has tried to improve students' mathematical abilities with its curriculum. Learning in the 2013 and independent curriculum is required to no longer be teacher-centred, but to be student-centred, so that students can actively participate in learning. The scientific approach is suggested in implementing learning in the 2013 curriculum ([Kemendikbud, 2014](#)) and the independent curriculum ([Jannah et al., 2024](#)). In line with this, there is an improvement in students' mathematical communication ability by applying a scientific approach to learning ([Fauzie et al., 2019](#)) because it can improve students' curiosity and interest in learning ([Rahmawati et al., 2019](#)). The steps for implementing a scientific approach according to the [Kemendikbud \(2014\)](#) are: The instructional sequence unfolds through the phases of observing phenomena, articulating inquiries, accumulating information through experimental engagement, associating or processing conceptual linkages, and ultimately communicating the constructed understanding.

In line with the scientific approach, applying the Problem-Based Learning (PBL)

model is the right step to improve students' mathematical communication ability because it can make the learning process more interactive. The PBL model is a student-centred learning model in which students are given relevant real problems as a stimulus for learning (Ardianti et al., 2021; Yusri, 2018). In this process, students are expected to work collaboratively to solve problems, seek information, and develop solutions. PBL encourages students to think critically and analytically, and develop communication ability, both oral and written, through group discussions and presentation of work results (Ardianti et al., 2021; Nainggolan et al., 2023). The 5 steps of implementing the Problem-Based Learning model according to Trianto (2009) are: The procedural trajectory encompasses learner immersion in the problem context, followed by the structuring and orchestration of student collaboration, the facilitation of investigative inquiry, the construction and exposition of discursive outcomes, and culminates in the analytical deconstruction as well as evaluative appraisal of the problem-solving process.

Applying the PBL model is expected to positively impact students' mathematical communication ability. This is supported by various studies that show that PBL can improve students' involvement in learning and help them develop higher-order thinking abilities. However, further research is still needed to understand how the PBL model can improve students' mathematical communication ability in the context of specific materials, such as two-variable linear inequality systems.

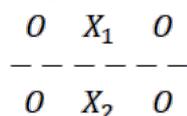
This inquiry seeks to ascertain whether both the attainment and the progressive amplification of students' mathematical communicative competence under the Problem-Based Learning (PBL) paradigm surpass those cultivated through conventional instructional modalities. Thus, the results are expected to contribute to developing effective learning strategies.

## Methods

### Research Design

This investigation was conducted within a quantitative methodological framework. It employed a quasi-experimental strategy, specifically a pretest–posttest non-equivalent group design involving both experimental and control cohorts. The experimental class was instructed through the Problem-Based Learning (PBL) model, whereas the control class was subjected to conventional pedagogical practices.. This research was conducted in a school that used the independent curriculum, so that learning in all classes uses a scientific approach. This research intends to describe and explain the application of the Problem-Based Learning model to improve students' mathematical communication ability on the material of two-variable linear inequality systems.

The research design of the study is presented in detail below.



Source: Lestari & Yudhanegara (2017)

Information:

- $O$  : Pretest and Posttest of experimental class and control class.
- $X_1$  : Treatment with the Problem-Based Learning model in the experimental class.
- $X_2$  : Treatment with the conventional learning model in the control class.
- — : Students were not randomly selected.

## Population and Sample Study

The demographic reservoir of this inquiry comprised tenth-grade denizens of a senior secondary institution situated within Bandung City's scholastic topography. From this academic microcosm, two intact pedagogical clusters were selectively extracted via purposive sampling—an intentional curation predicated upon delineated criteria (Amin et al., 2023). Each epistemic enclave accommodated 34 learners. The inaugural cluster was consecrated as the experimental cohort, destined to undergo mathematical enculturation through the Problem-Based Learning (PBL) orchestration. The second class, or control class, is a class that will receive mathematics learning with the conventional learning model. This research was conducted from April to May, the even semester of the 2023/2024 academic year.

## Data Collection Instruments and Techniques

This investigation mobilized a bifurcated instrumentation schema: evaluative (test-based) and non-evaluative apparatuses. The test instrument materialized as three validated descriptive items centered upon the system of linear inequalities in two variables. These instruments were administered in a pre-intervention (Pretest) and post-intervention (Posttest) sequence to calibrate both the attainment and the progressive augmentation of students' mathematical communicative competence. To quantify the escalation of such competence, analytical procedures were subsequently applied to the differential score configurations., the  $n_{gain}$  formula was used as follows.

$$n_{gain} = \frac{\text{posttest score} - \text{pretest score}}{SMI - \text{pretest score}}$$

Source: Lestari & Yudhanegara (2017)

Information:

$n_{gain}$  : Normalized gain

SMI : Ideal maximum score

The criteria for interpreting the  $n_{gain}$  value according to Lestari & Yudhanegara (2017) are as follows Table 1.

Table 1. Criteria of  $n_{gain}$

$N_{gain}$	Criteria
$n_{gain} \geq 0,70$	High
$0,30 < n_{gain} < 0,70$	Middle
$n_{gain} \leq 0,30$	Low

Source: Lestari & Yudhanegara (2017)

The non-test instrumentation consisted of structured observational protocols systematic recording sheets delineating both teacher and student enactments throughout the instructional continuum devised to scrutinize the fidelity and sequential actualization of each procedural phase embedded within the Problem-Based Learning (PBL) architecture in experimental classes.

## Data Analysis Techniques

The test instrument data were analysed using Pretest, Posttest, and  $N_{gain}$  scores. Analysis of students' mathematical communication ability improvement begins with a prerequisite test, namely the normality and homogeneity tests. The normality test was

conducted using the Shapiro-Wilk test because the sample was less than 50 people. The test was carried out to determine whether the pretest, posttest, and N\_gain data came from a normally distributed population or not. The homogeneity test using the Levene test was conducted to determine whether the Pretest, Posttest, and n\_gain data had a homogeneous variance or not. Subsequently, the inferential trajectory proceeds to hypothesis examination via the independent-samples t-test predicated upon the assumption of variance homogeneity. This parametric apparatus is invoked exclusively under conditions of normal distribution and homogeneous variance. In the eventuality that distributional normality and variance equivalence are not satisfied, the analytical course is redirected toward a non-parametric alternative, namely the Mann-Whitney procedure. Prior to interrogating the increment of students' mathematical communicative competence, the consummative attainment of such competence is initially subjected to examination.

Non-test instrument data is analysed based on the results of observers' observations during the learning process. The criteria for evaluating the observation sheet are based on whether or not the stages of the Problem-Based Learning model are implemented. This ensures that all stages of mathematics learning with the Problem-Based Learning model are carried out properly.

## Results

The empirical substrate of this investigation was extracted from evaluative apparatuses, specifically the pre-intervention and post-intervention score matrices derived from both the experimental and control cohorts. The resultant pretest-posttest performances, together with the computed n-gain indices distilled from those score differentials, are encapsulated in Table 2 hereunder.

Table 2. Statistical Results: Descriptive Data Pretest, Posttest, and N\_gain

Class	N	Pretest		Posttest		N_gain	
		Average	STD	Average	STD	Average	Category of Improvement
Experiment	34	19.53	10.29	60.65	22.13	0.53	Middle
Control	34	21.41	14.33	48.65	26.98	0.37	Middle

The dataset articulated in Table 2 encompasses the pretest and posttest score configurations of both experimental and control cohorts, each calibrated to a maximal ceiling of 100. Furthermore, the n-gain indices were algorithmically derived from the differential interplay between the pretest and posttest attainments. The tabular exposition reveals that the control cohort's mean pretest score marginally eclipses that of the experimental cohort, with a negligible discrepancy of 1.88—an infinitesimal divergence suggesting parity in baseline mathematical communicative competence across the two groups. Conversely, Table 2 delineates a pronounced posttest asymmetry: the experimental cohort surpasses the control cohort by a substantive margin of 12.00 points. Such a considerable differential intimates that the mathematical communicative proficiency of students within the experimental constellation demonstrably exceeds that of their control counterparts..

The evidentiary metrics employed to ascertain the attainment of students' mathematical communicative competence consist of the pretest and posttest score arrays. The outcomes of the Shapiro-Wilk normality diagnostics administered to the pretest and posttest distributions of both the experimental and control cohorts are

delineated in Table 3 hereunder.

Table 3. Results of the Normality Test of Pretest and Posttest Data

	Sample Class	Tests of Normality (Shapiro-Wilk)			Information
		Statistics	df	Sig.	
Pretest	Experiment	0.944	34	0.083	Normally distributed
	Control	0.922	34	0.018	Not normally distributed
Posttest	Experiment	0.929	34	0.029	Not normally distributed
	Control	0.902	34	0.005	Not normally distributed

Based on Table 3, the normality test results using IBM Statistics 25 Software show that the Sig. value pretest of the experimental class is  $> 0.05$ , while the Sig. the value of the other is  $< 0.05$ . We can conclude that the experimental class's pretest score data emanates from a Gaussian-distributed population, whereas the remaining dataset originates from distributions that deviate from normality..

The Mann–Whitney non-parametric procedure will be administered to the pretest score distributions of both cohorts to interrogate whether the mean baseline mathematical communicative competence of students in the experimental and control constellations does not differ in any statistically consequential manner. The hypothesis in this test is as follows.

$H_0 : \mu_1 \leq \mu_2$  (No significant difference in the average initial mathematical communication ability between students in the experimental and control classes.)

$H_1 : \mu_1 > \mu_2$  (Significant difference in the average initial mathematical communication ability between students in the experimental and control classes.)

The significance level used is 5% ( $\alpha = 0,05$ ) with the following test criteria.

Should the Sig. coefficient be  $\geq \alpha = 0.05$ , the null hypothesis ( $H_0$ ) is upheld; conversely, if the Sig. value falls below  $\alpha = 0.05$ ,  $H_0$  is consequently repudiated. The inferential outcomes of the Mann–Whitney non-parametric analysis applied to the pretest score distributions of the experimental and control cohorts are exhibited in Table 4 beloww.

Table 4. Results of the Mann-Whitney Pretest Data Test

Test Statistics	
	Pretest
Mann-Whitney U	519,500
Wilcoxon W	1114.500
Z	-0.719
Asymp. Sig. (2-tailed)	0.427

Based on Table 4, the results of the Mann-Whitney test using IBM Statistics 25 Software show that the *Sig value. (2 – tailed) = 0.427*  $> \alpha = 0.05$ , then  $H_0$  it is accepted. There is no significant difference in the average initial mathematical communication ability between students in the experimental and control classes..

Furthermore, the Mann-Whitney test will be conducted on the Post-test scores of both classes to ascertain whether the consummative stratum of students' mathematical communicative attainment within the experimental cohort demonstrably transcends, in statistically consequential magnitude, that of the control assemblage. The hypothesis in

this test is as follows.

$H_0 : \mu_1 \leq \mu_2$  (The culminative manifestation of students' mathematical communicative attainment within the experimental cohort did not exhibit a statistically consequential elevation relative to that observed in the control cohort)

$H_1 : \mu_1 > \mu_2$  (The apical attainment of students' mathematical communicative competence in the experimental cohort registered a statistically salient ascendancy over that of their counterparts in the control cohort.)

The significance level used is 5% ( $\alpha = 0,05$ ) with the following test criteria.

In the event that the Sig. magnitude attains or exceeds the threshold  $\alpha = 0.05$ , the null postulate ( $H_0$ ) is sustained; contrarily, should the Sig. coefficient descend beneath  $\alpha = 0.05$ ,  $H_0$  is consequently nullified. The inferential yield of the Mann–Whitney non-parametric interrogation applied to the post-test score distributions of the experimental and control cohorts is exhibited in Table 5 hereunde.

Table 5. Results of the Mann-Whitney Test of Posttest Data

Test Statistics	
	Posttest
Mann-Whitney U	426,500
Wilcoxon W	1021,500
Z	-1,860
Asymp. Sig. (2-tailed)	0.063

Based on Table 5, the Mann-Whitney test results using IBM Statistics 25 Software show that the  $Sig. = \frac{0.063}{2} = 0.0315 < \alpha = 0.05$ , then  $H_0$  is rejected. This means that the achievement of students' mathematical communication ability in the experimental class is significantly higher than that of the students in the control class.

Subsequent to the ritualistic traversal of prerequisite diagnostics and inferential adjudications imposed upon the pretest and posttest matrices of both experimental and control constellations, an analogous statistical inquisition is enacted upon the n-gain magnitude. This procedural reiteration is orchestrated to interrogate whether the ascensional gradient of mathematical communicative prowess within the experimental enclave eclipses, in statistically consequential fashion, that of its control analogue. The Shapiro–Wilk normality assay administered to the n-gain distributions of the bifurcated cohorts yields the outcomes encapsulated in the ensuing Table 6.

Table 6. Results of the Normality Test of N\_gain Data

Tests of Normality (Shapiro-Wilk)					
	Sample Class	Statistics	df	Sig.	Information
N_gain	Experiment	0.935	34	0.043	Not normally distributed
	Control	0.878	34	0.001	Not normally distributed

Anchored in the exposition of Table 6, the normality diagnostics executed via IBM Statistics 25 divulge that the n-gain distributions of both the experimental and control cohorts deviate from Gaussian conformity. Consequently, a Mann–Whitney non-parametric inferential procedure is administered to the respective n-gain aggregates to ascertain whether the amplification of mathematical communicative competence within the experimental assemblage significantly surpasses that observed in the control

counterpart.\. The hypothesis in this test is as follows.

$H_0 : \mu_1 \leq \mu_2$  (The escalation of students' mathematical communicative capacity within the experimental cohort did not attain a statistically superior magnitude relative to that manifested by the control cohort)

$H_1 : \mu_1 > \mu_2$  (The augmentation of students' mathematical communicative proficiency in the experimental cohort manifested a statistically pronounced superiority over that observed within the control cohort.)

The significance level used is 5% ( $\alpha = 0,05$ ) with the following test criteria.

Should the Sig. coefficient be  $\geq \alpha = 0.05$ , the null hypothesis ( $H_0$ ) is retained. Conversely, if the Sig. coefficient is  $< \alpha = 0.05$ ,  $H_0$  is repudiated. The outcomes of the Mann–Whitney non-parametric examination applied to the posttest distributions of the experimental and control cohorts are delineated in Table. 7 below.

Table 7. Results of the Mann-Whitney Test of N\_gain Data

Test Statistics	
	N_gain
Mann-Whitney U	381,000
Wilcoxon W	976,000
Z	-2.417
Asymp. Sig. (2-tailed)	0.016

Based on Table 7, the Mann-Whitney test results using IBM Statistics 25 Software show that the  $Sig. = \frac{0.016}{2} = 0.008 < \alpha = 0.05$ , then  $H_0$  it is rejected. This means that the improvement of students' mathematical communication ability in the experimental class is significantly higher than that of the students in the control class.

The analysis of non-test instrument data was obtained from the observers' observations written on the observation sheet. The summary of the observer's observations is shown in Table 8 below.

Table 8. Summary of The Observer's Observations

Activity	2 <sup>nd</sup> meeting	3 <sup>rd</sup> meeting	Percentage
Introduction (5)	5	5	100%
Main (8)	8	8	100%
Closing (5)	4	5	90%

Based on Table 8, the results on the observation sheet showed that the introduction and main activities were 100% well done. While in the closing activities, only 90% were carried out from the 2 learning meetings. However, this figure is very good because only 1 point was not implemented, namely in the section “The teacher tells the material to be learned at the next meeting”.

## Discussion

The evidentiary corpus utilized to scrutinize students' mathematical communicative attainment comprised the pre-intervention and post-intervention assessment scores derived from both the experimental and control cohorts. The experimental group was immersed in mathematics instruction orchestrated through the Problem-Based Learning (PBL) paradigm The control class received mathematics learning with the conventional learning model. This research was conducted in a school

that used the independent curriculum, so that learning in all classes uses a scientific approach. Pretest data were used to determine the initial ability in the mathematical communicative articulation manifested by learners within both the experimental and control cohorts. Subsequently, the post-intervention assessment corpus was subjected to analytical scrutiny to extrapolate the extent of mathematical communicative attainment exhibited by participants across the two instructional contingents.

The results of the pretest data analysis showed that the initial mathematical communication ability of experimental class students and control class students was no different. In accordance with the Pretest data in Table 2, the average difference in Pretest scores of experimental and control class students is only 1.88, with the control class higher than the experimental class. Students' initial mathematical communication ability in both classes is assumed to be equal before being treated. This is reinforced by the results of the Mann-Whitney non-parametric test with a *Sig. value. (2 – tailed) = 0,472 >  $\alpha = 0,05$* , then  $H_0$  is accepted. In essence, no statistically discernible disparity was detected in the mean baseline mathematical communicative competence between the experimental and control cohorts.

The post-interventional data exegesis divulged that the experimental cohort exhibited a more elevated stratum of mathematical communicative actualization than its control counterpart. In consonance with the Postes statistics delineated in Table 2, an arithmetic divergence of 12.00 points materialized between the mean Postes scores of the two cohorts, with the experimental constellation occupying the superior echelon. This quantitative asymmetry found further substantiation through the inferential calibration of the Mann-Whitney non-parametric apparatus. with a  $Sig. = \frac{0.063}{2} = 0,0315 < \alpha = 0,05$ , then  $H_0$  is rejected. That is, the achievement of mathematical communication ability of students in the experimental class is significantly higher than that of students in the control class.

PBL learning stages that involve students more actively are one of the factors with respect to the consummation of students' mathematical communicative attainment, the experimental cohort eclipsed the control constellation. Such a tendency resonates with the postulations of [Hafidloh et al. \(2020\)](#), wherein the performative indices of mathematical communicative articulation under the Problem-Based Learning (PBL) schema demonstrably outperformed those cultivated through orthodox instructional modalities. Corroboratively, [Layliyyah et al. \(2022\)](#) illuminated that the epistemic inauguration of concepts via representational mediation within the PBL trajectory serves as a catalytic conduit for intensifying students' mathematical communicative dexterity.

An overview of the improvement of mathematical communication ability can be seen based on the results of the analysis of Pretest and Posttest data on mathematical communication achievement testing. Roughly speaking, it can be estimated that the improvement of the mathematical communication ability of students in the experimental class is higher than students in the control class. However, to ensure this, an analysis test was conducted to assess the improvement of students' mathematical communication ability in both classes. The dataset employed to evaluate the progression of students' mathematical communicative competence is N\_gain data, obtained by calculating the difference between students' Pretest and Posttest scores.

The analysis of the n-gain data revealed that students in the experimental cohort exhibited a more substantial escalation in mathematical communicative proficiency than their counterparts in the control group. As reflected in the n-gain results presented in

Table 2, the experimental class attained a mean n-gain score of 0.53, situating it within the moderate improvement category. This is better when compared to improving students' mathematical communication ability in the control class, which only has an average n\_gain of 0.37. However, it is also included in the middle category. This is reinforced by the results of the Mann-Whitney non-parametric test with a  $Sig. = \frac{0.016}{2} = 0,008 < \alpha = 0.05$ , then  $H_0$  is rejected. In other words, the augmentation of students' mathematical communicative competence in the experimental group is statistically and substantively superior to that observed in the control group.

The improvement of the mathematical communication ability of students in the experimental class is higher than that of students in the control class, which can occur due to differences in the treatment of learning models in both classes. The improvement of students' mathematical communication ability in the experimental class can be higher because, by receiving treatment in the form of a Problem-Based Learning model, students solve contextual problems given in groups, which can further support the growing up of mathematical communication capability.

In line with this, [Rahmalia et al. \(2020\)](#) found that students' mathematical communication abilities improved more in classes with PBL models compared to those in classes that received conventional learning. This can occur because with students in heterogeneous groups, completing the LKPD can provide opportunities for students to communicate their ideas regarding how to solve it, so that it can support and improve their mathematical communication ability. Furthermore, the results of research by [Ningsih et al. \(2021\)](#) indicated that the enhancement of students' mathematical communicative competence under the Problem-Based Learning model was more pronounced, as the instructional dynamic compelled learners to assume a more participatory and agentic role compared to those engaged solely through a scientific approach.

Grounded on the observation results during two learning sessions adopt the Problem Based Learning (PBL) model, there are both the preliminary and core activities were implemented 100% effectively. This indicates that the teacher successfully managed the initial and main phases of the lesson, including facilitating students to understand the problem, engage in discussions, and actively seek solutions in accordance with the PBL syntax.

In the closing activity, 90% of the components were carried out, with one point not implemented the teacher did not inform students about the material for the next meeting. However, this did not significantly affect the overall learning process. In general, the observation results show that the PBL model was implemented effectively, and the teacher was able to make an affective and well-directed learning environment.

## Conclusion

Based on the results of this study, the conclusion of this research are: 1) the achievement of mathematical communication ability of students with a scientific approach who received the Problem-Based Learning model was higher than students with a scientific approach alone; 2) the improvement of mathematical communication ability of students with a scientific approach who received the Problem-Based Learning model was higher than students confined exclusively to a scientific-oriented approach. Accordingly, the Problem-Based Learning (PBL) framework may be strategically deployed in mathematics instruction to substantially fortify learners' mathematical

communicative acumen.

### Suggestion

For future research, it is recommended that subsequent studies expand the scope of investigation by incorporating a larger and more diverse sample drawn from multiple schools or regions in order to enhance the generalizability of the findings. Researchers may also consider employing a mixed-methods approach that integrates qualitative techniques such as interviews, reflective journals, or classroom discourse analysis to obtain deeper insights into how students construct and articulate mathematical ideas during the Problem-Based Learning process. Furthermore, extending the duration of the intervention and examining its impact across different mathematical topics or educational levels could provide a more comprehensive understanding of the model's long-term effectiveness. Future inquiries might also explore the interaction between Problem-Based Learning and other pedagogical variables, including students' prior mathematical ability, learning motivation, and collaborative dynamics, thereby offering a more nuanced depiction of the factors that mediate the development of mathematical communication competence.

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