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The Effect of Mathematical Prior Knowledge and Problem-Based Learning on Students' Problem-Solving Ability in Calculus

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ABSTRACT

Students with low initial mathematical understanding have difficulty solving mathematical problems especially in Calculus subject that require higher-order thinking skills, one of which is problem-solving ability. Then, problem-solving skills need to be developed using Problem Based Learning models. This study aims to examine the influence of mathematical prior knowledge (MPK) and the problem-based learning (PBL) model on the problem-solving ability of Computer Engineering students at UNIPA in calculus. This quantitative study uses a factorial experimental design. Data were collected through documentation and test instruments, and analyzed using factorial ANOVA with SPSS 23. The results show that students in the PBL class had significantly higher problem-solving ability compared to those in the control class. Furthermore, students with high MPK in the PBL group scored the highest. It can be concluded that both MPK and PBL significantly affect students' problem-solving ability in calculus.

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1. INTRODUCTION

Mathematics plays a crucial role in technological advancement, particularly in computer science, through its foundational contributions such as algorithmic thinking and problem-solving processes (Edy Budiman, 2015; Fajar Mahardika, 2019; Zulkipli, 2023). Algorithms in computers are expected to solve logical and mathematical problems using computers, so mathematical problem-solving abilities are required (Zulaini Masruro Nasution et al., 2023).

The ability to solve mathematical problems is one of the mathematical skills or what is often referred to as soft skills that is important and needs to be mastered by students and college students who study mathematics (Heris Hendriana et al., 2017). Thus, problem-solving is a critical skill for students in mathematics and computer science.

Problem Solving is "...a fundamental human activity. In fact, the greater part of our conscious thinking is concerned with problems" (George Polya, 2014). The problem-solving ability developed by Polya (1945) consists of (1) understanding the problem is linking known elements with questioned elements and formulating them into a mathematical model of the problem, (2) devising a plan is linking known elements with questioned elements and formulating them into a mathematical model of the problem, (3) carrying out the plan is choosing a solution strategy, elaborating and executing calculations or solving the mathematical model, (4) looking back is interpreting the results in relation to the original problem and rechecking the validity of the solution (Anggraeni et al., 2020; Heris Hendriana et al., 2017). Thus, heuristic process in problem-solving skills emphasize the ability to choose effective strategies to obtain the most appropriate solution to a given problem (Dwi Erna Novianti et al., 2017).

Problem-solving abilities are supported by several internal factors, one of which is the ability or Mathematical Prior Knowledge (MPK) that can help college students understand the core material that will be studied (I Putu Eka Irawan et al., 2016). The core material in mathematics relates to branches of mathematics itself, which consist of algebra, geometry, arithmetic, and calculus.

Calculus is the study of change and has a wide range of applications in the fields of science, economics, and engineering, as well as solving various problems that cannot be solved by elementary algebra (Astri Nurputri et al., 2017). The material of Calculus includes limits, derivatives, integrals, and infinite series (Rejeki, 2017). Calculus subject learned by students of the Department Teknik Informatika at Nusa Nipa University (UNIPA) over two consecutive semesters divided into two branches: Differential Calculus, specifically in semesters 1 and Integral Calculus in semester 2 as mandatory courses.

Calculus is the science that studies changes and has wide applications in the fields of science, economics, and engineering, as well as being able to solve various problems that cannot be solved with elementary algebra (Astri Nurputri et al., 2017). The principle of Calculus is that one can always use a more accurate approximation to obtain a more accurate answer (Irmayanti et al., 2021). The material of Calculus studied by students of Information Engineering at UNIPA is divided into two semesters, namely Basic Calculus in the first semester which covers limits, functions, and derivatives, and Integral Calculus in the second semester.

Beside that, the Computer Engineering students at UNIPA are one of the groups of students who study and apply the principles of computer science and mathematical analysis in designing, testing, developing, and evaluating operating systems, software, and computer performance (Heni Ismiyati & Arief Hidayat, 2023). Thus, UNIPA Computer Engineering students need to have initial mathematical and problem-solving skills because they are required to study Calculus in order to design, test, develop, and evaluate operating systems, software, and computer performance according to their expertise.

Some researches emphasizes that to understand the problem-solving abilities of students in calculus material, one must pay attention to their foundational mathematical knowledge (Nuriana R. Dewi et al., 2020; Soesanto & Dirgantoro, 2021). Mathematical prior knowledge (MPK) refers to the foundational mathematical concepts that students have mastered prior to engaging with more complex material, such as calculus (Suryani et al., 2020). Beside prior mathematical knowledge, to develop mathematical problem-solving skills, an appropriate learning model such as Problem Based Learning (PBL) is needed. PBL is a learning model that brings students together on authentic (real) problems and is expected to be able to construct their own knowledge, foster inquiry and higher-order skills, promote independence, and increase self-confidence (Fuji Silvi et al., 2020). The PBL model is one that emphasizes student activity to obtain a solution to a problem (Gede Adi Juliawan et al., 2017). The advantages of the PBL model are that students are encouraged to have problem-solving skills in real situations, develop their own knowledge through learning activities, and the learning focuses on problems so that unrelated material does not need to be learned, thereby reducing the burden on students from memorizing or retaining information (Fuji Silvi et al., 2020).

Previous research shows that the implementation of the PBL model has improved the process and enhanced students' mathematical problem-solving skills (Tia Andesma & Rini Dian Anggraini, 2019). There is an interaction effect between the PBL Model and students' problem-solving abilities, especially Information Technology students (Rini Widia Putri et al., 2022).

In Fact, students still find calculus difficult because it requires a high level of mathematical problem-solving skills (Parma & Saparwadi, 2015), and learners with low mathematical ability levels will struggle to solve mathematical problems, even when using logic (Prendergast et al., 2018). However, limited empirical studies have been conducted on how MPK and PBL simultaneously affect calculus problem-solving ability, especially in the context of Computer Engineering students at UNIPA.

This study aims to examine the influence of mathematical prior knowledge (MPK) and the problem-based learning (PBL) model on Computer Engineering students’ problem solving ability in calculus. The urgency of this research is to obtain a valid picture of whether MPK and PBL have an impact on the development of mathematical problem-solving abilities, especially in Calculus material for students in the Information Technology program at UNIPA. This study contributes novelty by integrating MPK and PBL within a factorial design to assess their interaction effects on problem-solving abilities in calculus—an approach not previously applied to Computer Engineering students at UNIPA.

2. METHOD

This study uses a quasi-experimental research design because all subjects in the study group were used in the experiment (Handayani et al., 2020) .

Table 1. Research Design

MPK	Control Class (x_1)	PBL Class (x_2)
High (y_1)	x_1y_1	x_2y_1
Medium (y_2)	x_1y_2	x_2y_2
Low (y_3)	x_1y_3	x_2y_3

The population includes all active first-year students of the 2023 Information Technology program at UNIPA. A sample of 81 students was selected using purposive sampling, consisting of those who have attended Basic Calculus but have not repeated the course. The sampling technique used is purposive sampling, which means selecting samples based on specific needs deemed suitable as data sources (Ahmad Tanzeh, 2018) to ensure homogeneity in terms of academic exposure and eliminate the bias from repeated course takers.

Two Data collection techniques used in this study, namely documentation and tests. The documentation technique in this research is a data recording table about the students' MPK scores taken from the Final Exam scores in Basic Calculus. The test technique is used to obtain data on students' mathematical problem-solving abilities. The problem-solving test was validated by expert judgement and tested for reliability using the Cronbach's Alpha formula.

Data analysis used Balanced Factorial ANOVA that are required 2 tests, namely the classical assumption test for ANOVA and the research hypothesis test. According to Deauna (in Drs. I Nyoman Arcana, 1999) , the classical assumption tests are: (1) the sample is drawn from a normally distributed population, (2) the variances between groups are homogeneous, (3) the groups must be independent from each other, and (4) the data should be in interval scale. The normality and homogeneity classical assumption tests will utilize SPSS 23 application. The research hypothesis test consists of the following steps: (1) formulating statistical hypotheses, (2) determining the significance level, (3) conducting Balanced Factorial ANOVA calculations with the help of SPSS 23 application, (4) drawing conclusions, (5) performing multiple comparison tests if the research results refute the research hypothesis or $\mathbf{H_0}$ is rejected.

3. RESULTS AND DISCUSSION

3.1. Results

The results explained as follows.

Mathematical prior knowledge of students was taken from the final exam data of students in the Basic Calculus course or before the PBL model was applied.

Table 2. MPK results in the Control Class and PBL Class

	Mean	Standard Deviation	Max	Min
Control Class	70.8	11.5	95.7	51.4
PBL Class	71.9	14.3	87.1	40.0

Table 2 explains the data on Initial Mathematical Understanding. Furthermore, a normality test and a homogeneity test were conducted using the SPSS 23 application to determine whether the two classes are normally distributed and homogeneous.

Table 3. Results of Normality Test and Homogeneity Test

	Control Class	PBL Class	Conclusion
Normality Test	0.200	0.94	Normal
Homogeneity Test	0.171		Homogene

Based on Table 3, it can be explained that the tests for normality and homogeneity are significantly fulfilled at a significance level of 0.05, which can be seen from the significance level > 0.05, thus proceeding to record the number of students based on MPK.

Table 4. Number of Students Based on MPK

MPK	Control Class	PBL Class	Total
High (y_1)	7	5	12
Medium (y_2)	26	28	54
Low (y_3)	8	7	15
Total	41	40	81

Based on Table 4, it can be explained that the average student is in the MPK category of medium. After that, treatment is applied to one of the classes using the PBL model, and a problem-solving ability test is administered.

Table 5. Results of Problem-Solving Ability After Implementing the PBL Model

	Mean	Standard Deviation	Max	Min
Control Class	72.1	12.5	98.2	50.9
PBL Class	88.1	7.6	100.0	67.3

Based on Table 5, it can be explained that after the treatment, the average problem-solving ability in the PBL class or experimental class is higher compared to the control class. This can be explained in detail in Table 5.

Tabel 6. Problem Solving Ability Results Based on MPK

MPK	Control Class (x_1)	PBL Class (x_2)
High (y_1)	91.2	98.8
Medium (y_2)	73.8	89.5
Low (y_3)	54.6	76.2

Based on Table 6, it can be explained that the average problem-solving ability of PBL class students is higher in each category, namely good in the high, medium, and low categories. This data will be tested using a balanced factorial ANOVA test, which will first be tested with classical assumption testing.

Table 7. Results of Normality Test and Homogeneity Test

	Normality Test	Conclusion	Homogeneity Test	Conclusion
Control Class	0.200	Normal	0.152	Homogene
PBL Class	0.105	Normal		
MPK High	0.993	Normal	0.085	Homogene
MPK Medium	0.200	Normal		
MPK Low	0.351	Normal		

Table 7 shows the normality test indicating a sig value > significance level of 0.05, thus each class and each MPK category is normally distributed, and the homogeneity test between classes and between MPK categories shows homogeneity because the sig value > significance level of 0.05. After the classical assumption tests are fulfilled, it continues with the Balanced Factorial ANOVA test.

Table 8. Results of the Balanced Factorial ANOVA Calculation using SPSS 23

Tests of Between-Subjects Effects

Dependent Variable: Problem Solving

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Conclusion
Corrected Model	12154.932[a]	5	2430.986	116.046	.00	
Intercept	362534.569	1	362534.569	17305.959	.00	
CLASS	3112.827	1	3112.827	148.594	.00	H_0 rejected
MPK	6475.258	2	3237.629	154.552	.00	H_0 rejected
CLASS * MPK	345.432	2	172.716	8.245	.01	H_0 rejected
Error	1571.140	75	20.949			
Total	533294.730	81				

Corrected Total	13726.072	80			
a. R Squared = .886 (Adjusted R Squared = .878)					

Based on Table 8, column F can be explained as follows.

- $F_{obs} = 17305.959$ dan $F_{tab} = F_{(0,05;1,75)} = 3.989$ therefore it is known that$F_{obs} > F_{(0,05;1,75)}$. It means H_0 rejected, which indicates that there is a significant difference in mathematical problem-solving abilities of students between the control class and the PBL class.
- Nilai $F_{hit} = 148.594$ dan $F_{obs} = F_{(0,05;2,75)} = 3.119$ therefore it is known that $F_{obs} > F_{(0,05;2,75)}$. It means H_0 rejected indicating that there is a significant difference in the mathematical problem-solving ability of students in MPK with high, medium, and low categories.
- Nilai $F_{obs} = 154.552$ dan $F_{tabel} = F_{(0,05;2,75)} = 3.119$ therefore it is known that$F_{obs} > F_{(0,05;2,75)}$. It means H_0 rejected which indicates that there is a significant interaction of students' mathematical problem-solving abilities in MPK and PBL.

The explanation in Table 8 indicates that there are differences, which is followed by a Multiple Test.

Table 9. Multiple Comparison Results using SPSS 23

Multiple Comparisons

Dependent Variable: Problem Solving

	(I) MPK	(J) MPK	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	**Low**	**Medium**	-16.9476*	1.27872	.000	-20.0052	-13.8901
		High	-30.2848*	1.72568	.000	-34.4111	-26.1585
	Medium	**Low**	16.9476*	1.27872	.000	13.8901	20.0052
		High	-13.3372*	1.46580	.000	-16.8421	-9.8323
	High	**Low**	30.2848*	1.72568	.000	26.1585	34.4111
		Medium	13.3372*	1.46580	.000	9.8323	16.8421

Based on observed means.
The error term is Mean Square(Error) = 20.949.
*. The mean difference is significant at the ,05 level.

From Table 9, it can be explained that there is a significant difference marked with (*) in the mean-Difference column between the Control Class and the PBL Class for each MPK category.

3.2. Discussion

Previous research emphasizes that to understand students' problem-solving abilities in calculus material, it is necessary to consider their initial mathematical skills/knowledge (Nuriana R. Dewi et al., 2020; Soesanto & Dirgantoro, 2021) and this study correspond, indicating a difference in the average scores obtained by students in the high MPK category compared to other categories. Thus, MPK is one of the factors that can influence students' success in learning mathematics, especially in calculus material (Tatag Yuli Eko Siswono, 2018)

Beside that, develop mathematical problem-solving skills, an appropriate learning model such as Problem Based Learning (PBL) is needed. The results of this study support previous research conducted by (Tia Andesma & Rini Dian Anggraini, 2019) showing that the implementation of the PBL model has improved the process and enhanced students' mathematical problem-solving abilities as seen from the significant average difference between the control class and the PBL class. This can occur because the advantages of the PBL model are that students are encouraged to solve problems in real-life situations, build their own knowledge through learning activities, and learning is focused on problems so that irrelevant material does not need to be studied (Fuji Silvi et al., 2020).

This study also shows that there is a significant interaction effect between the mathematical problem-solving ability of Information Technology students and PBL. The results of this study support previous research (Rini Widia Putri et al., 2022). Thus, this research can help lecturers to pay attention implementing the PBL model as an alternative learning model that can be applied to improve mathematical problem-solving skills, especially in Calculus material. The limitation of this research is that the stages in problem-solving ability that are most influenced by MPK and PBL have not been explained in detail.

4. CONCLUSION

The conclusions of this research are: 1) The problem-solving ability of students in Calculus material is influenced by Mathematical Prior Knowledge (MPK); 2) The problem-solving ability of students in Calculus material is influenced by the learning model used, one of which is the PBL model; 3) The problem-solving ability of students in Calculus material can also be influenced by MPK and PBL.

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