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The Effect of Problem-Based Adaptive Learning on Students' Mathematical Concept Understanding Ability

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Abstract

The aim of this research is to find out whether there is a significant difference in the data on students' understanding of mathematical concepts with problem-based adaptive learning and conventional learning carried out at SMA Negeri 1 Pantai Labu. Class X students (n=150) were involved as research subjects as a population. Types of pseudo-experimental research with a quantitative approach. This research sample was taken using a stratified random sampling technique. The sample was divided into two groups, namely the experimental group consisting of 30 students who studied with Problem-Based Adaptive Learning and the control group consisting of 30 students who studied with conventional learning. This research is semi-experimental and the instrument is a concept understanding test. Data processing techniques include normality tests, homogeneity tests and independent sample t-tests with the help of the IBM SPSS Statistics 30 and Microsoft Excel programs. Based on the results of descriptive statistical tests, it was found that the average score for problem-based adaptive learning was 84.47 (SD=3,910) , while the average score for conventional learning was 89.40 (SD=2,513). The results of data analysis show that there is a significant difference between students who learn through problem-based adaptive learning and conventional learning, with a significance value of 0.12 > 0.05, which means H1 is accepted and H0 is rejected. So there is an influence of problem-based adaptive learning on the understanding of mathematical concepts of Class X students at SMA Negeri 1 Pantai Labu in the 2024/2025 academic year.

Keywords: Problem-Based, Adaptive Learning, Understanding Mathematical Concepts

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INTRODUCTION

Education is an important aspect in an individual's life and greatly influences daily activities, especially in society (Fau et al., 2023). Analysis of the progress of knowledge and technology, professional search, religious progress, education, and aspects of human life (Sadewo et al., 2022). Formal education is a means to increase students' knowledge. In accordance with the provisions of Law Number 20 Article 1 Paragraph (11) and (13), structured and integrated education includes basic education, secondary education, and higher education. (Denmark, Krone, 2022). Students' understanding of mathematical concepts poses a significant challenge in Indonesian mathematics education (Putri Khairani et al., 2021). Mire (2022) argues that mathematics was originally developed to solve problems in human life. Thus, mathematics was developed to meet human needs. Gauss as quoted by Evoulina (2024) stated that mathematics is the foundation of science, while accounting theory is part of mathematics. Currently, various fields of science have developed rapidly thanks to mathematics. This is because mathematics is a fundamental science that everyone should have (Permatasari, 2021).

The fundamental aspect of mathematics education that students must achieve is conceptual understanding (Aledya, 2019). With a deep conceptual understanding, students are better able to solve problems because they can relate and apply the concepts that have been learned. Conversely, if students' understanding of a concept is limited, students will have difficulty in choosing and using certain procedures to apply concepts and problem-solving algorithms (Suendarti, 2021). The National Council of Mathematics Teachers argues that students must acquire mathematical knowledge with understanding, actively building new insights from existing experiences and knowledge (Tukly et al., 2022). Conceptual understanding serves as a foundation for advancing to higher-level topics in mathematics education (Komariyah et al., 2018). Students' progress to the next level in mathematics education is made possible by an understanding of basic concepts (Natalia, 2021). The justification for this is that mathematics is a discipline that is inherently connected to other domains. and has no definite rules or boundaries. This indicates a correlation between the two concepts (Rizki et al., 2020). In line with the objectives of mathematics education that have been set, students are expected to be able to understand a mathematical concept to apply its principles effectively in problem solving. However, the following statement shows that students' understanding of mathematical concepts is inadequate; Research on this understanding shows that students' learning capacity is below 50%, this data was found from the results of students' daily tests and their level of active engagement with the subject matter is also inadequate. Based on observations of a mathematics teacher at a high school in Pantai Labu, there are several factors that influence students' low understanding of mathematical concepts, namely students' perceptions that mathematics lessons are very difficult, lack of appeal to the material, and minimal variation in the use of learning models.

The term “adaptive learning system” refers to an educational framework that adapts its operation to the unique abilities of individual learners (Wicaksana, 2020). Steichen et al. (2012) defines an adaptive learning system as an educational framework that adapts its approach to each learner according to their previous experiences, characteristics, and behaviors. Adaptive learning systems adjust their teaching strategies to meet the unique needs of each student, encouraging the achievement of their maximum potential in the educational environment. Brusilovsky (2007) outlined several factors that influence user modeling, including knowledge, interests, background, individual traits, work context, skills, and goals and tasks. Adaptive problem-based learning is a teaching method that is increasingly used to improve students' understanding of mathematics. Adaptive problem-based learning aims to adapt instruction to the unique needs of each student and encourage active participation from students during the learning process (Pujiriyanto et al., 2022). Difficulties with problem-based learning Earlier studies on mathematics education aimed to improve students' conceptual understanding of the subject. One example of prior research is a study that Fitrah conducted in 2017. The researchers had only just begun to formulate a methodology that would completely incorporate adaptive learning. This study set out to determine how problem-based learning affected students' performance in the classroom. Mathematical comprehension is the end goal of adaptive learning.

This research has the potential to significantly improve students' understanding of mathematical concepts. There is a gap in the current literature that this study intends to fill by exploring the effects of problem-based learning on students' comprehensive understanding of mathematical concepts. Adaptive problem-based learning was one of the more conventional ways of instructing pupils in mathematical problem-solving. How problem-based learning influences students' understanding of mathematical ideas needs to be thoroughly investigated.

METHOD

This study focuses on Grade X students at SMA Negeri 1 Pantai Labu in North Sumatra Province. The school is located on Jalan Ramunia 1, Perkebunan Ramunia Village, Pantai Labu District, Deli Serdang Regency, among other locations. The implementation of the study will be carried out in the second half of the 2024–2025 academic year. The 2023–2024 academic year will show the direct impact of Problem-Based Adaptive Learning on the understanding of mathematical concepts among Grade X students at SMA Negeri 1 Pantai Labu in Deli Serdang Regency. Therefore, the research methodology used in this study is a quantitative quasi-experimental design. All grade X students at SMA Negeri 1 Pantai Labu are the study population. This study uses a stratified sampling method. In determining this sample selection, the sampling technique used was Simple Random Sampling. It is said to be simple because sampling from the population is carried out randomly without paying attention to the strata in the population. Thirty students will be involved in Problem-Based Adaptive Learning, while the other thirty will use the conventional method. Representation includes Sample Determination, Classification into two groups (Experiment and Control) where the experimental group uses problem-based adaptive learning methods and the control group uses conventional learning, Measurement of Understanding of Mathematical Concepts with post test and analyzing data using the Normality Test and t-Test. Table 1 shows the research design implemented.

Table 1. Research Design

Group	Treatment	Post Test
Experiment(R)	X	O1
Control (R)	-	O2

Information :

R = The experimental group and control group of class X students at SMA Negeri 1 Pantai Labu were taken using the total sampling technique.

X = Learning that involves learning through the Problem-Based Adaptive Learning model in the experimental group.

O1 = The posttest results of the experimental group after receiving learning through the Problem-Based Learning model.

O2 = The posttest results of the control group that received conventional learning using the direct learning model.

The technique used is a test, which is based on exam questions. The assumption used is the capacity to understand conceptual relationships related to the subject matter being taught. Understanding a concept depends on the student's ability to articulate its meaning.

Analysis of the Validity of the Question Instrument

The validity of an instrument is indicated by its sensitivity to the target variable. The validity of the instrument in this study was tested using product moment correlation, as shown below:

$$r_{yx} = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[n\sum(X^2) - \sum(X)^2][n\sum(Y^2) - \sum(Y)^2]}}$$

Information :

r_{yx} : product moment correlation coefficient

x : score for each question/item

y : total score

n : number of respondents The validity testing criterion is that each item is valid if $r_{yx} < r_{tabel}$ obtained from the critical value of r product moment.(Indra Jaya, 2018)

The next step is to calculate using the t-test formula to get the calculated t value, with the formula.

$$t_{hitung} = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

The number of subjects is denoted by n, and the correlation coefficient is denoted by r. The next step is to compare certain levels of confidence (a) using tcount and ttable. The correlation index is valid if and only if tcount is ttable; if ttable for some levels of confidence (a), then the index is invalid.

Reliability

Evaluation of reliability coefficient using KR-21 technique. For dichotomous instruments, such as true-false, where the possible values are 1 and 0, the KR21 formula can be used. The KR 21 procedure is used to conduct reliability assessment.(Widodo et al., 2023)

$$r_{11} = (\frac{n}{n-1})(1 - \frac{M(n-M)}{nS_t^2})$$

Information :

r_{11} = instrument reliability
n = number of questions
M = mean/average score
S_t^2 = total variance

To calculate the total variance, the formula used is

$$nS_t^2 = (\frac{\sum X^2}{N})(\frac{\sum X}{N})^2$$

Information :

X= Score
N= Number of respondents
S_t^2= Total Variance

Table 2. Test Reliability Categories

No	Interval	Category
1	$0{,}80 \leq r_{11} < 1{,}00$	very high reliability
2	$0{,}60 \leq r_{11} < 0{,}80$	high reliability
3	$0{,}40 \leq r_{11} < 0{,}60$	moderate reliability
4	$0{,}20 \leq r_{11} < 0{,}40$	low reliability
5	$0{,}00 \leq r_{11} < 0{,}20$	very low reliability

Significant Analysis

Data analysis this study assessed students' mathematical problem-solving skills after participating in adaptive problem-based learning through descriptive data analysis. Inferential statistics is a subfield of statistics that extrapolates the results of statistical sample analysis to the entire population. Statistical tests, including normality tests and homogeneity tests, are conducted to verify that the variables being compared show similarities across groups. This is the initial stage of the procedure. Data from the sample are used to compare the means of the two groups through a t-test.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 3 presents the descriptive statistics for students' post-test scores in the control group (conventional learning) and the experimental group (problem-based adaptive learning). This initial observation suggests that the new teaching intervention may be more effective at helping students grasp mathematical concepts—in this case, trigonometry. The descriptive statistics reveal distinct differences between the control group, which was taught using conventional methods, and the experimental group, which received problem-based adaptive learning (PBAL). In the control group, the post-test scores ranged from 78 to 91, with a mean of 84.47 and a standard deviation of 3.910. By contrast, the experimental group's scores ranged from 85 to 93, yielding a higher average of 89.40 and a lower standard deviation of 2.513. These findings suggest that PBAL fosters a more uniform and elevated level of achievement among students.

Table 3. Descriptive Statistics for Control and Experimental Groups

Group	N	Range	Minimum	Maximum	Mean	Std. Deviation
Post-Test (Control)	30	13	78	91	84.47	3.910
Post-Test (Experiment)	30	8	85	93	89.40	2.513

The higher mean in the experimental group parallels findings from Ramli et al. (2020) and Suarniati et al. (2019), who observed that problem-based learning enhances students' conceptual understanding and problem-solving skills. Additionally, the narrower score dispersion in the experimental group is consistent with the view that adaptive instruction meets learners' individual needs more effectively, a result supported by Afikah et al. (2022) and Gillette (2017), who noted that problem-based approaches can heighten both engagement and depth of learning.

Normality and Homogeneity Tests

Before any parametric hypothesis test can be legitimately carried out, it is important to check that the underlying assumptions—specifically normality and homogeneity of variances—are met. Both the Kolmogorov-Smirnov and Shapiro-Wilk tests confirmed that the data for each group met the assumption of normality, since their p-values exceeded 0.05. This finding aligns with research protocols suggesting that parametric tests are suitable when data approximate a normal distribution (Ramli et al., 2020). Levene's test, however, yielded p-values in the 0.012–0.013 range, indicating the possibility of unequal variances between groups. Despite this, the study proceeded with the independent-samples t-test, recognizing that equal sample sizes in each group (30 students per group) help mitigate potential issues stemming from variance differences (Bright, 2024).

The normality test was conducted using the Kolmogorov-Smirnov and Shapiro-Wilk methods (Table 4). In both tests, the results indicate that the data for each group meet the assumption of normality, as the *p*-values for all tests exceed 0.05. Specifically, the Kolmogorov-Smirnov statistics for both the control and experimental groups show significance values above 0.200, while the Shapiro-Wilk tests yield significance values of 0.223 for the control group and 0.074 for the experimental group. These results imply that the distribution of students' test scores approximates a normal bell curve, making it valid to use parametric procedures such as the *t*-test.

Table 4. Descriptive Statistics for Control and Experimental Groups

Group	K-S Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Post-Test (Control)	0.107	30	0.200*	0.955	30	0.223
Post-Test (Experiment)	0.128	30	0.200*	0.937	30	0.074

Next, Levene's test was used to evaluate whether the variances of the two groups were statistically equal (homogeneous). While the Levene Statistic results (significance values of 0.012 or 0.013, depending on the calculation method) are below 0.05, indicating a potential variance difference, the subsequent analysis proceeded with the standard independent-samples *t*-test. This is commonly acceptable in practice, especially when sample sizes are relatively balanced between groups (30 students each). Nevertheless, researchers must remain aware that results labeled "Equal Variances Assumed" may be less accurate under these conditions, and attention should be given to the "Equal Variances Not Assumed" outcome as well.

Hypothesis Testing (T-Test)

After verifying data normality and considering the variance results, an independent-samples *t*-test was performed to compare the post-test scores of the experimental and control groups (Table 5). The test seeks to determine whether there is a statistically significant difference in understanding of mathematical concepts between the two teaching methods: problem-based adaptive learning (experimental) and conventional instruction (control). Although the reported *p*-values (0.012–0.013) are below 0.05, the analysis still proceeded with an independent-samples *t*-test. In practice, if variances are not equal, one can use the "Equal Variances Not Assumed" output (Bright, 2024). Since sample sizes are balanced (30 each), this approach remains statistically acceptable.

Table 5. Hypothesis testing result

	Equal Variances Assumed	Equal Variances Not Assumed
Levene's F	6.752	6.752
Levene's Sig.	0.012	0.012
t-value	-5.813	-5.813
df	58	49.467
p (two-tailed)	< 0.001	< 0.001
Mean Difference	-4.933	-4.933
Std. Error Difference	0.849	0.849
95% CI (Lower)	-6.632	-6.638
95% CI (Upper)	-3.234	-3.228

The *t*-value obtained is -5.813, with an associated *p*-value < 0.001. In typical social sciences and educational research, a threshold of 0.05 for statistical significance is used, and results with a *p*-value below 0.001 strongly indicate that the observed difference is highly unlikely to have arisen by chance. Furthermore, the mean difference of -4.933 suggests that, on average, the experimental group outperforms the control group by nearly 5 points on a typical 100-point scale (the negative sign comes from the way groups are coded in the analysis). The 95% confidence interval of the difference (ranging from about -6.6 to -3.2) reinforces that the true difference in means is consistently in favor of the experimental group.

Given that the Levene's test result showed a potential violation of homogeneity of variance, it is critical to note that the "Equal Variances Not Assumed" row, which adjusts the degrees of freedom, produces virtually the same outcome: a *t*-value of -5.813 and a similarly small *p*-value (< 0.001). Hence, regardless of how variance assumptions are handled, the conclusion remains that problem-based adaptive learning significantly boosts students' understanding of mathematical concepts compared to the conventional approach.

The independent-samples t-test shows a highly significant difference between the post-test scores of the control and experimental groups, with $t = -5.813$ and $p < 0.001$. The mean difference of -4.933 indicates that students in the experimental group, on average, scored nearly five points higher than those in the control group. These results align with previous research that reports significant gains in mathematical understanding when problem-based learning elements are introduced (Yulianti, 2023; Ahmad et al., 2023; Rosser, 2024). Even under the "unequal variances" assumption, the t-value and significance level remain virtually unchanged, reinforcing the robustness of the finding.

Discussion

Problem-based learning has drawn considerable attention in mathematics education for its capacity to elevate conceptual comprehension, critical thinking, and problem-solving abilities. Ramli et al. (2020) and Suarniati et al. (2019) highlight the effectiveness of PBL in grounding mathematics in real-life scenarios, thereby fostering deeper engagement and retention. The present study's experimental group outperformed the control group in both mean scores and score consistency, reinforcing the notion that PBL can create an environment where students collectively achieve and sustain higher levels of performance. Comparisons with other active learning approaches, such as inquiry-based or collaborative learning, further suggest that PBL consistently delivers positive outcomes, as noted by Afikah et al. (2022) and Gillette (2017), who emphasize improvements in higher-order thinking and knowledge retention.

Meta-analyses and systematic reviews confirm the long-term benefits of PBL for retention of mathematical concepts. Yulianti (2023) describes how such learning models enhance knowledge maintenance in vocational education settings, and Ahmad et al. (2023) point to PBL's prolonged impact on problem-solving performance. These findings accord with the present study's results, in which students who underwent problem-based adaptive learning exhibited a noticeable performance advantage that is unlikely to be transient. The adaptive component also resonates with growing interest in personalized instruction and technology-driven models (Cebrián et al., 2020; Cavanagh et al., 2020), which permit real-time adjustment of lesson content to individual student progress. Díez-Fonnegra and Losada (2022) reported similar outcomes in higher-level mathematics, demonstrating that adaptive frameworks can be scaled to varying academic contexts.

Motivation, engagement, and self-concept are known to shape how effectively students benefit from adaptive or problem-based learning strategies. High self-efficacy, alongside low math anxiety, appears to bolster achievement in such settings, as discussed by Ruijia et al. (2022) and Fatwana (2023). Conversely, students who harbor strong math anxiety may find it difficult to take full advantage of adaptive learning opportunities (Magnate & Sulatra, 2023). The interplay of these psychological factors highlights the importance of designing interventions that not only adapt to academic needs but also address affective dimensions of learning (Akın & Güzeller, 2017).

Teachers' readiness to employ adaptive learning tools and methodologies is another vital consideration, especially since professional development and supportive infrastructure are key to successful implementation. Mirata et al. (2020) and Rodrigues et al. (2022) emphasize that many educators require additional training to manage and integrate technological platforms effectively. Schools lacking dependable technology, adequate class size, or sufficient instructional time also encounter challenges in sustaining adaptive models (Brown, 2022; Lim et al., 2022). Nonetheless, continuous feedback and collaborative activities can help students navigate problem-based environments more independently (Pedrosa et al., 2020).

The broader literature underscores that PBAL can cultivate transferable skills, including critical thinking and creative problem-solving. Suratno (2023) found that integrating tools such as GeoGebra into problem-based frameworks strengthened students' systematic reasoning, which can extend to real-world applications. Chaidam and Poonputta (2022) observed that the benefits of these strategies often extend beyond a single discipline, suggesting a wider relevance of PBAL for developing lifelong learning skills. One concern, however, is that these gains may recede if adaptive or problem-based techniques are not sustained over time (Dewi & Agustika, 2023; Ninnuan & Wongsaphan, 2022), indicating that consistent and long-term implementation is crucial.

In assessing improvements in conceptual understanding, researchers have turned to both quantitative and qualitative measures. Standardized tests such as the Conceptual Understanding Test (Cajandig & Lomibao, 2020) or the Algebra Concept Inventory (Lear, 2019) provide benchmarks for student achievement, while alternative tools like delayed post-tests and transfer tasks capture longer-term and more transferable aspects of learning (Hussein & Csíkos, 2023; Crawford et al., 2018). These multifaceted assessment strategies ensure that the depth and durability of students' mathematical knowledge are accurately gauged, thus offering a more complete picture of their true learning gains.

In summary, the study's descriptive and inferential statistical results demonstrate that problem-based adaptive learning significantly surpasses conventional methods in improving students' mathematical concept understanding. Such outcomes mirror a substantial body of literature that highlights the synergy between problem-based pedagogies, adaptive technology, and motivational supports in advancing mathematics education. Although constraints such as technological access, class size, and teacher preparation may pose obstacles, research consistently underscores the strong potential of PBAL to foster sustained, higher-level engagement with mathematics for diverse student populations.

CONCLUSION

Based on the results and discussion of the research described above, it can be concluded that the influence of problem-based adaptive learning affects students' understanding of mathematical concepts in class X trigonometric material at SMA N 1Pantai Labu. This means that problem-based adaptive learning affects student learning outcomes on understanding mathematical concepts. To get high learning outcomes, teachers must use good problem-based adaptive learning methods. The suggestion for future researchers is to conduct further research on problem-based Adaptive Learning, given the importance of this in improving student learning outcomes.

RECOMMENDATION

After reviewing the findings of this research, which only focuses on the impact of adaptive problem-based learning on students' understanding of mathematical concepts, it is hoped that future researchers will dig deeper into the influence of adaptive problem-based learning to encourage further investigation in this area. In addition, it is recommended that future researchers carry out additional learning using other alternative learning models that are adapted to the subject matter, with the aim of identifying variations in understanding of mathematical concepts. These findings can then serve as guidelines for high school mathematics teachers so that students are more independent.

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