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Impact of Problem-Based Learning on Students' Mathematical Performance: A Quasi-Experimental Study

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ABSTRACT
Background: Many students still struggle to learn mathematics effectively, especially when lessons rely heavily on teacher explanations and lack real-world connection. To improve this, teaching strategies that involve students actively in the learning process are needed. One of them is the Problem-Based Learning (PBL) model, which helps students learn through solving meaningful problems.
Aims: This study explores how the Problem-Based Learning model influences students' understanding and performance in mathematics, focusing on the topic of linear equations in two variables for Grade VIII students.
Methods: A quasi-experimental design was applied, involving two student groups: one group was taught using the PBL model, while the other used traditional instruction. Students were given problem-solving tests before and after the learning activities. These tests were used to see how their skills developed during the learning process.
Finding: Students who took part in the learning process using the PBL method showed better understanding and stronger problem-solving abilities than those in the conventional group. The approach encouraged them to think more deeply, participate actively, and relate mathematics to everyday situations.
Significance: This research highlights that PBL can be a useful method for improving students' learning results in mathematics. Teachers are encouraged to consider using this model in their classes to make learning more meaningful and effective.

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INTRODUCTION

Mathematics is recognized as a subject that fosters logical reasoning and structured problem-solving, both of which are crucial for success in school and daily life. Despite its fundamental role, many students experience difficulties in learning mathematics, often perceiving it as abstract and disconnected from reality. This perception is largely a consequence of instructional approaches that emphasize passive learning, where teachers explain while students merely listen. In such environments, students rarely engage in active thinking or apply concepts to practical situations. As a result, the knowledge they gain tends to be shallow and temporary. Algebraic topics, including linear equations in two variables, are commonly taught through procedural drills without context, limiting students' conceptual understanding. Scholars have stressed the importance of adopting learner-centered pedagogies that promote active participation and real-world application. One such approach is Problem-Based Learning (PBL), which encourages students to construct meaning through exploring and solving contextual problems (Kikomelo et al., 2025; Martínez-Gómez & Nicolalde, 2025).

Problem-Based Learning presents opportunities for deeper engagement by situating learning in meaningful scenarios that require students to collaborate and think critically. Unlike traditional teaching, which often relies on direct explanation, PBL allows students to investigate, discuss, and apply knowledge independently or in small groups. The method supports a learning culture where students explore various solutions, evaluate their strategies, and reflect on their reasoning (Sukayasa et al., 2025; Utama et al., 2025). As they engage in this process, they not only deepen their understanding but also develop essential skills such as communication, self-regulation, and teamwork. Furthermore, PBL has been found to improve students' enthusiasm toward mathematics and increase their creative thinking (Pujiastuti et al., 2025; Purnomo et al., 2024). By integrating real-life problems with mathematical content, the

approach bridges the gap between theoretical knowledge and practical use. Such integration is particularly important in topics that students often find difficult or irrelevant, such as algebraic problem-solving.

While PBL has shown promising outcomes in various educational settings, its application in secondary-level mathematics—especially in topics like linear equations—remains underexplored. Previous research has primarily examined PBL in science education, higher education, or teacher training programs (Aripin et al., 2025; Ortiz et al., 2025). Even in studies focused on mathematics, the emphasis tends to be on digital integration or general learning skills, such as critical thinking, rather than on measurable improvement in student achievement (Du et al., 2025; Mayangsari et al., 2025). Moreover, many of these studies do not specify the mathematical content being taught, making it difficult to determine the effectiveness of PBL on concepts. Linear equations in two variables are foundational for students to progress in algebra, yet they are often introduced with little contextual support. Introducing PBL in this domain may help students make sense of abstract procedures by relating them to real-life situations. However, there is a noticeable gap in empirical evidence assessing the impact of PBL on students' learning outcomes in this specific topic. This calls for focused research that evaluates how PBL influences understanding and performance in core areas of mathematics.

Prior research has highlighted the potential of PBL in enhancing students' engagement and thinking skills in mathematics. Kikomelo et al., (2025) found that students responded positively to teachers' implementation of PBL, though the study focused on perception rather than academic performance. Martínez-Gómez & Nicolalde (2025) examined mobile-based PBL and noted increased motivation among learners, yet the impact on learning outcomes remained unclear due to the role of technology. (Mayangsari et al., 2025) explored PBL for teaching proportions using Google Sites, demonstrating its digital adaptability, though it lacked focus on core algebra topics. Utama et al. (2025) and Sukayasa et al. (2025) emphasized improvements in students' critical thinking through PBL, but their research centered on reasoning skills, not test scores or concept mastery. Similarly, Aripin et al. (2025) and Ortiz et al. (2025) implemented PBL in specific contexts like statistics and teacher training, indicating that the model is flexible but underused in junior secondary mathematics. Other studies have dealt with mathematical creativity, connections, or elementary education settings, making it difficult to generalize their findings to students learning linear equations. While these findings show the breadth of PBL application, they also reveal that much of the research avoids directly measuring achievement outcomes in algebraic content. This underscores the need for more focused and controlled studies at the junior high school level, especially for mathematical topics that are foundational for future learning.

Although PBL has been shown to be effective in fostering student engagement and higher-order thinking, there is limited empirical evidence that directly evaluates its impact on student achievement in specific algebraic topics. Most existing studies either emphasize students' perceptions, critical thinking, or the integration of technology, leaving a gap in understanding how PBL influences actual learning outcomes in core mathematical areas. Moreover, few studies have employed quasi-experimental designs to compare PBL with conventional teaching in real classroom settings. Research that does focus on student achievement often overlooks middle school learners or applies PBL to general mathematical topics without addressing core competencies such as solving linear equations. This presents a critical need to investigate how PBL affects students' understanding of linear equations in two variables—a topic that forms the basis for more advanced mathematics. Filling this gap would contribute significantly to both the theoretical understanding of PBL's effectiveness and practical strategies for mathematics instruction at the secondary level.

The main objective of this study is to examine the effect of the Problem-Based Learning model on the mathematical achievement of junior high school students, specifically in the topic of linear equations in two variables. Using a quasi-experimental design, the research aims to determine whether students taught through PBL perform better in solving mathematical problems compared to those taught using conventional methods. This study also seeks to provide evidence-based recommendations for educators

on how PBL can be implemented effectively in middle school mathematics to enhance conceptual understanding and academic success.

METHOD

Research Design

This study employed a quasi-experimental design with a non-equivalent control group pretest-posttest structure, which is commonly used in educational research where random assignment is not feasible. Such designs are effective for evaluating instructional interventions in real-world classroom settings . The experimental group received instruction through the Problem-Based Learning (PBL) model, while the control group underwent conventional teaching methods. Both groups were assessed before and after the intervention to measure the impact on students' mathematical problem-solving abilities.

Participants

The participants comprised 36 eighth-grade students from SMP Integral Minhajuth Thullab, Lampung, Indonesia, during the 2019/2020 academic year. Two intact classes were selected: one as the experimental group and the other as the control group, each containing 18 students. Purposive sampling was employed to ensure both groups had comparable academic backgrounds, particularly in mathematics, based on previous performance and teacher recommendations. This method is appropriate when randomization is not feasible, but group equivalence is desired

Instruments

A mathematics problem-solving test was developed to evaluate students' abilities in solving linear equations in two variables. The test consisted of five open-ended questions, each designed to assess the four stages of problem-solving as outlined by Polya: understanding the problem, devising a plan, carrying out the plan, and reviewing the solution . A scoring rubric was utilized to evaluate responses, assigning weights to each stage based on complexity. Prior to implementation, the test underwent validation for content and reliability, ensuring its effectiveness in measuring the intended competencies.

Data Analysis

Data were analyzed using both descriptive and inferential statistics. Descriptive statistics, including mean and standard deviation, provided an overview of student performance. Inferential statistics involved the Shapiro-Wilk test for normality, Levene's test for homogeneity of variances, and an independent samples t-test to determine significant differences between groups. All analyses were conducted using IBM SPSS Statistics, a software widely used for statistical analysis in educational research. A significance level of 0.05 was set for all tests.

RESULTS AND DISCUSSION

Results

The purpose of this study was to examine the effectiveness of the Problem-Based Learning (PBL) model in improving students' mathematical achievement, particularly in solving linear equations in two variables. This section presents the findings from both descriptive and inferential statistical analyses conducted on pretest and posttest scores of the experimental and control groups. Table 1 summarizes the mean scores, standard deviations, and variances for both groups.

Table 1. Descriptive Statistics of Posttest Scores

Group	N	Mean	Standard Deviation	Variance
Experimental	18	72.33	8.20	67.25
Control	18	65.11	9.24	85.36

As shown in the table, the experimental group, which received PBL-based instruction, achieved a higher average score (M = 72.33) than the control group (M = 65.11). This suggests a noticeable difference in learning outcomes between the two groups.

To visually illustrate this difference, a bar chart was constructed with error bars representing the standard deviations.

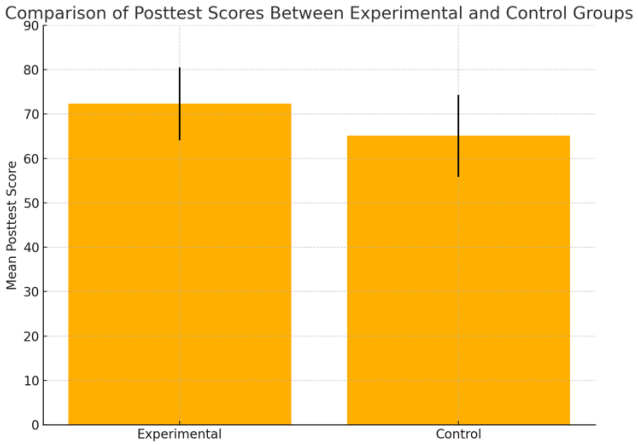

Figure 1. Comparison of posttest mean scores between the experimental and control groups. Error bars represent standard deviations.

Prior to hypothesis testing, assumption checks were conducted to ensure the appropriateness of the statistical procedures. The Shapiro-Wilk test was applied to assess the normality of the posttest score distributions, and the results indicated that the data for both groups followed a normal distribution ($p > 0.05$). Additionally, Levene's test was employed to verify the homogeneity of variances between the groups, and it also confirmed that the assumption of equal variances was satisfied ($p > 0.05$). These outcomes validated the use of an independent samples t-test to evaluate the effectiveness of the instructional model.

The inferential analysis revealed a statistically significant difference in posttest scores between the experimental and control groups. The independent samples t-test produced a t-value of 2.986 with a p-value of 0.005, which is lower than the conventional alpha level of 0.05. Since the t-value exceeded the critical value ($t(34) = 2.034$), the null hypothesis was rejected. This finding provides strong evidence that the Problem-Based Learning model had a meaningful positive impact on students' mathematical performance compared to traditional instruction.

Discussion

This study examined the impact of the Problem-Based Learning (PBL) model on students' mathematics learning outcomes, especially in solving linear equations in two variables. The quantitative results showed that students who learned using the PBL model had better performance than those taught through traditional methods. The improvement was evident across various stages of problem solving, from identifying problems to evaluating solutions.

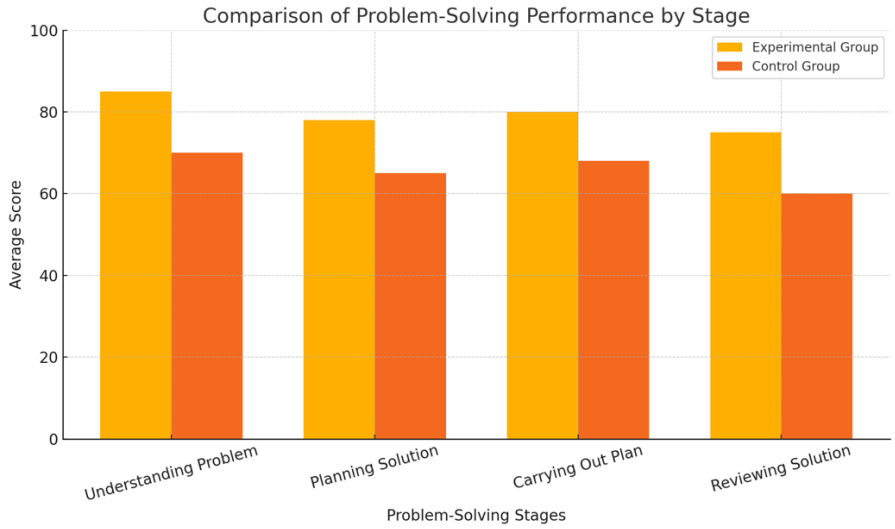

Figure 2. Average performance of students on different stages of mathematical problem-solving in the experimental and control groups.

As illustrated in Figure 2, students in the PBL group consistently performed better in each component of problem-solving ability. These results support the idea that PBL encourages learners to engage more deeply with the material, enhances their reasoning ability, and fosters independence in learning. The structured steps in the PBL model help students analyze problems, plan strategies, and evaluate their own understanding through collaboration and contextualized practice.

The findings of this study are consistent with both international and national research. Yusri (2018) and Permastya & Margiati (2015) found that PBL positively influences students' mathematical performance, especially in problem-solving contexts. Similar findings were reported by Andriyana & Ardani (2017), who showed that problem cards in PBL further stimulated student thinking, and by Bandi et al. (2015), who noted significant improvements in learning outcomes when PBL was applied in junior high school settings. Furthermore, Bilolo et al. (2022) confirmed the effectiveness of PBL in enhancing understanding of set theory among Grade VII students, while Luthfiana et al. (2018) highlighted the impact of PBL in promoting students' critical thinking in algebraic contexts. Lastly, Riska & Raharja (2019) emphasized how PBL accommodates various learning styles and improves students' conceptual understanding in mathematics.

These consistent findings across different contexts reinforce the theoretical foundation of PBL in constructivist learning, where students construct knowledge through experience, dialogue, and reflection. Involving students in solving meaningful problems encourages not only deeper comprehension but also the development of communication, collaboration, and metacognitive skills.

Although the present study was conducted with a limited sample and focused only on one topic, the alignment between this study and prior research suggests that the PBL model can be a promising alternative to traditional mathematics instruction. Given the increasing demand for student-centered learning, this model holds potential to be expanded more widely in Indonesian classrooms to support better learning outcomes in mathematics.

Implications

The findings from this study show that Problem-Based Learning (PBL) can be a valuable approach to improve students' understanding and performance in mathematics, especially in topics that are usually considered abstract, such as linear equations. When students are actively involved in solving real-life problems, they become more engaged and are able to think critically. This has

important implications for teachers, curriculum developers, and school leaders. Teachers are encouraged to adopt more interactive and student-centered methods like PBL to help learners build stronger mathematical thinking. In addition, teacher training programs should consider including PBL strategies so that future educators are better prepared to implement them in the classroom. Schools and policymakers can also support this shift by providing time, training, and resources that allow for meaningful implementation of such models.

Limitations

Although the results of this study are promising, there are some limitations that need to be considered. First, the number of participants was relatively small and limited to one school, which may affect how widely the results can be applied. Second, the focus was only on one mathematical topic—linear equations in two variables—so the effectiveness of PBL in other topics was not explored. Third, the duration of the intervention was short, which may not be enough to see the long-term impact of the learning model. Finally, the study used paper-based tests as the main instrument, which may not fully capture the broader benefits of PBL such as collaboration or communication skills.

Suggestions

Future research could explore the use of PBL in different mathematical topics, such as geometry, statistics, or number patterns, to see whether similar results can be achieved. It would also be beneficial to involve more schools and larger groups of students to increase the reliability and generalizability of the findings. Researchers may consider combining quantitative and qualitative methods, for example by including interviews or classroom observations, to better understand how students interact and learn during PBL activities. For teachers and schools, it is recommended to start implementing PBL gradually, perhaps beginning with simpler problems or integrating PBL into selected lessons. Over time, with proper support and reflection, PBL can become a regular and effective part of mathematics teaching.

CONCLUSION

This study aimed to explore how the Problem-Based Learning (PBL) model affects students' mathematical achievement, especially in solving problems involving linear equations in two variables. The results showed that students who learned through the PBL approach performed better than those who were taught using traditional methods. They not only achieved higher scores, but also showed stronger skills in understanding problems, planning strategies, solving, and reviewing their work.

The improvement in student performance suggests that involving learners in solving meaningful problems helps them understand mathematical concepts more deeply. PBL encourages students to think critically, work together, and connect math to real-life situations. These experiences make learning more enjoyable and effective.

Although the research was done with a small group and focused on one topic, the findings give useful insight for teachers and schools. Using PBL can be a good way to improve learning outcomes, especially when teaching abstract or difficult math topics. Overall, PBL has strong potential to support better mathematics learning and should be considered as part of classroom instruction.

AUTHOR CONTRIBUTIONS STATEMENT

SA was responsible for conceptualizing the research idea, designing the methodology, and conducting the classroom intervention. In addition, Author 1 led the data collection process and performed the initial statistical analysis. **P** and **SQ** contributed to refining the research framework, assisted in interpreting the results, and helped in drafting, reviewing, and editing the manuscript. Author 2 also ensured the alignment of the article with academic writing standards and publication requirements.

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