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The Effect of Problem-Based Learning Model on Vocational Students' Mathematical Concept Understanding in Solving Numerical Problems

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Abstract

This study was motivated by observations of challenges faced by vocational school students in understanding mathematical concepts. To address this issue, a Problem-Based Learning (PBL) model that actively involved students through numerical problem-solving was implemented. The sample consisted of 44 students from two Grade X classes at a vocational high school in East Jakarta. Numerical problems in the form of descriptive questions based on the System of Linear Inequalities in Two Variables (SPtLDV) were used as post-test instruments to assess students' mathematical concept understanding. The experimental class achieved an average post-test score categorized as high. Hypothesis testing showed that students' understanding of mathematical concepts using the PBL model was significantly better than with the conventional approach. The effect size, calculated using Cohen's d formula, was 2.12—classified as high—confirming the effectiveness of the PBL model in enhancing students' understanding of mathematical concepts through numerical problem-solving.

Keywords: *Problem Based Learning; mathematical conceptual understanding; numerical problem*

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INTRODUCTION

A fundamental skill that students' must possess in learning mathematics is the ability to comprehend mathematical concepts (Giriansyah et al., 2023). Mathematical understanding needs to be developed systematically and continuously, as students must grasp prior material to successfully solve mathematical problems (Asnila et al., 2016; Yelvalinda et al., 2019). However, the results of PISA 2022 indicate that Indonesian students' mathematical abilities remain low, with the country ranking 79th out of 90 and an average score of 366 (OECD, 2024). Despite the importance of understanding mathematical concepts, students in Indonesia still struggle to grasp mathematical material, as indicated by the PISA 2022 results.

Rahayu et al. (2018) stated that students' competence in mastering, explaining, applying, and linking various mathematical concepts is defined as the ability to understand mathematical concepts. The ability becomes the foundation in analyzing and solving problems in real situations (Agustina, 2018). Therefore, the ability to understand mathematical concepts is considered necessary to be mastered by students because it is useful in working on math problems with real contexts.

Current mathematics learning emphasizes the application of mathematical concepts by connecting students' everyday experiences with mathematics (Mayasari et al., 2019; Mayasari & Habeahan, 2021). The application of the ability to understand mathematical concepts through real contexts can be applied to numerical problems that have 5 forms, one of which is a numerical problem in the form of descriptions whose solution requires understanding of concepts (Liswati et al., 2021). The process of solving numerical problems consists of four stages: formulating, employing, interpreting, and evaluating (Fachrudin, 2022). These four processes are interconnected in applying mathematics to solve real-world problems, as illustrated in detail in Figure 1 (Fachrudin, 2022).

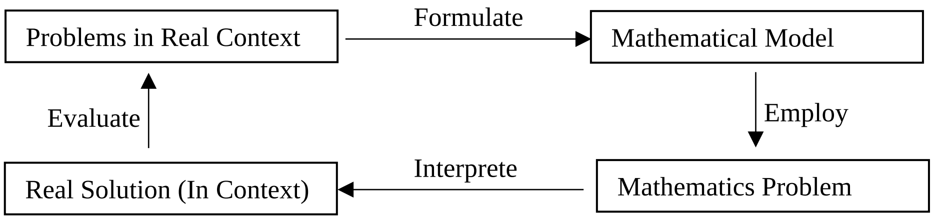

Figure 1: Numerical problem-solving process

Numerical questions are categorized into four content domains: 1) Numbers, 2) Geometry and Measurement, 3) Algebra, and 4) Data and Uncertainty. Therefore, understanding mathematical concepts in real-world contexts can be applied across various content domains of numerical questions. In addition to the content domain, numerical questions also incorporate contexts that are relevant to students' environments, including social, cultural, scientific, or mathematical-scientific aspects. The context of numerical problems is divided into three categories: 1) Personal, which relates to individual interests; 2) Socio-cultural, which involves the connection between individual interests, culture, and related social issues; and 3) Scientific, which pertains to problems, activities, and scientific evidence—either current or futuristic (Liswati et al., 2021).

The results of research by Sulastri et al. (2024), students in solving numerical problems fall into the good category. Having the ability to understand mathematical concepts makes it easier to remember and easier to solve math problems involving various formulas (Aini et al., 2020). Meanwhile, low understanding of mathematical concepts can cause obstacles when connecting various mathematical concepts (Neno et al., 2020). Therefore, success when answering numerical questions is influenced based on the capacity of students mathematical concept understanding abilities.

Several studies have reported that students, particularly at the vocational high school level, still struggle with understanding mathematical concepts. Surven et al. (2022) and Mayasari & Habeahan (2021) found that low levels of understanding were marked by students' difficulties in solving contextual problems, representing mathematical ideas, and constructing models from given situations. Similarly, Handayani & Ramadhani (2020) and Fitri et al. (2023) revealed that students often fail to convert concepts into mathematical forms or operations. These findings suggest that the lack of conceptual understanding is a common and urgent issue in mathematics education. Despite these findings, there remains a lack of empirical evidence on the effectiveness of the Problem-Based Learning (PBL) model in enhancing vocational students' mathematical concept understanding, especially in solving numerical problems. Therefore, this study addressed this gap by examining the impact of the PBL model on the understanding of mathematical concepts among vocational high school students.

The root causes of this problem may stem from both external and internal factors. Teacher-centered instructional practices and limited student engagement can hinder the development of deep understanding (Rohmah et al., 2024). Additionally, students' individual characteristics, such as low interest, limited talent, or cognitive challenges, may also contribute to poor conceptual grasp (Arini & Mahendra, 2016; Rahma & Kurniawati, 2024). Therefore, improving students' mathematical concept understanding requires a shift toward more student-centered, participatory learning models.

One promising approach is Problem-Based Learning (PBL), which emphasizes student engagement in solving real-world problems. PBL model consists of several key phases. The learning process begins by directing students to identify and understand the problem that needs to be solved. Following this, students are encouraged to organize and engage in learning activities relevant to the problem. During the process, both individual and group investigations are carried out under the guidance of the teacher. The findings from these investigations are then developed further and presented by the students. Finally, evaluation and reflection are conducted to assess the effectiveness of the problem-solving process (Setiawan et al., 2022).

The PBL model not only enhances students' problem-solving skills but also deepens their understanding of mathematical concepts through active engagement. This learning approach encourages students to take greater responsibility for their own learning, and fosters a more meaningful, contextualized educational experience. PBL encourages students to link new concepts with prior knowledge, promotes active inquiry, and fosters meaningful learning experiences (Silalahi et al., 2023). Within this model, the teacher acts as a facilitator and motivator rather than the sole source of knowledge (Mardani et al., 2021). Research has shown that PBL is effective in improving students' mathematical concept understanding (Silalahi et al., 2023 ; Rahma & Kurniawati, 2024).

While previous studies confirmed the effectiveness of PBL in conceptual development, a gap remained in the integration of numerical problems within the PBL framework. Silalahi et al. (2023) did not specifically explore the integration of numerical problems as a core component of problem-based learning. Meanwhile, Sulastri et al. (2024) examined the ability to understand mathematical concepts through numerical problem-solving, but their study did not employ the PBL model. To address this gap, the researcher investigated the effect of the problem-based learning model on vocational students' ability to understand mathematical concepts in the context of solving numerical problems.

One of the vocational schools in East Jakarta was used as the place where this research was conducted. Because vocational high schools aim to prepare students to enter the world of work through the skills they have. In this process, understanding mathematical concepts has an important role because vocational competencies that directly or indirectly require the ability to think logically, analytically, and quantitatively. Based on the results of interviews with mathematics teachers, the ability to understand mathematical concepts of grade 10 students was found to be lacking by researchers. This was evident from the ATS (Mid-Semester Assessment) scores, where many students still scored below the KKM. The percentage of students reaching KKTP is 41.86%, while students who do not reach KKTP are 58.14%. For this reason, researchers will conduct research related to the experimentation of the PBL model on the ability to understand mathematical concepts in solving numeration problems in vocational students. The right learning model, and linking mathematical problems with real problems in the form of numerical problems to optimize learning outcomes so that students can understand mathematical concepts.

METHODS

This study employed a quantitative approach using a quasi-experimental design, aimed at examining the cause-and-effect relationship between variables without implementing full randomization of research subjects (Anantasia & Rindrayani, 2025). The research was conducted during the second semester of the 2024/2025 academic year at a vocational high school in East Jakarta. The population consisted of 175 Grade 10 students across seven classes. The sample comprised two groups selected through cluster-based random sampling. The experimental group was taught using the Problem-Based Learning (PBL) model, while the control group received instruction through a conventional approach using PowerPoint presentations.

Data were collected using a test instrument designed to measure students' understanding of mathematical concepts through descriptive numerical questions. The test focused on the topic of the System of Linear Inequalities in Two Variables (SPtLDV). An example of one of the numerical problems used in the study is shown in Figure 2.

> In the Pancasila Student Profile Strengthening Project (P5) Entrepreneurship activities, the school is organizing a bazaar. Each class will sell several food or beverage products. Class X Accounting students are selling mango juice and chocolate ice. The selling price is 1 cup of mango juice for Rp5,000, and 1 cup of chocolate ice for Rp4,000. Their initial capital is only Rp200,000. The profit obtained from mango juice and chocolate ice has a ratio of 13:10. The profit from mango juice is Rp1,300. On the day of sale, the students only provide no more than 45 cups. Class X Accounting students want to obtain maximum profit. Use the corner point method to find out the maximum profit that will be obtained!

Figure 2: Example of a Numerical Problem Used in The Study

This instrument was developed by the researcher based on learning objectives and indicators of understanding mathematical concepts, which were adapted from Mawaddah & Maryanti (2016) and Gusmania & Agustyaningrum (2020). These indicators include: 1) restating a concept, 2) presenting concepts in various forms of mathematical representation, 3) selecting and applying appropriate procedures or operations, and 4) applying concepts or algorithms to solve problems.

To ensure the quality of the instrument used in data collection, the mathematical concept understanding test underwent both validity and reliability testing. The validity test aimed to confirm that the instrument accurately measured aspects of students' understanding of mathematical concepts. Content validity was assessed by expert reviewers, including lecturers and mathematics teachers, while construct validity involved testing the instrument with vocational high school students. Furthermore, the reliability test was conducted to evaluate the consistency and stability of the instrument in measuring the same ability over time, using the Cronbach's Alpha technique, which yielded a coefficient of 0.772.

Before the treatment was administered, a preliminary test was conducted using Mid-Semester Assessment (ATS) data. The Mann-Whitney test was applied to ensure the equivalence of initial conditions between the experimental and control classes. Following the implementation of the treatment, students' mathematical concept understanding test results were analyzed. The descriptive statistics included minimum and maximum scores, standard deviation, and variance. Additionally, the results were categorized according to the percentage levels of mathematical concept understanding ability, as presented in Table 1.

Table 1. Percentage Categories of Mathematical Concept Understanding Ability

Score Range	Category
86 – 100	Very High
71 - 85	High
56 – 70	Moderate
41 - 55	Low
0 - 40	Very Low

Source: (Djaali & Muljono, 2008; Melinia & Mulyono, 2022)

Hypothesis testing in this study was conducted using the Mann-Whitney test, as the data did not meet the assumptions of normality and homogeneity, as evidenced by the results of the normality and homogeneity tests, respectively. To evaluate the extent of the impact of the PBL model on students' understanding of mathematical concepts, the effect size was calculated. The criteria for interpreting the effect size are presented in Table 2 below.

Table 2. Effect Size Criteria

Large Effect Size	Description
0.00 – 0.20	Has a Weak Effect (Very Low)
0.21 – 0.50	Has Low Effect
0.51 – 1.00	Has Medium Effect
>1.00	Has High Effect

Source: (Cohen et al., 2018)

At the 5% significance level, the hypotheses tested in this study include:
$H_0: \mu_1 = \mu_2$ (There is no difference in the ability to understand mathematical concepts in solving numerical problems of experimental and control class students).
$H_0: \mu_1 \neq \mu_2$ (There is a difference in the ability to understand mathematical concepts in solving numerical problems of experimental and control class students).

RESULTS AND DISCUSSION

Results

Pre-Research Test

At the initial stage, a pre-research analysis was conducted, which included descriptive statistics and the Mann-Whitney test using SPSS, based on ATS (Midterm Assessment) scores from the experimental and control classes. The Mann-Whitney test was selected because the data did not meet the assumption of normality. This preliminary analysis aimed to determine whether a significant difference existed between the two groups. Descriptive statistics were presented first, followed by the Mann-Whitney test. The descriptive results are shown in Table 3.

Table 3. Descriptive Statistics of Pre-Research Data

	Data Description					
	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Experiment Class	21	50	95	75.95	11.138	124.048
Control Class	23	60	95	78.04	11.652	135.771

Table 3 shows that the experimental class had a mean score of 75.95 with a standard deviation of 11.138, while the control class had a mean score of 78.04 with a standard deviation of 11.652, indicating variability in both groups. Normality and homogeneity tests conducted on the pre-research data revealed that the data were not normally distributed. Specifically, the control class showed a significance value of 0.015,

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which was below the 0.05 threshold. Therefore, the Mann-Whitney test was used to examine the equivalence between the two classes, as shown in Table 4.

Table 4. Mann-Whitney U Test Results (Pre-Research)

	ATS Result
Mann-Whitney	216.000
Wilcoxon W	447.000
Z	-0.608
Asymp. Sig. (2-tailed)	0.543

The Asymp. Sig. value of 0.543 indicates that the null hypothesis (H_0) was not rejected. This suggests that there was no statistically significant difference in the average ATS scores between the two sample groups, ensuring that any differences in the experimental outcomes could be attributed to the treatment applied rather than to pre-existing disparities between the groups. The balance test had also been conducted by Irawati (2018) in her research, which was aimed at ensuring that differences in experimental results were caused by the treatment applied, not by other factors.

Research Hypothesis Test

The post-test was administered to both sample classes to assess students' understanding of mathematical concepts through numerical questions. Furthermore, the results were used to test the research hypothesis. Prior to the hypothesis testing, a description of the research data is presented in Table 5.

Table 5. Description of Post-test Result Data

	Data Description				
	N	**Minimum**	**Maximum**	**Std. Deviation**	**Variance**
Experiment Class	18	19	97	11.138	124.048
Control Class	19	22	50	11.652	135.771

Based on Table 5, the experimental class post-test results had a mean score of 70.78 with a standard deviation of 21.686, indicating variability in the data. Meanwhile, the control class had a mean score of 36.16 with a standard deviation of 8.643, also showing data variation. The number of students who took the post-test differed from the total number listed in Table 3, as some students were absent. The distribution of the mathematical concept understanding scores based on numerical questions for both classes is shown in Figure 3.

Figure 3: Graph of Post-test Results of Experiment and Control Classes

Following the data presentation in Table 5, hypothesis testing was carried out. The normality test results for the post-test data are shown in Table 6.

Table 6. Post-test Normality Test Results

	Kolmogrov-Smirnov		
	Statistic	**Df**	**Sig.**
Experiment Class	0.245	18	0.006
Control Class	0.164	19	0.190

Table 6 shows that the significance value for the experimental class was below 0.05, indicating that the data were not normally distributed. Subsequently, a homogeneity test was conducted, and the results are presented in Table 7.

Table 7. Post-test Homogeneity Results

		Lavene Statistic	**Df1**	**Df2**	**Sig.**
Post-test Result	Based on Mean	18	1	35	0.012
	Based on Median	19	1	35	0.26

Table 7 shows a significance value of 0.012 based on the mean, which is less than 0.05, indicating that the data were not homogeneous. Since the data did not meet the assumptions of normality and homogeneity, the Mann–Whitney test was used. The results are shown in Table 8.

Table 8. Hypothesis Test Results of Post-test Data Using the Mann-Whitney Test

	Value
Mann-Whitney	38.500
Wilcoxon W	228.500
Z	-4.039
Asymp. Sig. (2-tailed)	0.000
Exact Asymp. Sig [2*(1-tailed)]	0.000

Table 8 showed the post-test data in the Mann-Whitney test got an Asymp. Sig. of 0.000, which was less than 0.05, meaning H_0 was rejected. Thus, there was a difference between the two samples. This could be seen from the average post-test score of the experimental class, which was higher at 70.78, compared to the control class, which was only 36.16.

Next, the effect size test was conducted on the post-test results to measure the significance or influence of the study, independent of sample size. The test utilized *Cohen et al.* (2018) formula, with an s_p value of 16.33. The d (effect size) value was then canculated using Cohen's formula as follows:

$$d = \frac{\mu_1 - \mu_2}{s_p} = \frac{70.78 \ - 36.16}{16.33}. = 2.12.$$

The results indicated an influence from the PBL model, where the obtained d value of 2.12 was categorized as high. This was in line with the findings of Widyastuti & Airlanda (2021) where the effect size test results were in the high category (d > 1.00), which meant that the PBL model had a very large effect on mathematical problem-solving skills.

Discussion

Based on the distribution of post-test data in Figure 3, the results were classified according to the categories of mathematical concept understanding ability, referring to the guidelines by Djaali & Muljono (2008) and Melinia & Mulyono (2022). In the experimental class, 2 students (11%) were in the moderate category, 8 students (44%) were in the high category, and 5 students (28%) were in the very high category. Although some students scored in the low or very low categories, a considerable number achieved scores in the sufficient, high, and very high categories. This indicates an improvement in the ability to understand mathematical concepts following the implementation of the Problem-Based Learning (PBL) model.

This improvement suggests that the PBL model not only enhanced student engagement with the material but also supported more effective comprehension of abstract mathematical concepts—particularly for students who had previously faced difficulties in conventional learning environments. Supporting this finding, Pasaribu et al. (2025) reported that while some students remained in the low category after the post-test, the majority were in the medium category, reflecting a generally positive perception of PBL-based learning.

The results of the hypothesis testing (Table 8) revealed that students who received instruction through the PBL model demonstrated significantly better conceptual understanding than those taught using conventional methods with PowerPoint assistance. This finding aligns with research by Mubaid et al. (2019), which indicated that the PBL approach improved student outcomes by fostering active participation in the learning process. Similarly, Sulastri et al. (2024) reported that students' ability to understand mathematical concepts when solving numerical problems was categorized as good. Furthermore, research by Safitri et al. (2023) highlighted the significant impact of PBL, as students in the experimental class exhibited increased confidence and academic performance.

This study employed numerical problems grounded in everyday contexts (Lestari & Siswono, 2022). The numerical problem used—depicted in Figure 2—was constructed using a real-life context related to SPtLDV material. According to Kemendikbud (2021), numerical problems fall into three contextual categories: personal, socio-cultural, and scientific. They also require cognitive processes such as understanding, application, and reasoning. The problem presented in Figure 2 was given to students as part of the post-test instrument. Students' responses are shown in Figure 4.

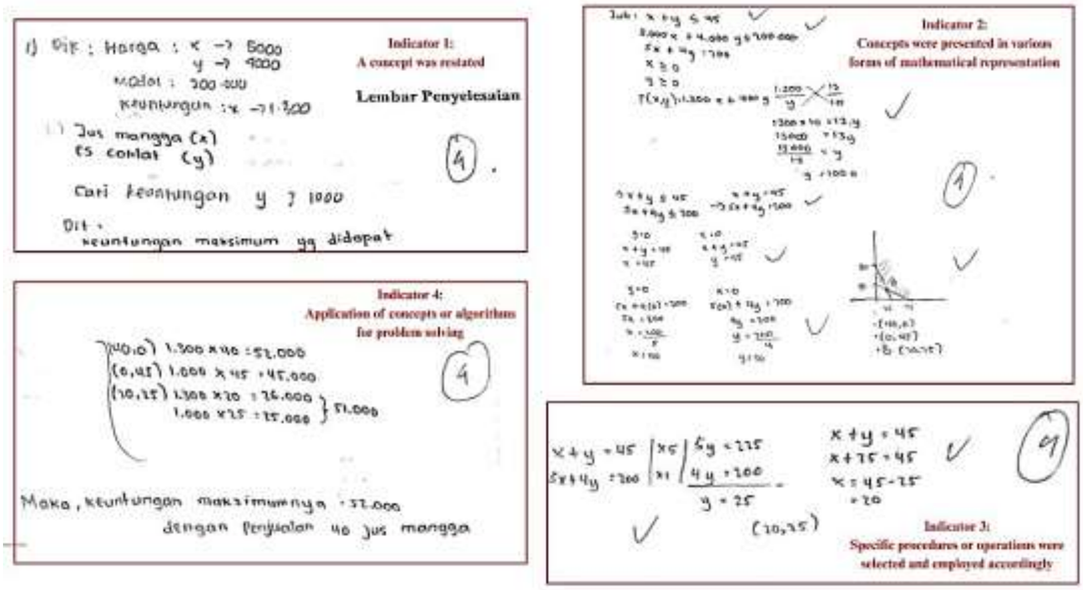

Figure 4. Student Answer Results

Post-test analysis revealed improved student understanding of mathematical concepts after the application of the PBL model. This improvement was reflected in students' ability to understand and apply concepts in numerical problem contexts. The responses shown in Figure 4 illustrate that students were able to apply mathematical concepts to solve these problems. For the first indicator, students successfully restated the given information. In the second indicator, they constructed graphs based on identified intersection points. In the third indicator, they solved the problems using appropriate procedures, such as elimination and substitution. In the fourth indicator, students applied mathematical concepts and procedures to solve real-life problems related to SPtLDV material using the corner point test method.

Based on both descriptive and inferential analysis, the application of the PBL model positively affected learning effectiveness and enhanced students' understanding of mathematical concepts through numerical problems. These results are consistent with the findings of Rahma and Kurniawati (2024), who reported a significant positive impact of PBL on students' understanding of SPLTV material.

This study had some limitations. The instrument used only employed numerical problems in a personal context and did not include socio-cultural or scientific elements. Therefore, future research was recommended to develop numerical problems with more diverse contexts and conduct the study over a longer period of time. These efforts would have provided a more comprehensive understanding of the effect of PBL on mathematical concept understanding ability through numerical problem solving.

CONCLUSION AND SUGGESTIONS

This study aimed to examine the impact of the PBL model on enhancing students' understanding of mathematical concepts through numerical problem solving. The sample included 44 students from two Grade X classes. The research instruments underwent content validation by mathematics teachers and lecturers, while construct validation involved students from vocational high schools. The analysis revealed that the average level of mathematical concept understanding was higher in the class that implemented the PBL model compared to the control class. The calculated effect size was categorized as 'high'. Although some students remained in the low category based on post-test results, the significant increase in students categorized as medium to very high demonstrated the model's effectiveness and positive impact.

These findings suggest that the PBL model is a promising alternative for improving mathematical concept understanding through numerical problem solving. Further research is recommended to develop numerical problems that incorporate more varied contexts and to extend the duration of the study to gain a more in-depth perspective on PBL's impact.

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