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Integrating Deep Learning into Problem-Based Learning: Enhancing Relational Understanding in Trigonometry

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Abstract: This study examines the model Problem Based Learning's effect that has been integrated by Deep Learning approach on the relational understanding of students in trigonometry. A quantitative method with true experimental design is used, meanwhile the type of research is posttest-only design. The sample is 58 students of grade X from *SMA* A. Wahid Hasyim, divided into an experimental group ($n = 27$) receiving PBL integrated with Deep Learning, and the control group ($n = 31$) receiving conventional learning model. The instrument was a validated essay posttest. Data were analyzed by using mean score of both groups independently and the statistics of inferential that contains hypothesis test and effect size test. The results came up as the mean score of the experimental group (77.26) was significantly better than the mean score of the control group (36.39). The hypothesis using t-test resulted as $p = 0.000$ ($p < 0.05$), and the effect size score was 0.941 (very large effect). Thus, the PBL model with the Deep Learning as an approach has a significant effect on enhancing students' relational understanding of trigonometry.

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INTRODUCTION

Education is a collaborative ecosystem between teachers and students that aims to optimize the learner's development through the provision of information, character building, skills, and deep understanding (Shihab, 2019; Aththahirah et al., 2025). Within the school system, education is governed by a curriculum, which is defined as planned and systematic learning experiences designed to foster student competencies (Usdarisman et al., 2024). The curriculum is structured to prepare students for future life through mentoring, teaching materials, also the process of learning (Herman et al., 2023; UU Sisdiknas No. 20 of 2003).

In this context, the current curriculum that is being currently used is the Merdeka Curriculum, which has been adopted by most schools, including madrasahs and religion-based schools, based on the *Peraturan Kementerian Agama* Number 347 of 2022 (Muthrofin & Fathurrahman, 2024). In A. Wahid Hasyim High School is no exception. A. Wahid Hasyim High School is a pesantren-based school where the classroom division is based on gender. Even so, research that has been conducted by Pennington et al. (2017) showed such separation does not have a significant effect on Learning outcomes related to STEM (Science, Technology, Engineering, and Mathematics).

Building on the application of Merdeka Curriculum, one learning model that has been recommended in the Curriculum of Merdeka includes Problem Based Learning (PBL). PBL is a teaching approach that begins with learners comprehending an issue and identifying potential solutions, then selecting the appropriate a way to resolve the matter (Nuranita et al., 2025). This model emphasizes active participation, collaboration, and independent exploration through contextual problems. Students are given the opportunity to investigate, hypothesize, and draw conclusions from the data they collect themselves (Hardianti et al., 2025). Based on social constructivism theory, PBL encourages students to understand mathematics through real-world contexts, not merely as symbolic rules detached from reality (Sugiandi et al., 2025). Studies indicate the efficacy of PBL in enhancing conceptual comprehension and mathematical problem-solving abilities (Azwah et al., 2025; Naim & Barokah, 2025). PBL provides contextual problems that require students to identify relevant information, design problem-solving strategies, discuss alternative solutions, and reflect on the results obtained. This process allows for active knowledge construction, making the concepts learned more meaningful and integrated with students' experiences (Hasanah et al., 2026).

However, PBL alone may not be sufficient to achieve deep conceptual understanding. In addition to PBL, the Minister of Elementary, Middle, and High School Education Abdul Mu'ti encourages using the Deep Learning as an approach within the Merdeka Curriculum. An approach that prioritizes conscious, purposeful, and enjoyable learning is known as deep learning. holistically (Ministry of Elementary, Middle, and High School Education, 2025). This approach focuses on critical thinking, conceptual understanding growth, and active student participation, and meaningful learning (Wibowo et al., 2025; Nurul et al., 2025). Its three principles—mindful, meaningful, and joyful learning—ensure that students are mentally and physically engaged, connect new knowledge with prior experiences, and are motivated through positive emotions. This approach does not simply emphasize the achievement of academic outcomes, but rather the process of forming a whole, reflective, and meaningful conceptual understanding (Siregar et al., 2025).

Despite the potential of both PBL and Deep Learning, the reality at SMA A. Wahid Hasyim, particularly in grade X, mathematics learning still uses a conventional teacher-centered model, which is not aligned with the demands of the Merdeka Curriculum that calls for student-centered learning. In fact, the trigonometry material taught in grade X is rich in contextual problems and requires deep conceptual understanding (Susanti et al., 2024). The application of PBL alone has limitations because it may lead to procedural activities without deep reflection if not accompanied by an approach that emphasizes conceptual understanding. For this reason, a more integrated strategy is needed.

Based on initial observations, grade X students at SMA A. Wahid Hasyim tends to be active in learning activities, so the PBL framework combined with the Deep Learning as an approach is considered suitable for implementation. In this integration, PBL serves as an operational framework to identify, analyze, and solve problems, while Deep Learning ensures that the process builds a strong cognitive foundation and connected knowledge networks. This research innovates by embedding the Deep Learning context into the PBL model in trigonometry material, with the hope of pupils' comprehension in a more significant manner.

To justify this integration, it is important to review previous research. Previous research shows that students' conceptual grasp of mathematics is improved by the Problem Based Learning (PBL). Ritonga (2022) found that there is a significant effect caused by PBL on the student's conceptual understanding in trigonometry. This studiy proven by the result of t-test score is 0.000, with the level of significant level is $\alpha = 0.05$. Meanwhile, Yulianti & Gunawan (2019) reported an N-gain of conceptual understanding in the experimental class of 0.51, which is greater than the control group's 0.31 with an effect size of 0.36, and critical thinking also improved.

On the other hand, the Deep Learning approach has also been studied. Dewi et al. (2026) stated that Deep Learning approach gives a significant and positive effect to the student's conceptual understanding. It's proven by the hypothesis test (t-test) resulted in the significant score of $\alpha = 0.05$. Also there's a study by Julia et al. (2025) that stated PBL with a Deep Learning Approach has a significant effect to the student learning outcomes. However, previous studies still have limitations: none have studied the effect of PBL with the Deep Learning approach in students' conceptual understanding. This constitutes the research gap that This research attempts to satisfy.

In order to close this gap, the current study is grounded in a solid theoretical foundation. This research is based in constructivism theory, which states that children actively create knowledge via their experiences and interactions with their surroundings (Salsabila & Muqowim, 2024). The characteristics of constructivism include student-centered learning, the exchange of new knowledge with prior knowledge, social interaction, and contextual learning. The PBL model reflects constructivism principles because students construct their own knowledge through problem-solving, while The teacher serves as the facilitator (Nurhuda et al., 2023).

Furthermore, PBL is a teaching strategy that starts with contextual issues to encourage students to learn and solve them (Ardianti et al., 2022). The phases of PBL includes: issue orientation, student organization, inquiry guidance, work development and presentation, and process analysis and evaluation (Pramartha & Parwati, 2025). There are problems related to students' understanding of concepts in trigonometry material. These problems need to be addressed to support good learning in the future. Therefore, the learning module with a An option to teaching students' conceptual knowledge is the problem-based learning syntax, especially in trigonometry material (Bazuri & Arliani, 2022). The advantages of PBL include improving understanding of lesson content, training real-world problem solving, and developing lifelong learning skills (Yulianti & Gunawan, 2019; Rahmawati, 2019). However, its disadvantages are that if students are unmotivated or lack deep reflection, learning can become procedural (Hermansyah, 2020).

In contrast, the Deep Learning approach is defined as learning that emphasizes three principles: mindful, meaningful, and joyful learning holistically (Ministry of Elementary, Middle, and High School Education, 2025). The integration of PBL with Deep Learning combines contextual problem-solving with deep conceptual understanding. PBL serves as an operational framework, while Deep Learning ensures that the process builds a strong cognitive foundation and meaningful reflection (Adrian et al., 2023). It is highly crucial to integrate deep learning in order to enhance the effectiveness of PBL. Deep learning places more emphasis on deep conceptual comprehension, the connections between concepts, and metacognitive reflection than surface learning, which just concentrates on memorization of data for test passing. (Putri et al., 2026). The integration steps include: problem orientation with joyful learning, organizing students with mindful learning, guidance and presentation with meaningful learning, and reflective evaluation. Students' interest in learning and problem-solving skills are positively increased by the model of problem-based learning using a deep learning approach (Dewi et al., 2025).

Finally, it is essential to define what is meant by student understanding in this study. Student understanding is not merely memorizing procedures, but the ability to connect mathematical ideas flexibly (Suhendar & Ekayanti, 2018). According to Skemp, understanding is divided into two types: instrumental understanding (applying rules without knowing the reasons) and relational understanding (understanding why and how concepts are interconnected) (Rachmawati et al., 2023). The indicator of relational understanding are: (1) The students' ability to classify objects based on needs that can form a concept, (2) Applying concepts algorithmically, (3) Providing examples of a concept, (4) Repeating the concepts that have been learned, (5) Presenting representative mathematical concepts, (6) Relating several mathematical concepts, and (7) The ability to develop the necessary and sufficient conditions for a particular concept. This study will measure students' relational understanding after the implementation of PBL with the Deep Learning approach.

METHOD

This study employs an experimental research design and is quantitative in nature. A True Experimental Design is the kind of experiment that is employed. Because the research volunteers were picked at random, this kind of study was used. A true experiment is the kind of research design that is employed when participant selection is done at random (Isnawan, 2020). Meanwhile, The type of research used is a Posttest-Only Design. Each of the two groups in this design was selected at random. While another group does not receive the treatment (X), the first group does. The experimental group is the one that gets the therapy, while the control group is the one that doesn't (Sugiyono, 2019). Both groups were then measured for their understanding through a posttest. The research design can be seen in Table 1.

Table 1. The Design Research

Groups	The Treatment	The Posttest
A	X	O
B	-	O

With: A = Experimental group (receiving PBL integrated by Deep Learning)
B = Control group (receiving conventional instruction)
X = Giving treatment by using PBL integrated by Deep Learning
O = Posttest for both groups

Following this design in Table 1., the research was conducted at SMA A. Wahid Hasyim, located in Tebuireng, Jombang. All grade X pupils in the four classes (X-1, X-2, X-3, and X-4) during the 2025–2026 school year made up the research population. The sample was collected using simple random sampling, resulting in different classes: X-1 is the experimental class (receiving PBL integrated by Deep Learning) that has 27 students, and X-2 as the control class (receiving conventional instruction) that has 31 students. This study is chosed not to conduct a pretest because based on the observation in the school resulted in all of the four classes in grade X has a similar conceptual understanding. The observation is done by interviewing the teacher and observing the learning process in the classroom. The stages of PBL integrated by Deep Learning Approach that has been used in experimental group is taken then modified from the framework created by Julie et al. (2025). The model can be seen in Table 2.

Table 2. Stages of PBL integrated by Deep Learning

Steps of PBL	Elements of Deep Learning
Orientation to the Problems At this stage, students are given a problem that is different from the starter question. The problem provided is authentic and relevant to real-life contexts. Students are given a trigonometry problem related to everyday	*Joyful Learning* Students are presented with problems in the form of animations to create an interesting and fun learning atmosphere.

Steps of PBL	Elements of Deep Learning
life as a learning stimulus.	
Organizing Students to Learn In this stage, the teacher guides students to identify what they already know (for example, understanding what sides and angles are, as well as what a right triangle is), what they need to learn (sine, cosine, tangent, and so on), and how to learn it.	*Meaningful Learning* Students actively connect the knowledge they already have from previous subjects with the trigonometry material they are learning.
Directing Independent and Group Inquiry At this stage, the teacher guides students in collecting data/information (knowledge, concepts, theories about trigonometry) through various methods to find different alternative solutions to the problems given at the beginning of the lesson.	*Joyful Learning* Students are invited to learn concepts in trigonometry (sin, cos, tan, sec, csc, cot) through GeoGebra.
Developing and Presenting Work Teachers guide students in choosing the most appropriate solution from various problem-solving alternatives that students find.	*Joyful Learning* Students present their work in the form of group presentations in front of the class. This is done with the aim of creating an interactive and enjoyable atmosphere in the classroom.
Analyzing and Evaluating the Problem-Solving Process The teacher facilitates students to reflect on or evaluate the problem-solving process they have carried out.	*Mindful Learning* Students analyze and evaluate the steps and strategies they use to solve problems.
Final Reflection and Feedback The teacher invites students to reflect on what they have learned and also provides feedback on the students' work, both individually and in groups.	*Meaningful Learning* Students reflect on learning activities to strengthen metacognitive skills and develop scientific thinking abilities. Students are also given feedback as part of the ongoing learning process, which encourages them to understand the material more deeply and grow further.

To measure the outcome of the treatment, the main A posttest in the form of an essay test was utilized consisting of four questions with graded difficulty levels, ranging from basic conceptual understanding to application in complex contextual problems. Each question was designed to measure different dimensions of understanding: explaining concepts in one's own words, applying trigonometric formulas correctly, analyzing relationships between concepts, evaluating alternative solutions, and solving non-routine problems in real-life contexts. The posttest was developed based on the competency indicators of trigonometry in the Merdeka Curriculum for grade X senior high school, and was validated by experts in mathematics education and mathematics teachers.

For data analysis, two techniques were used to interpret the data: descriptive and inferential statistics. The descriptive statistic technique was used to calculate the mean of the experimental group and the control group separately. The formula used to calculate the mean is as follows Equation (1) (modified from Zalfa, 2024)

$$Mean\ score = \frac{Total\ score\ of\ the\ group}{Total\ students\ in\ the\ group} \quad (1)$$

Then the results were construed in accordance with the categories shown in the Table 3.

Table 3. Interpretation Criteria for Mean Scores

Mean Score Interval	Category of Students' Understanding
$85 < \bar{x} \leq 100$	Excellent
$70 < \bar{x} \leq 85$	Great
$55 < \bar{x} \leq 70$	Good
$40 < \bar{x} \leq 55$	Poor
$0 \leq \bar{x} \leq 40$	Extremely Poor

After the mean score of both groups being calculated then categorized, the results are compared. Meanwhile the inferential statistic technique used the parametric test to prove a hypothesis and an effect size test to determine the magnitude of the treatment. Before choosing a type of parametric test, the normality and the homogeneity of the data were examined. Then if the data both has a normal and homogeneity distribution, the Independent Samples t-test is a parametric test chosen to test the following hypothesis:

H_0 : $\mu_1 = \mu_2$
It means that there is no significant difference between the trigonometry understanding of students who learn with PBL integrated with Deep Learning and students who learn with conventional methods.

H_1 : $\mu_1 \neq \mu_2$
It means that there is a significant difference between the trigonometry understanding of students who learn with PBL integrated with Deep Learning and students who learn with conventional methods.

This Independent Samples t-test was calculated at the significance level of $\alpha = 0.05$ with criteria: (1) Accept H_0 if the $p - value > 0.05$, and (2) Reject H_0if the $p - value \leq 0.05$.

Additionally, to measure the influence size of the treatment, an effect size test using Cohen's d was conducted. The "effect size calculator" website is then used to determine the Effect Size value using the Cohen's d values that were acquired. The results were then interpreted according to the categories shown in Table 4.

Table 4. Effect Size's Score Interpretation Criteria

Effect Size's Score	Interpretation
$ES < 0,2$	Small
$0,2 \leq ES < 0,5$	Medium
$0,5 \leq ES < 0,8$	Large
$ES \geq 0,8$	Very Large

Source: modified from Widyastuti & Airlanda, (2021)

After all of the data have been calculated and interpreted, the results can be concluded.

RESULTS

The posttest was administered to both the experimental group ($n = 27$) and the control group ($n = 31$) after the treatment. The mean score of the experimental group was 77.26, while the mean score of the control group was 36.39. Based on the interpretation criteria shown in Table

1, the experimental group achieved a "Good" category of understanding, whereas the control group fell into the "Very Poor" category. This initial descriptive comparison suggests that the treatment had a positive impact, but further statistical testing is required to confirm the significance of this difference.

Before testing the hypothesis, the normality and homogeneity of the data were examined. The Kolmogorov-Smirnov test was the normality test that has been used to determine whether the data were normally distributed. The significance level was set at $\alpha > 0.05$. The results can be viewed in Table 5.

Table 5. Normality Test Results (Kolmogorov-Smirnov)

Group	Statistic	Df	Sig. (2-tailed)	Decision
Experimental Class	0.740	27	0.644	Normal
Control Class	—	—	0.191	Normal

Since the significance values for both groups were greater than 0.05, the data were concluded to be normally distributed. And then Levene's test was conducted as the homogeneity thest to assess the equality of variances between the two groups. The significance level was set at $\alpha > 0.05$. The result is shown in Table 6.

Table 6. Homogeneity Test Results (Levene's Test)

Basis	Levene Statistic	df1	df2	Sig.
Based on Mean	2.913	1	56	0.093

The significance value (0.093) exceeded 0.05, indicating that the variances between the experimental and control groups were homogeneous. And because the data satisfied both normality and homogeneity assumptions, a parametric independent samples t-test was performed to compare the mean scores between the two groups. The significance level was $\alpha = 0.05$. The results can be read in Table 7.

Table 7. Independent Samples t-test Results

Variable	t	df	Sig. (2-tailed)	Mean Difference
Posttest Scores	20.766	56	0.000	40.872

The results showed a significance value of 0.000 ($p - value < 0.05$), indicating a statistically significant difference between the experimental and control groups. Therefore, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_1) was accepted. This means that there was a significant difference in trigonometry understanding between students who learned using the PBL model with the Deep Learning approach and those who learned using conventional instruction.

To determine the magnitude of the effect of the treatment, Cohen's d effect size was calculated. Table 8. presents the group statistics needed for this calculation.

Table 8. Group Statistics for Effect Size

Group	N	Mean	Std. Deviation
Experimental	27	77.26	5.156
Control	31	36.39	9.017

The effect size was calculated using the pooled standard deviation as follows (2)

$$d = \frac{\overline{X}_1 - \overline{X}_2}{S_p} = \frac{77.26 - 36 - 39}{7.345} = 5.56 \quad (2)$$

After getting the cohen's d result, the effect size is calculated using *Effect Size Calculator*. According to it, if the cohen's d score is 5.56 means that the effect size is 0.941. It means that the effect size score fell within the range of $ES \geq 0{,}8$, indicating a "Very Large Effect" category. This result confirms that the PBL model with the Deep Learning approach not only produced a statistically significant difference but also had a substantial practical impact on students' understanding of trigonometry.

DISCUSSION

The findings of this study provide empirical evidence regarding the effectiveness of the Problem Based Learning (PBL) model integrated with the Deep Learning approach in enhancing students' understanding of trigonometry. The descriptive statistical analysis revealed that the mean posttest score of the experimental group (77.26) was substantially higher than that of the control group (36.39). According to the interpretation criteria, the experimental group achieved a "Good" category of understanding, while the control group fell into the "Very Poor" category. This finding aligns with the research by Fauzurradjak (2021), which reported that the PBL model could improve students' understanding of trigonometry in grade X. This result is also similar with the one that has been conducted by Megawati et al. (2024) which resulted in average of students' understanding of mathematical concept is improved when using problem based learning than a conventional learning. The significant difference in mean scores suggests that the integration of Deep Learning principles—mindful, meaningful, and joyful learning—into the PBL framework provided a more enriching learning experience compared to conventional instruction.

Moving beyond descriptive comparisons, the inferential analysis further confirmed the effectiveness of the integrated model. The independent samples t-test yielded a significance value of 0.000 ($p < 0.05$), leading to the rejection of the null hypothesis (H_0) and acceptance of the alternative hypothesis (H_1). This result indicates a statistically significant difference in trigonometry understanding between students who learned through the PBL model with the Deep Learning approach and those who learned through conventional methods. This finding is consistent with the research by Maman et al. (2026), which stated that the application of Deep Learning in mathematics education supports the reinforcement of conceptual understanding in a more meaningful way. Also Asih et al. (2019) said that PBL has a significant effect on the students' conceptual understanding. The significant difference can be attributed to the student-centered nature of PBL combined with the reflective and engaging characteristics of Deep Learning, which together foster deeper cognitive processing.

Furthermore, to assess the practical significance of the intervention, Cohen's d effect size was calculated. The effect size was found to be 0.941, which falls into the "Very Large Effect" category ($ES \geq 0{,}8$). This finding confirms that the PBL model with the Deep Learning approach not only produced a statistically significant difference but also had a substantial practical impact on students' understanding. Sari et al. (2021) also has a similar result which is the effect size score of the PBL on the students' mathematical understanding is 0.79 and the standar of error's value is 0,181 which is quite high. Then, this findings can be concluded as the large effect size underscores the pedagogical value of integrating Deep Learning principles into PBL, particularly for topics that require deep conceptual understanding, such as trigonometry. In other words, the magnitude of the effect indicates that this integrated model is not merely statistically significant but also educationally meaningful.

The success of the experimental group can be explained through the three core principles of Deep Learning. First, joyful learning was implemented through the use of animations, GeoGebra visualizations, and interactive problem-solving activities, which created an engaging and enjoyable classroom atmosphere. This aligns with the theoretical framework of joyful learning, which emphasizes positive emotions such as curiosity, enthusiasm, and motivation (Ministry of Primary and Secondary Education, 2025). Second, meaningful learning was facilitated through the use of student worksheets (LKPD) and contextual problems such as measuring tree height and leaning ladders, which enabled students to connect new trigonometric concepts with their prior knowledge and real-life experiences. This meaningful connection facilitated deeper conceptual understanding as opposed to rote memorization of formulas. Third, mindful learning was encouraged through reflection activities and group discussions, which prompted students to become aware of their own thinking processes (metacognition). Students were asked to evaluate their problem-solving strategies, compare results across groups, and reflect on what they had learned, helping them internalize the material more deeply. Consequently, these three principles worked synergistically to enhance relational understanding.

When compared with prior studies, The findings of this study extend previous research in several important ways. While Julia et al. (2025) demonstrated the effects of PBL with a Deep Learning Approach on physics and only focusing on the student learning outcomes, the current study with the similar syntax of learning model is focused on the students' understanding in trigonometry. Unlike Ritonga (2022), who examined PBL's effect on mathematical conceptual understanding without focusing on trigonometry or integrating Deep Learning, this study specifically targeted trigonometry and embedded Deep Learning into the PBL syntax. Moreover, while Dewi et al. (2026) conducted a study on Deep Learning Approach without integrating it to any learning model, the present study directly implemented Deep Learning in a specific learning model that is Problem Based Learning. Finally, Yulianti & Gunawan (2019) reported effect sizes of 0.36 for conceptual understanding and 0.66 for critical thinking using PBL alone; in contrast, the current study achieved a much larger effect size of 5.56 by integrating Deep Learning. These comparisons highlight the added value of combining Deep Learning principles with the PBL framework.

Beyond theoretical contributions, the results of this study have several practical implications for mathematics education. First, the PBL model with the Deep Learning approach can be recommended as an alternative teaching strategy for topics that require deep conceptual understanding, such as trigonometry. Second, teachers should consider designing learning activities that incorporate joyful elements (e.g., visual media, interactive tools), meaningful connections (e.g., real-world problems), and mindful reflection (e.g., self-evaluation). Third, the integration of technology, particularly GeoGebra, proved to be effective in enhancing joyful and meaningful learning, suggesting that digital tools can support the implementation of Deep Learning principles in mathematics classrooms.

To better appreciate the actual mechanism behind the success of the integrated model, it is worth tracing step by step how each phase of the PBL syntax, when deliberately paired with one of the three Deep Learning principles, directly addresses Skemp's seven indicators of relational understanding in trigonometry.

The process begins in the orientation to problems phase, where students are presented with authentic, real-life problems, such as a ladder leaning against a wall or a point moving along a unit circle. The use of animations and visual media creates an engaging atmosphere, which embodies joyful learning. Critically, this phase is not merely about capturing attention. It also sets the stage for two of Skemp's indicators: students are given concrete examples of trigonometric ratios in action, which supports their ability to provide examples of a concept. At the same time, they must begin distinguishing between sides, angles, and the relevant functions needed to solve the problem, which is the first step toward classifying objects based on needs.

Following this, during the organizing students to learn phase, the teacher activates students' prior knowledge about right triangles and basic angle relationships. This is where meaningful learning comes into play. Rather than presenting trigonometry as a set of isolated formulas, students are guided to connect new ideas with what they already know. This directly reinforces the indicator of repeating the concepts that have been learned, and it also initiates the process of applying concepts algorithmically, because students are now expected to begin structuring their solution steps in a systematic way.

The third stage, directing independent and group inquiry, gives students the freedom to explore trigonometric concepts through dynamic tools like GeoGebra. The use of technology here once again supports joyful learning, but more importantly, this phase enables students to see how sine, cosine, and tangent behave across different quadrants and how these functions are interrelated. It is during this stage that the indicators of presenting representative mathematical concepts and relating several mathematical concepts are most prominently developed, as students are not just memorizing values but actively observing how changes in one function affect the others.

Moving forward, in the developing and presenting work phase, students collaborate to present their findings and compare alternative strategies. This stage, also supported by joyful learning through interactive presentations, gives students repeated opportunities to provide examples of a concept and to justify why certain procedures are more effective than others. In doing so, they further refine their ability to apply concepts algorithmically, not mechanically, but with understanding.

The reflective work happens in the analyzing and evaluating the problem-solving process phase, where mindful learning becomes central. Here, students are asked to evaluate their own solution strategies, compare them with those of their peers, and consider whether their approaches would work under different conditions. This reflective practice is particularly relevant for developing the indicator of the ability to develop the necessary and sufficient conditions for a particular concept. Students begin to ask not only "does this work?" but also "why does this work?" and "when should I use this strategy instead of another?"

Finally, in the final reflection and feedback stage, the teacher facilitates a whole-class discussion and provides individual feedback. Grounded once again in meaningful learning, this phase requires students to synthesize their understanding and generalize it to new contexts. By revisiting core identities like $sin^2\theta + cos^2\theta = 1$ and examining how these identities hold across multiple quadrants, students continue to work on the indicators of relating several mathematical concepts and repeating the concepts that have been learned.

What emerges from this analysis is that the integration is not accidental or superficial. Each phase of the PBL syntax has been deliberately aligned with a specific Deep Learning principle, and together, they systematically and coherently target all seven of Skemp's indicators. This is why the students in the experimental group did not simply perform better on procedural tasks; they developed a more interconnected, reflective, and deeply internalized understanding of trigonometry.

However, several limitations should be acknowledged. It should be mentioned that this study was conducted at a school with a single-gender classroom system located in a pesantren. The classroom dynamics are different even though Pennington et al. (2017) demonstrated that these environments do not significantly impact STEM outcomes when compared to mixed-gender classrooms. Students may feel more comfortable participating actively in single-gender settings, but they may also lose out on the variety of viewpoints that arise in mixed groups. This implies that implementing the same integrated approach in public or coeducational institutions would necessitate modifications, especially in the way educators oversee group discussions and guarantee gender parity in participation. Therefore, school administrators and teachers should see the model as a flexible framework that can be tailored to their particular classroom culture rather than as a set formula. The recommendations might not be easily implemented outside of pesantren contexts without this thorough contextual assessment. Additionally, the study focused only on the subtopics of trigonometric ratios in right triangles and trigonometric ratios in various quadrants, so the findings may not automatically apply to other trigonometry topics or other branches of mathematics. The study also employed a posttest-only design without a pretest, which assumes that both groups had equivalent prior knowledge; although random sampling was used, the absence of a pretest remains a methodological limitation. Despite these limitations, the consistency of the findings with existing literature strengthens the validity of the conclusions.

Finally, future research should consider expanding the scope of participants to include multiple schools across different regions or educational levels to test the consistency of the findings. Researchers could also explore the integration of the PBL model with the Deep Learning approach on other mathematics topics or other subjects. Further studies might employ a pretest-posttest control group design to more precisely measure the gain in understanding. Finally, qualitative research methods, such as interviews or classroom observations, could be used to gain deeper insights into students' experiences and cognitive processes during the implementation of this integrated model. Despite these limitations, the present study provides robust empirical evidence that the PBL model with the Deep Learning approach has a positive and significant effect on students' understanding of trigonometry, and it is recommended as an effective alternative strategy for promoting deep conceptual learning in mathematics.

CONCLUSION

Based on the results of data analysis, the findings of this study are: (1) Problem Based Learning with Deep Learning Approach gives a better result on the students' conceptual understanding of trigonometry than conventional learning. This finding is indicated by the mean posttest score of the experimental group (77.26) was substantially higher than that of the control group (36.39), with the experimental group achieving a "Good" category of understanding while the control group fell into the "Very Poor" category. (2) The Problem Based Learning model with Deep Learning Approach has a significant effect on the students' conceptual understanding, which is proven by the independent samples t-test yielded a significance value of 0.000 ($p < 0.05$), confirming a statistically significant difference between the two groups. (3) Problem Based Learning integrated by Deep Learning Approach has a very large effect on the students' conceptual understanding of trigonometry. This proven by effect size value was calculated to be 0.941, which falls into the "Very Large Effect" category, indicating a substantial practical impact. In conclusion, the Problem Based Learning model with the Deep Learning approach has a positive and significant effect on improving students' understanding of trigonometry. Therefore, this model is recommended as an effective alternative teaching strategy for mathematics teachers at the senior high school level, particularly for topics requiring deep conceptual understanding. It can be concluded that the general result of this study is the application of Problem Based Learning model that has been integrated by Deep Learning as an approach can enhance students' conceptual understanding of trigonometry.

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