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Evaluating the Impact of Problem-Based Learning on Mathematics Achievement

Rifdatul Zahra[1], Asih Mardati[2], Yeyen Febrilia[3]
Ahmad Dahlan University, Yogyakarta, Indonesia[1,2], Muhammadiyah University of Bangka Belitung, Pangkalpinang, Indonesia[3]
rifdatul2000005288@webmail.uad.ac.id[1], asih.mardati@pgsd.uad.ac.id[2], yeyen.febrilia@unmuhbabel.ac.id[3]

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ABSTRACT
Mathematics is often perceived as a challenging subject by many elementary school students due to its abstract nature and the limited use of contextual learning approaches. This study aimed to investigate the effect of Problem-Based Learning (PBL) on students' mathematics achievement in fraction topics. A quasi-experimental design with a non-equivalent control group was employed involving 36 fifth-grade students at SD Muhammadiyah Noyokerten. The participants were assigned to an experimental group receiving PBL instruction and a control group receiving conventional instruction. Data were collected using pretests and posttests and analyzed using descriptive statistics, the Shapiro-Wilk normality test, and the Wilcoxon Signed-Rank Test. The results indicated significant improvements in mathematics achievement in both groups, with the experimental group demonstrating a substantially greater increase in mean scores (from 53.33 to 82.22) than the control group (from 62.78 to 72.78). These findings suggest that Problem-Based Learning is associated with greater improvements in elementary students' mathematics achievement, particularly in learning fractions.

INTRODUCTION

Mathematics constitutes a fundamental pillar of scientific knowledge, as virtually all disciplines are connected to and supported by mathematical principles. This is unsurprising because, beyond mathematical knowledge itself, mathematics provides the language, processes, and theoretical frameworks that shape and strengthen scientific understanding. Consequently, mathematics has become one of the core subjects within the Indonesian education system and is taught continuously from primary education through higher education (Fatimah et al., 2022).

By its nature, mathematics is characterized by abstract objects and ideas. The abstract nature of mathematics encompasses facts, concepts, operations, and principles (Mardati & Febrilia, 2023). In contrast, according to Jean Piaget's theory of cognitive development, children aged 7-11 years, corresponding to primary school students, are generally in the concrete operational stage of intellectual development (Mardati et al., 2024). At this stage, students tend to rely on concrete objects and experiences and typically demonstrate concrete, rational, and objective ways of thinking when interpreting situations. The discrepancy between the abstract characteristics of mathematics and the intellectual developmental stage of students has been identified as one of the factors influencing variations in students' learning outcomes (Christi et al., 2023).

Mathematics is a distinctive field of knowledge compared with other scientific disciplines (Permatasari & Darmawijoyo, 2020). It is widely recognized as an abstract body of knowledge organized hierarchically and grounded in deductive reasoning. These characteristics inevitably have important implications for the teaching and learning of mathematics.

Observations conducted in October 2023 in a fifth-grade classroom at SD Muhammadiyah Noyokerten revealed that most students perceived mathematics as a difficult and uninteresting subject. This finding became evident during classroom evaluations conducted after instructional sessions, where teachers posed oral questions related to the lesson content. Of the 18 students in the class, only three were able to answer the questions correctly. Another issue identified was that students experienced considerable difficulty in understanding mathematical concepts when instruction was not supported by concrete objects or manipulatives. Furthermore, many students struggled to recognize the relevance of mathematics to everyday life. These challenges reduced students' motivation to participate actively in mathematics learning and ultimately contributed to low mathematics achievement.

The low learning outcomes of fifth-grade students at SD Muhammadiyah Noyokerten were reflected in the fact that more than 50% of students failed to achieve the Minimum Mastery Criterion (KKM). The school had established a KKM score of 70 for mathematics. Students' performance data further illustrate this issue: the average score on daily assessments was 45.5, with only five students meeting the KKM; the average mid-semester examination score was 47.5, with eight students achieving mastery; and the average end-of-semester examination score was 49.5, with only nine students meeting the required standard. The large proportion of students who failed to reach the KKM indicates insufficient understanding of mathematical problems and concepts.

Considering these challenges, improvements in instructional practice are necessary to enhance the quality of mathematics learning. One potential solution is to design instruction that aligns with students' developmental characteristics and learning needs. Teachers are encouraged to create enjoyable learning environments that incorporate real-life and concrete contexts, thereby fostering students' interest and engagement in learning activities (Febrilia et al., 2025). In this regard, the selection of an appropriate instructional model can help teachers establish active, meaningful, and enjoyable learning experiences (Wiryana & Alim, 2023).

A learning model can be defined as a systematic framework or approach used to design, implement, and manage instructional processes. Learning models assist teachers in organizing content delivery, facilitating student engagement, and structuring assessment procedures. In selecting an appropriate instructional model, several key elements should be considered, including learning objectives, instructional methods, interaction patterns, evaluation strategies, and contextual factors such as students' characteristics and needs, resource availability, and the learning environment (Durukan & Sağlam Arslan, 2022; Thum et al., 2025).

As educators, teachers are required to select instructional models that effectively support students' understanding of learning materials. In this context, the Problem-Based Learning (PBL) model was considered particularly suitable for addressing the challenges identified in this study. Problem-Based Learning is an instructional approach in which students learn by solving structured problems that are closely related to real-world situations (Gonzalez, 2019; Hu et al., 2018; Meutia et al., 2020; Yin et al., 2021). This model places students in situations where they are required to identify problems, gather relevant information, analyze data, develop solutions, and present their findings (Rodríguez-Nieto et al., 2025; Tee, 2022). Through this process, students independently acquire the knowledge and skills necessary for problem solving and lifelong learning.

Furthermore, because Problem-Based Learning engages students in authentic and meaningful contexts, it has the potential to enhance students' intrinsic motivation toward mathematics learning, which in turn may contribute to improved learning outcomes (Juniati & Jamaan, 2024; Putri et al., 2022;

Rozana et al., 2020). Based on the issues outlined above, an experimental study was conducted to investigate the effect of Problem-Based Learning (PBL) on mathematics learning outcomes among students at SD Muhammadiyah Noyokerten.

METHOD

This study employed a quasi-experimental research design using a non-equivalent control group design. The design involved two groups, namely an experimental group and a control group (Anttila et al., 2021; Badolo et al., 2025). The independent variable in this study was Problem-Based Learning (PBL), while students' learning outcomes served as the dependent variable. Prior to administration, the instrument was reviewed by two mathematics education experts and one elementary school teacher to ensure content validity.

Data were collected through classroom observations and achievement tests. Accordingly, the research instruments consisted of observation sheets and test items. The data were analyzed using descriptive statistics and inferential statistics. Descriptive statistics were used to summarize students' pretest and posttest scores, whereas inferential statistics were employed to examine differences between the pretest and posttest scores. Descriptive analysis was used to examine the implementation of learning activities in both the experimental and control classes, as well as the pretest and posttest results.

Inferential statistical analysis was conducted in two stages. First, the normality assumption was examined using the Shapiro-Wilk test. Because the assumption of normality was violated, the Wilcoxon Signed-Rank Test was employed to compare the pretest and posttest scores within each group. The decision criteria for hypothesis testing were as follows: if the significance value was less than 0.05 (Sig. < 0.05), the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted. Conversely, if the significance value exceeded 0.05 (Sig. > 0.05), the null hypothesis (H_0) was accepted and the alternative hypothesis (H_1) was rejected.

RESULTS AND DISCUSSIONS

The effect of the Problem-Based Learning (PBL) model on the mathematics learning outcomes of fifth-grade students at SD Muhammadiyah Noyokerten was examined involving a total of 36 students from two classes, namely Class VA and Class VB. Class VA served as the control group, while Class VB was assigned as the experimental group. The independent variable in this study was the Problem-Based Learning (PBL) model (X), whereas the dependent variable was students' learning outcomes (Y). To measure the effect of the intervention, both groups were administered pretests and posttests.

The assessment instruments consisted of 10 pretest items and 10 posttest items designed to evaluate students' mathematics learning outcomes before and after the implementation of the instructional intervention. The results obtained from the pretest and posttest administrations are presented below.

Table 1. Descriptive Statistics Data

Group	Test Type	N	Minimum	Maximum	Mean	SD
Experimental	Pre-test	18	10	90	53.33	24.97
Experimental	Post-test	18	50	100	82.22	16.65
Control	Pre-test	18	40	80	62.78	11.79
Control	Post-test	18	40	100	72.78	15.65

Based on Table 1, differences in the statistical characteristics of students' scores were observed between the experimental and control groups. The descriptive statistics indicate that, prior to the intervention, the experimental group achieved a higher maximum pretest score than the control group. Specifically, the highest pretest score in the experimental group reached 90, whereas the highest score

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in the control group was 80. Following the intervention, however, both groups achieved the same maximum posttest score of 100.

In terms of minimum scores, the experimental group recorded a lower minimum pretest score than the control group, with scores of 10 and 40, respectively. In contrast, the posttest results showed an improvement in the experimental group, with its minimum score increasing to 50, while the minimum score in the control group remained at 40. This finding suggests that the implementation of Problem-Based Learning (PBL) contributed not only to improving average performance but also to raising the achievement level of lower-performing students.

Regarding measures of central tendency, the experimental group initially demonstrated a lower mean pretest score than the control group, with average scores of 53.33 and 62.78, respectively. However, following the intervention, the experimental group outperformed the control group, achieving a mean posttest score of 82.22 compared with 72.78 in the control group. The larger increase in the mean score of the experimental group provides preliminary evidence of the effectiveness of the PBL approach in improving mathematics learning outcomes.

With respect to measures of dispersion, differences in standard deviation were observed between the two groups for both pretest and posttest scores. During the pretest, the experimental group exhibited greater variability in student performance (SD = 24.97) than the control group (SD = 11.79), indicating a wider distribution of initial abilities among students in the experimental class. Following the intervention, the variability of scores in the experimental group decreased substantially (SD = 16.65), whereas the control group recorded a standard deviation of 15.65. The reduction in score variability in the experimental group suggests that the PBL intervention may have contributed to more consistent learning outcomes among students.

Prior to hypothesis testing, a normality test was conducted to determine whether the data satisfied the assumptions required for selecting the appropriate statistical test. Prior to hypothesis testing, a normality test was conducted to determine whether the data satisfied the assumption of normality. The normality test was performed to determine whether the pretest and posttest data were normally distributed.
The decision criteria for the normality test were as follows:

a. If the significance value was greater than 0.05 ($p > 0.05$), the data were considered to be normally distributed.
b. If the significance value was less than 0.05 ($p < 0.05$), the data were considered not to be normally distributed.

The results of the normality test conducted using SPSS are presented in the following table.

Table 2. Normalitas Test Analyzes

Dataset	Shapiro-Wilk Sig.	Interpretation
Pretest Experimental	0.445	Normal
Posttest Experimental	0.028	Not Normal
Pretest Control	0.153	Normal
Posttest Control	0.560	Normal

As presented in Table 2, the Shapiro-Wilk test indicated that three of the four datasets were normally distributed, whereas the posttest scores of the experimental group were not ($p = 0.028$). This result suggests that the assumption of normality was not fully satisfied for all datasets. Furthermore, the Shapiro–Wilk test of the difference scores (posttest minus pretest) showed that the experimental group's difference scores did not meet the normality assumption ($p = 0.050$), whereas the control group's difference scores were normally distributed.

Because one of the paired difference distributions violated the normality assumption, the use of a non-parametric alternative was considered more appropriate. Therefore, the Wilcoxon signed-rank test was employed to examine the differences between the pretest and posttest scores within each group. This approach was selected because it does not require the assumption of normality and provides a more robust analysis for small samples with non-normal data distributions.

Following the completion of the prerequisite assumption tests, hypothesis testing was conducted to examine the effect of the Problem-Based Learning (PBL) model on students' mathematics learning outcomes. In this study, the hypothesis test was performed using the Wilcoxon signed-rank test with the assistance of SPSS version 26 for Windows. The results of the hypothesis testing are presented in Table 3.

Table 3. Results of the Wilcoxon signed-rank test

Group	Z	p	Decision
Eksperiment	-3.724	<.001	Significant
control	-2.551	0.009	Significant

As presented in Table 3, The results of the Wilcoxon Signed-Rank Test revealed a Z value of -3.724 with an Asymp. Sig. (2-tailed) of 0.000 ($p < 0.05$). These findings indicate a statistically significant difference between the pretest and posttest scores in the experimental group. Therefore, the null hypothesis (H_0), which states that there is no difference between the pretest and posttest scores, was rejected, while the alternative hypothesis (H_1) was accepted. Furthermore, the test results showed that all students demonstrated improved scores following the intervention (Positive Ranks = 18; Negative Ranks = 0; Ties = 0). This finding indicates that the instructional model implemented in the experimental group consistently enhanced students' learning outcomes. Consequently, the intervention had a statistically significant positive effect on improving students' academic performance.

The results of the Wilcoxon Signed-Rank Test for the control group yielded a Z value of -2.551 with an Asymp. Sig. (2-tailed) of 0.009 ($p < 0.05$). These results indicate a statistically significant difference between the pretest and posttest scores in the control group. Accordingly, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_1) was accepted.

The analysis further revealed 11 positive ranks, 2 negative ranks, and 5 ties. This indicates that most students demonstrated improved learning outcomes after the instructional period, although two students experienced a decline in their scores and five students showed no change between the pretest and posttest. These findings suggest that the instructional activities implemented in the control group also contributed to improvements in students' learning outcomes; however, the improvement was less consistent across participants than that observed in the experimental group.

The findings of this study are consistent with previous research demonstrating that the application of Problem-Based Learning can enhance students' mathematics achievement (Fadilah et al., 2021; Fathonah et al., 2025; Hendra, 2021). Similarly, several earlier studies reported that the use of the PBL model significantly improved the learning outcomes of fifth-grade elementary school students (Atikah & Istiq'faroh, 2023; Atikah et al., 2023; Robiyanto, 2021; Sari & Rusnilawati, 2022; Setyani et al., 2020). One possible explanation for these findings is that Problem-Based Learning emphasizes the process of solving authentic and meaningful problems, making it particularly suitable for mathematics instruction aimed at improving learning outcomes. Through engagement with problem-solving activities, students are encouraged to apply their prior knowledge to new situations while simultaneously developing creativity, critical thinking, systematic reasoning, and empirical logic, all of which contribute to the development of scientific attitudes (Robiyanto, 2021).

In addition, instructional modules designed according to the principles and syntax of Problem-Based Learning provide teachers with a structured framework for implementing classroom activities. The implementation of Problem-Based Learning followed five stages proposed by Arends: (1) orienting students to the problem, (2) organizing students for learning, (3) guiding individual and group investigations, (4) developing and presenting solutions, and (5) analyzing and evaluating the problem-solving process. The clearly defined stages embedded within the PBL model facilitate more organized, effective, and meaningful learning experiences, thereby supporting the achievement of intended learning objectives.

The Wilcoxon Signed-Rank Test indicated statistically significant improvements in mathematics achievement in both the experimental and control groups. However, the magnitude of improvement observed in the experimental group was considerably larger than that of the control group, with an average increase of 28.89 points compared to 10.00 points in the control group. Although the present study did not directly compare gain scores between groups, the descriptive findings suggest that Problem-Based Learning may provide greater opportunities for improving students' understanding of fraction concepts than the instructional approach implemented in the control class.

One possible explanation for this result is that Problem-Based Learning actively engages students in identifying, discussing, and solving contextual mathematical problems. Through collaborative investigation and reflection, students are encouraged to construct their own understanding of fraction concepts rather than merely receiving information from the teacher. This learning process is consistent with constructivist learning theory, which emphasizes active knowledge construction through meaningful experiences.

The positive contribution of Problem-Based Learning may be particularly relevant in fraction learning because fractions are often regarded as one of the most abstract topics in elementary mathematics. Contextual problem situations embedded within PBL activities may help students connect symbolic fraction representations with real-life experiences, thereby reducing misconceptions and improving conceptual understanding.

Several limitations should be acknowledged. First, the study employed intact classroom groups without random assignment, which limits the strength of causal inference. Second, the analysis focused primarily on within-group comparisons using the Wilcoxon Signed-Rank Test and did not include direct between-group comparisons or analyses of gain scores. Future studies are encouraged to employ more robust analytical approaches, such as ANCOVA or independent-samples t-tests on gain scores, to provide stronger evidence regarding the comparative effectiveness of Problem-Based Learning.

CONCLUSION AND SUGGESTION

Based on the findings of this study conducted with fifth-grade students at SD Muhammadiyah Noyokerten on the topic of fractions, it can be concluded that the implementation of the Problem-Based Learning (PBL) model was associated with substantial improvements in students' mathematics learning outcomes. The descriptive results indicate that the experimental group achieved a mean pretest score of 53.33, which increased to 82.22 in the posttest, representing an improvement of approximately 28.89 points or about 54.2% relative to the initial score. In contrast, the control group obtained a mean pretest score of 62.78 and a mean posttest score of 72.78, corresponding to an improvement of 10.00 points or approximately 15.9%.

The Wilcoxon Signed-Rank Test further demonstrated statistically significant improvements in mathematics achievement in both groups. The experimental group showed a statistically significant improvement ($Z = -3.724$, $p < .001$), while the control group also demonstrated a significant improvement ($Z = -2.551$, $p = .009$). However, the magnitude of improvement observed in the experimental group was considerably greater than that of the control group. These findings suggest that the implementation of the Problem-Based Learning model may provide greater benefits for improving students' mathematics learning outcomes than the instructional approach employed in the control group, which was based on cooperative learning strategies. In particular, the emphasis of PBL on authentic problem solving, active student engagement, and independent knowledge construction appears to contribute positively to students' understanding of fraction concepts and overall mathematics achievement.

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