

ENHANCING STUDENTS' CRITICAL THINKING THROUGH PROBLEM-BASED LEARNING IN SINE RULE INSTRUCTION: A QUASI-EXPERIMENTAL STUDY

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Abstract

The purpose of this study is to evaluate how well the Problem-Based Learning (PBL) approach enhances students' critical thinking abilities when studying the law of sines. The study employed a quantitative methodology using a non-equivalent control group design, which is a quasi-experimental design. Two classes of high school students served as the research subjects: the experimental class, which got PBL-based instruction, and the control class, which employed traditional instruction. A descriptive test was used as the research tool to gauge critical thinking abilities using indications of interpretation, analysis, assessment, and inference. Effect size, N-Gain computation, and an independent sample t-test were used to examine the data. The findings demonstrated that students' critical thinking abilities in the experimental class and the control class differed significantly ($p < 0.05$). With a big effect size value, the improvement in students' critical thinking abilities in the experimental class fell into the moderate to high range. These results show that PBL is successful in helping students strengthen their critical thinking abilities, particularly when it comes to comprehending the abstract and contextual idea of the sine rule. The study's conclusions highlight how crucial it is to use problem-based learning models while teaching mathematics in order to promote student participation and the growth of higher-order thinking abilities. This study contributes both theoretically and practically to the creation of cutting-edge mathematics education that is pertinent to the needs of the twenty-first century.

Key Word : Critical Thinking; Learning Mathematics; Problem-Based Learning; Quasi-Experiment; Sine Rule

Introduction

Mathematics is one of the important subjects in learning. Learning mathematics is strategically important for the development of higher-order thinking abilities, especially critical thinking (Chikiwa & Schäfer, 2018; Higgins, Wallace, & Bazzul, 2018; Meyer, 2018; J. H. Park & Lee, 2018). This skill is essential for students to be able to examine, assess, and make logical conclusions when faced with a variety of mathematical and contextual difficulties, in addition to being able to solve problems procedurally (Higgins et al., 2018; Putri & Jazuli, 2025; Son, Han, Kang, & Kwon, 2016). Trigonometry, particularly the idea of the sine rule, is one area of mathematics that requires critical thinking abilities (Fauzurradjak, 2020; Nur, Fatmi, & Hidayati, 2020). Strong analytical abilities are necessary because this topic deals with the relative relationship between side lengths and angles in triangles, which is not usually observable directly. The sine rule can be stated mathematically as:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

Even though this idea is crucial, many students find it difficult to understand the sine rule conceptually. It is challenging for students to tackle non-routine or contextual problems because they often memorize formulas without comprehending the relationships between elements (Belladina, Handayanto, & Shodiqin, 2019; Putri & Jazuli, 2025). This suggests that students' critical thinking abilities are still underdeveloped when it comes to learning mathematics (Im, Yoon, & Cha, 2016; Kim et al., 2019). The learning approach, which is still dominated by traditional, teacher-centered approaches, is one element contributing to this state of affairs (H. J. Park, Byun, Sim, Han, & Baek, 2016). Learning places a strong emphasis on providing formulas and standard practice problems, which discourages pupils from thinking deeply (Kaya & Aydin, 2016). Students are therefore less used to analyzing issues, assessing solutions, and connecting ideas to actual circumstances.

Math instruction must be focused on fostering critical thinking abilities through an active, contextual, and student-centered approach in order to meet the expectations of 21st-century education (Nachlieli & Tabach, 2019). Problem-Based Learning (PBL), which starts learning with real-world challenges, is one pertinent learning model. PBL encourages students to recognize issues, collect information, analyze data, and methodically create and assess solutions (Firdaus, Asikin, Waluya, & Zaenuri, 2021). The use of PBL in the context of the law of sines gives students the chance to gain a deeper understanding of topics through real-world challenges, like directly measuring hard-to-reach distances or assessing angles in a variety of scenarios (Nuranita, Ramadani, Cristianti, & Anawati, 2025). Through problem-solving exercises, this method enables pupils to naturally build critical thinking abilities.

However, there is currently a dearth of research that focuses on critical thinking abilities and specifically examines the use of PBL on the law of sines. Additionally, not much study has been done on how PBL can help students grasp abstract trigonometric concepts through critical thinking. According to the description, a thorough analysis of the PBL model's application in teaching the sine rule material in terms of students' critical thinking skills is required (Sukwantini, 2019). It is anticipated that this research will aid in the creation of more efficient and pertinent mathematics learning models that meet the demands of contemporary education. The effectiveness of using the Problem-Based Learning (PBL) approach to teach the sine rule material in terms of students' critical thinking skills is the problem formulation covered in this study. In the meantime, the goal of this study is to evaluate how well students' critical thinking skills are affected when the Problem-Based Learning (PBL) approach is used to teach the sine rule content.

Contextual problems serve as the main catalyst for learning in the student-centered learning model known as problem-based learning (PBL) (Putut, Emanuel, Nusantara, Rahman, & Rahardi, 2023). Constructivist theory, which holds that students actively create knowledge via experience and interaction with the environment, is the foundation of PBL (Putut, Emanuel, Nusantara, & Rahardi, 2024). Operationally, PBL's syntax consists of problem orientation, student organization for learning, individual and group research, work development and presentation, and analysis and assessment of the problem-solving process (Putri & Jazuli, 2025). PBL has the benefit of helping students gain a deeper knowledge of mathematics by connecting abstract ideas to real-world scenarios. Through problem analysis, decision-making, and reflection on the answers, PBL also fosters critical thinking in pupils.

A key idea in trigonometry, the law of sines describes how side lengths and angles in any triangle relate to one another. This idea is essential for many applications, including mapping, navigation, and indirect distance measurement. However, students frequently find it challenging to fully understand the concept due to its abstract character and the interactions between variables. This problem usually results from pupils concentrating just on applying the formula without comprehending its related significance. Therefore, in order for students to comprehend and use the sine rule more flexibly, a teaching strategy that links the idea to practical situations is required.

A higher-order thinking ability, critical thinking entails the process of logically and methodically assessing, evaluating, and reaching conclusions (Lee, Ang, & Dipolog-Ubanan, 2019; van Rooij, Jansen, & van de Grift, 2018). Critical thinking abilities are essential in the context of learning mathematics because they allow pupils to comprehend problems thoroughly and identify suitable solutions. Mathematical critical thinking abilities can be demonstrated by the following:

1. Correctly analyzing and comprehending issues
2. Examining connections between ideas or data
3. Assessing tactics and solutions
4. Coming to responsible and logical conclusions
5. This skill must be developed through demanding learning exercises that promote inquiry and introspection.

Nowadays, students' abilities in thinking critically were still lacking. Students' critical thinking abilities can be greatly enhanced using the PBL methodology (van Herpen, Meeuwisse, Hofman, Severiens, & Arends, 2017). This is because PBL's features necessitate that students deal with unstructured, open-ended challenges; gather and examine data; create a range of substitute solutions; assess how well the final solutions work. Students actively participate in higher-order thinking exercises through this procedure. PBL helps students not only use formulas in the context of the law of sines, but also comprehend the reasoning behind their application and assess whether the solutions are suitable for the given issue settings (Olani, 2017). As a result, PBL serves as a method for methodically developing critical thinking abilities in addition to being a learning strategy.

The application of PBL and students' critical thinking abilities are theoretically closely related. PBL offers a setting for learning where students can develop a conceptual grasp of the sine rule by investigating problems, gain analytical abilities to comprehend the connection between angles and sides, assess answers using mathematical reasoning, when addressing contextual issues, reach the right conclusions (Hassel & Ridout, 2018). To put it another way, PBL helps students enhance their critical thinking abilities when learning mathematics, especially when it comes to the sine rule. Through an active, contextual, and problem-based learning method, PBL is anticipated to enhance students' critical thinking abilities.

The following research hypotheses can be developed using this theoretical framework:

H0: Students' critical thinking abilities about the sine rule are unaffected by the application of the Problem-Based Learning (PBL) approach.

H1: Students' critical thinking abilities about the sine rule are impacted by the application of the Problem-Based Learning (PBL) approach.

Research Method

Due of the researcher's inability to complete subject randomization (random assignment), this study used a quantitative technique with a quasi-experimental design method. The layout that was employed is Non-Equivalent Control Group Design. Among the research variables employed are Independent Variable (X), that is Model of Problem-Based Learning (PBL) and critical thinking abilities of students are the dependent variable (Y). Control variables include learning time, the instructor, and the material (sine rule). Population in this research is every high school student in the eleventh

grade and the sample which are purposive, were used to choose two groups. First is PBL-based experimental class and conventional learning in the control class. The sample size is between 60 and 70 students. The following phases of the research were carried out:

- a. Stage of Preparation, consists of creating educational resources (lesson plans based on PBL), making test devices for critical thinking, instrument validity and reliability testing, research authorization
- b. Stage of implementation
 - In both classes, a pretest
 - Administration of treatment: PBL learning in an experimental class (4–6 meetings), control class → traditional education
 - In both classes, a posttest
- c. The Last Phase, that includes data analysis and processing, interpretation of the findings, and making inferences

Expert validation from who expertised in mathematics education was used for content validation, while Pearson Product Moment correlation testing was used for empirical validity. Cronbach's Alpha value was used for reliability testing, and if α is greater than 0.70, it is considered dependable; if α is less than 0.70, it is not. Prerequisite tests and hypothesis testing were used in the data analysis process. The Levene test was used for the homogeneity test, and the Kolmogorov-Smirnov/Shapiro-Wilk normality test was utilized for the precondition test. In contrast, the hypothesis test compared the post-test results using the t-test for independent samples. $G \geq 0.7 \rightarrow$ high, $0.3 \leq g < 0.7 \rightarrow$ medium, and $g < 0.3 \rightarrow$ low are the categories of the N-Gain Score.

Results and Discussion

The results of the descriptive analysis show a difference in the improvement of critical thinking skills between the experimental class (PBL) and the control class (conventional), as shown in Table 1 below.

Table 1.
Critical Thinking Skills of the Experimental and Control Classes

Group	N	Pretest (Mean \pm SD)	Posttest (Mean \pm SD)	N-Gain
Experiment (PBL)	32	52.31 \pm 8.45	81.56 \pm 7.92	0.61 (Medium–High)
Control	31	51.87 \pm 8.12	68.24 \pm 9.15	0.34 (Medium)

The Shapiro-Wilk normality test yielded a score of $p > 0.05$, indicating that the data is normally distributed. The homogeneity test (Levene Test) revealed that the data is homogeneous since $p > 0.05$. As a result, the data satisfies the parametric testing standards. With $t(61) = 5.87$

and the p value < 0.001 , the findings of the hypothesis test using the independent sample t -test indicate that there is a significant difference between the critical thinking skills of students who study with PBL and conventional learning. Cohen's d was used to calculate the effect's magnitude, and the result was $d = 1.02$ (big category). This demonstrates that PBL adoption has a significant impact on raising students' critical thinking skills.

Based on the critical thinking indicators, the analysis results are as shown in Table 2 below.

Table 2.
Average Score per Indicator

Indicators	Experiment	Controlled
Interpretation	84.2	71.5
Analysis	82.6	69.3
Evaluation	79.8	66.7
Inference	79.6	65.4

The interpretation and analysis indicators showed the greatest progress in the experimental class, suggesting that PBL is successful in assisting students in comprehending and analyzing issues. The findings demonstrated that students' critical thinking abilities about the sine rule were considerably enhanced by the application of Problem-Based Learning (PBL). Constructivism theory, which emphasizes that information is actively produced through meaningful learning experiences, is consistent with this conclusion. PBL's features, which use problems as the foundation for learning, can account for the experimental class's greater development. In this process, students actively participate in problem analysis, idea connections, and solution evaluation in addition to receiving information. The primary elements of critical thinking—interpretation, analysis, assessment, and inference—are directly trained through these exercises.

Beyond merely memorizing formulas, PBL gives students the chance to gain a deeper understanding of the relationship between sides and angles in the context of the law of sines. For instance, students must choose the proper approach, choose the pertinent formula, and assess the outcomes when confronted with an indirect distance measuring problem. A deeper conceptual grasp is fostered by this process. Procedural learning, on the other hand, tended to restrict students' thinking in the control group. Most of the time, students just followed the teacher's instructions without comprehending the reasoning behind them. Lower posttest and N-Gain scores indicate that critical thinking abilities only partially developed as a result.

The high effect size ($d = 1.02$), which shows that PBL has a significant practical impact on learning in addition to being statistically significant, further supports this conclusion. This is a crucial sign that PBL should be suggested as a trigonometry learning approach, especially for the sine rule. Additionally, the study per indication reveals that the skills of interpretation

and analysis saw the biggest increase. This suggests that PBL is highly successful in the early phases of critical thinking, which include comprehending and evaluating issues. Improvements in the evaluation and inference components, however, were comparatively less significant, suggesting that the reflection and conclusion-drawing phases of PBL implementation need to be strengthened.

Overall, the study's findings support the idea that PBL is a successful teaching strategy for raising students' mathematical critical thinking abilities. The necessity for educators to create difficult contextual situations and lead discussions that inspire students to think critically are the research's practical ramifications. Therefore, it can be said that PBL's benefit is found in its capacity to combine active learning procedures with the growth of critical thinking abilities. According to the sine rule, PBL enhances both learning results and the caliber of students' thought processes.

Conclusions

The application of the Problem-Based Learning (PBL) approach in mathematics instruction on the law of sines has a major impact on enhancing students' critical thinking abilities, according to the research findings and discussion. Additionally, the data demonstrates that PBL is successful in fostering a variety of critical thinking markers, especially in the areas of interpretation and analysis. Compared to students learning through traditional methods, PBL students are better able to comprehend problems in-depth, recognize connections between topics, and develop suitable problem-solving techniques.

The large effect size suggests that PBL has a major practical impact on raising the standard of mathematics education in addition to being statistically significant. Therefore, PBL can be utilized as a successful alternative learning paradigm to help students strengthen their critical thinking abilities, especially when it comes to abstract trigonometry elements like the sine rule. Overall, this study supports the development of students' higher-order thinking skills by demonstrating how problem-based learning can foster a more dynamic, contextual, and relevant learning environment. It is recommended that math teachers apply the Problem-Based Learning (PBL) paradigm more widely in their instruction, especially for conceptual and applied concepts like the rule of sines, based on the research findings. In order to maximize student involvement and critical thinking, teachers must also create contextual situations that are pertinent to their students' lives. Teachers should focus especially on the reflection and assessment phases when implementing PBL since they are related to higher-order critical thinking indicators (evaluation and inference), which still require improvement. To guarantee that all students, including those with weaker ability, can successfully engage in the learning process, suitable scaffolding techniques are also required. Examining PBL implementation with other

characteristics like student involvement, learning motivation, or self-efficacy is one of the recommendations for further research.

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