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Enhancing Students' Concept Understanding Through The Problem-Based Learning Model: An Experimental Study

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ABSTRACT

Improving students' conceptual understanding in science remains a key challenge in higher education, particularly in teacher training programs. Problem-Based Learning (PBL) has been widely proposed as an effective model to foster deeper learning and critical thinking. This study investigates the effectiveness of the PBL model in enhancing students' conceptual understanding in fundamental science concepts course. A quasi-experimental design with a nonequivalent control group was employed. The study involved 78 fourth-semester students from the PGMI program at UIN Sunan Kalijaga, divided into an experimental group (PBL model) and a control group (cooperative model), each comprising 39 students. Pretest and posttest data were collected using validated essay-based instruments focused on the topic of static electricity. Data were analyzed using normality, homogeneity, and independent sample t-tests with SPSS 26. Both groups showed improvement, but the experimental class demonstrated significantly higher gains in conceptual understanding. The posttest mean score of the experimental group was 88.54 (Very High), compared to 78.72 (High) in the control group. Statistical analysis confirmed a significant difference between the groups ($p = 0.00 < 0.05$), indicating the effectiveness of the PBL model. The results support the use of PBL as a pedagogical approach to enhance science concept mastery. Given its impact, PBL is recommended for wider application in science education, though further research with diverse samples and long-term designs is suggested.

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1. INTRODUCTION

In 2018, the Program for International Student Assessment (PISA) published its most recent assessment on the literacy levels of its member nations, including Indonesia. Considering this report, the literacy level of Indonesian students is ranked 74th out of 79 member countries (Sidiq et al., 2021; OECD 2022). PISA (Progamme for International Student Assessment) in 2022 will again release its latest report data regarding reading, mathematics and science. According to the Ministry of Education and Research, Indonesia's 2022 Pisa results experienced an increase in ranking, up 6 positions compared to before. However, there will be a decline in Indonesia's average in 2022.

Based on this report, in the science category, Indonesia got a score of 383, which is decreased compared to 2018, Indonesia got a score of 396 (OECD, 2023; Bilad et al., 2024). Indonesia is concerned about this rating since it indicates a nation's literacy level, which affects its capacity to compete in the globalized world (Fitriansyah et al., 2020). A nation's capacity to compete is significantly impacted by its degree of scientific literacy (Amaringga et al., 2021) because scientific literacy is a skill in using individual scientific knowledge to solve problems (Zulfiani et al., 2020; Muhibbuddin et al., 2023). Scientific literacy has become a critical skill for Indonesia's youth to acquire in light of global technological advancements. Regretfully, Indonesia's scientific literacy level remains low, trailing considerably behind other countries with a score of 383 in the 2022 PISA assessment. To raise the standard of science in Indonesia, greater attention should be paid to this case. Enhancing pupils' comprehension of scientific topics is one endeavor that might be undertaken.

Natural Sciences (Science) is an important subject that has a role in education in Indonesia. In science, students are encouraged to find the material themselves and are able to convey this material in a complex way (Yunianti et al., 2019). Therefore, PGMI students as teacher candidates are provided with basic science concept material through basic science concept courses that focus in physics in the fourth semester, physics learning must make students not only know and memorize physics concepts but must make students understand and understand these concepts and connect the relationship between one concept and another concept (Zahara Syarifah et al., 2021).

However, the truth in the area is that not all students have a solid understanding of the fundamental ideas of science: they are unable to reinterpret the concepts they have studied, and when asked about them, they merely read the meaning without understanding it. Students find it challenging to apply fundamental science concepts when asked to solve physics-related problems. Understanding is a type of knowledge or an individual's viewpoint on an issue (Hasbullah et al., 2019). Understanding is one aspect of the cognitive domain (Junaid et al., 2021). Anderson & Krathwohl (Dewantoro & Mustadi, 2019) added that comprehension is the process of creating meaning from the information that is taught, such as what the teacher says, writes, and illustrates. Understanding facts, language, and experiences through pictures, analogies, and models allows students to analyze and apply concepts, principles, and processes (Saldo & Walag, 2021). This is an example of concept understanding. According to Bloom's taxonomy, understanding is categorized as cognitive level C2. The following are markers of comprehension in the cognitive domain, using Anderson & Kratwohl's revised Bloom's taxonomy (Gunawan & Paluti, 2017): interpreting, exemplifying, classifying, summarizing, concluding, comparing, and explaining.

To make things easier for pupils to understand, a learning model that can help them is needed. Among these is the Problem-Based Learning (PBL) model. The concepts of cooperative learning are applied in small groups using an instructional approach known as problem-based learning (PBL) (Ghani et al., 2021). Through practice and reflection, students are able to develop independent learning habits, build mental models for learning, and solve challenges in a group setting (Yew & Goh, 2016). The issue is brought up at the start of the lesson, and stu Students can create independent learning habits, mental models for learning, and group problem-solving skills through practice and reflection students are then tasked with finding a solution (Nurhaedah et al., 2022). As stated by Arends (Mamalu et al., 2023; Yuhani et al., 2018), the problem-based learning (PBL) paradigm is a teaching strategy that centers education on problems and challenges by offering concrete and significant real-life experiences. The PBL paradigm can help improve students' understanding of scientific ideas. More active and creative learning is encouraged for kids who are interested in science (Kodariyati & Astuti, 2016, Janah & Widodo, 2013; Tiarini et al., 2019; Rahman et al., 2022).

Several previous research results have proven the effectiveness of the implementation of the Problem-Based Learning (PBL) model, specifically, this aims to improve the quality of education and learning, and specifically it only aims to provide a positive influence in order to improve problem solving, critical thinking, creativity (Selçuk et al., 2013; Hidayati & Wagiran, 2020), innovate and can improve concept understanding(Halim et al., 2017). Problem-Based Learning (PBL) has shown its effectiveness in various educational contexts with diverse outcomes according to learning needs and objectives. In different educational contexts, PBL can improve students' understanding of concepts while also helping them apply those concepts in real life, making it an effective method for developing applied thinking skills (Padmavathy & Mareesh, 2013) Meanwhile, in K–12 education, Wirkala and Kuhn (2011) found that students who learn through PBL better understand and can apply concepts effectively compared to traditional lecture methods. This study also emphasizes the importance of the collaborative element in PBL, which contributes significantly to student learning outcomes (Wirkala & Kuhn, 2011).

While not all learning objectives are entirely met, PBL in medical education enables students to customize their learning activities based on their needs and interests. This illustrates how adaptable PBL approaches are in assisting students in comprehending content that is pertinent to their real-world requirements (Sockalingam et al., 2012). In addition, Hmelo-Silver (2004) outlined how PBL boosts intrinsic motivation in addition to assisting pupils in developing their critical thinking abilities and capacity for independent study. Because PBL may more effectively combine theory and practice, it is a useful strategy in a variety of academic fields (Hmelo-Silver, 2004). All things considered, PBL is a versatile and successful teaching strategy that raises students' motivation to learn, conceptual comprehension, and analytical abilities. The success of its execution depends on the quality of the implementation, the educational atmosphere, and the collaboration of all stakeholders. Given this rationale, the study's goal was to determine whether the based learning paradigm enhances students' understanding of subjects in basic science classes. Therefore, this study aims to assess how well the problem-based learning (PBL) paradigm enhances students' conceptual understanding in courses covering basic science concepts. This study aims to ascertain whether the problem-based learning (PBL) methodology improves students' conceptual understanding.

2. METHODS

This study employed a quantitative research approach, which emphasizes systematic and empirical investigation through statistical analysis of numerical data. A quasi-experimental design with a non-equivalent control group was utilized to assess the effectiveness of the intervention. The participants consisted of 78 fourth-semester students enrolled in the *Basic Science Concepts* course at UIN Sunan Kalijaga. They were divided evenly into two groups: 39 students in the experimental group, who received instruction using the Problem-Based Learning (PBL) model, and 39 students in the control group, who were taught using a cooperative learning model.

Table 1. Research design

Group	Pretes	Treatment	Posttes
Experiment	O1	X1	O2
Control	O3	X2	O4

Information:
O1 : Experimental Class Pretest,
O2 : Experimental Class Posttest,
O3 : Control Class Pretest,
O4 : Control Class Posttest,
X1 : Treat it with the application of PBL,
X2 : Treat it with cooperative application.

To ascertain students' initial conceptual knowledge in the two sample classrooms, a pretest was administered in both the experimental and control classes as the first stage in this study. The data from this stage is analyzed first using prerequisite statistical tests before testing using the T test. If both sample classes have carried out prerequisite tests then the two sample classes are given treatment according to what is planned in table 1. Next, a posttest is applied to obtain data on the level of understanding of the concept. to students. This posttest data was also subjected to the required statistical analysis before a T test was performed to ascertain the difference in the average conceptual understanding between students in the two sample courses. Expert-validated description questions serve as a concept-understanding aid in this study. The Normality, Homogeneity, and Hypothesis tests were among the data analysis methods used once the concept understanding data for both courses had been collected. Data analysis methods were carried out using SPSS version 26 for Windows.

3. FINDINGS AND DISCUSSION

3.1 Finding

The study was conducted at the PGMI program of UIN Sunan Kalijaga, involving 78 fourth-semester students who were divided into two groups: Class A as the control group and Class B as the experimental group. The research instrument consisted of ten essay questions focused on the topic of static electricity. The content of these questions was reviewed and validated by subject matter experts to ensure alignment with the learning objectives. To determine the instrument's validity, the Pearson Product-Moment correlation was employed, comparing each item score with the total test score. The validity and reliability analyses were conducted to confirm that the instrument accurately measured students' conceptual understanding.

Table 2. Results of the Validity Test of Student Understanding Questions

Question Number	r-count	r-tabel (α = 0.05)	Information
1	0.625	0.312	Valid
2	0.712	0.312	Valid
3	0.521	0.312	Valid
4	0.430	0.312	Valid
5	0.510	0.312	Valid
6	0.675	0.312	Valid
7	0.482	0.312	Valid
8	0.533	0.312	Valid
9	0.610	0.312	Valid
10	0.540	0.312	Valid

According to Table 2 above, each of the ten questions has a significance value higher than 0.05. It serves as an example of how any question may be used to gauge how well pupils comprehend the idea of static electricity. Additionally, Table 3 displays the reliability test results.

Table 3. Instrument Reliability

Indicator	Value
Number of Question Items	10
Number of Respondents	78
Cronbach's Alpha	0.802
Reliability Category	High

Based on Table 3 above, the reliability test carried out with the research instrument can be considered reliable, shown by the Cronbach's Alpha coefficient of 0.802 greater than 0.05. These results show that the instrument developed is able to accurately assess students' understanding of concepts. Therefore, it can be concluded that the tested instrument is valid and reliable. This research was carried out in 3 weeks with 3 meetings in the research class. At the beginning of the meeting, the researchers used a pretest in the experimental and control classes with 10 descriptive questions. After getting the final score, the score is then qualified according to the qualifications stated in the research (Rahayu, 2018), as in Table 4 below.

Table 4. Qualification of concept understanding test scores

Score Percentage	Criteria
$85 \leq score \geq 100$	Very High
$70 \leq score\ < 85$	High
$55 \leq score < 70$	Enough
$40 \leq score\ 55$	Low
$0 \leq score < 40$	Very Low

In the pretest results of the experimental and control classes before being given treatment, the average score for each class was obtained as in Figure 1.

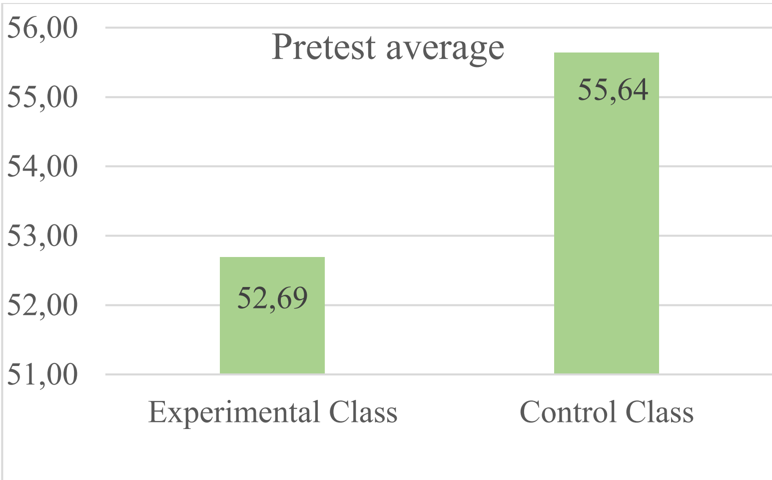

Figure 1. Pretest Average Graph for Experimental and Control Classes

Based on the pretest results, the control group obtained an average score of 55.64, categorized as "Sufficient," while the experimental group scored an average of 52.69, falling into the "Low" category, according to the criteria set by Rahayu (2018) (see Figure 1). These results indicate that both groups had a limited understanding of the targeted scientific concepts prior to the intervention. Therefore, it was deemed necessary to implement a suitable learning model to improve students' conceptual understanding.

In the following sessions, the experimental group received instruction using the Problem-Based Learning (PBL) model, while the control group was taught using a cooperative learning approach. The PBL model, as outlined by Yulianti and Gunawan (2019), consists of four main steps: (1) presenting the problem or topic to students, (2) facilitating student learning plans, (3) guiding individual or group learning experiences, and (4) encouraging students to create and present their findings. The PBL model was applied to Class B (experimental group), whereas Class A (control group) continued with the cooperative learning strategy.

During the third meeting, a posttest was administered to both groups using the same set of ten descriptive questions. After scoring, the results were categorized based on Rahayu's (2018) classification criteria. The average posttest scores of both groups were then analyzed and presented in Figure 2 to compare the outcomes following the respective treatments.

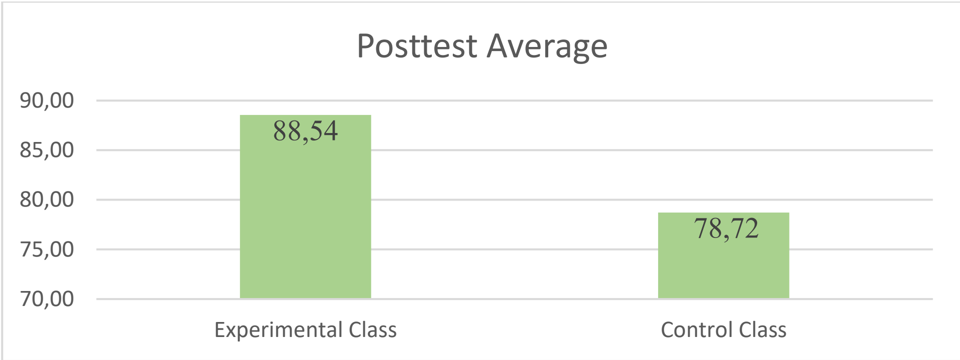

Figure 2. Posttest average graph for experiment and control

In Figure 2, with an average score of 78.72, the control group was classified as "High", whereas the experimental group was classified as "Very High" with an average score of 88.54. Both classes showed notable gains, but the experimental class which was taught using the PBL paradigm saw a bigger rise than the control group, which was taught using the cooperative approach. Before assessing the hypothesis, the researcher performed precondition tests, including homogeneity and normality checks.

To decide which statistical tests will be employed in the investigation, the Normality Test is required. Parametric type statistics can be used to test the hypothesis if the data is regularly distributed. Nonparametric techniques, on the other hand, can be used for hypothesis testing if the data is not regularly distributed. In this study, SPSS version 26 for Windows was used to perform a normality test. The test criteria state that the data is normally distributed if the significance value (sig) is greater than 0.05 and not normally distributed if the sig is less than 0.05. The findings of the study's normalcy test are shown in Table 5 below.

Table 5. Normality test calculations based on data.

Class	N	Kolmogrof-Smirnov	Shapiro-Wilk	Description
Experimental Pretest	39	0.200	0.255	Normal
Experimental Posttest	39	0.178	0.190	Normal
Control Pretest	39	0.200	0.725	Normal
Control Posttest	39	0.200	0.211	Normal

This study's data is distributed regularly, as indicated by table 3, which displays the overall data from the experimental and control groups, both pretest and posttest, with Kolmogorov-Smirnov and Shapiro-Wilk sig values > 0.05. Since 39 < 50 was the amount of research data, the Shapiro-Wilk test was applied. A homogeneity test will be conducted following the conclusion that the data is normal. Since this study examines two sets of data, the homogeneity test employs the Levene formula (Gliner et al., 2016). The results of the homogeneity of variance test were computed using SPSS version 26 for Windows. The sample is regarded as homogeneous if the significance value (sig) is more than 0.05. The homogeneity test results are shown in Table 6.

Table 6. Calculation of the levene homogeneity test based on data

Sig Based on Mean	Information
0.703 > 0.05	Homogen

Based on Table 6, the significance value (Sig.) based on the mean is 0.703, which is greater than the threshold of 0.05. This indicates that the data variances between the groups are homogeneous. Given that both the normality and homogeneity assumptions are satisfied, it is appropriate to proceed with parametric statistical analysis for hypothesis testing.

The hypothesis test was conducted to determine whether there is a significant difference in conceptual understanding between the experimental and control groups. The analysis was based on the posttest mean scores of both groups. Since the data meet the assumptions of normal distribution and equal variance, the Independent Samples t-test was used as the appropriate statistical test. The results of this hypothesis test are presented in Table 7.

Table 7. Parametric Hypothesis Testing: Independent Sample T-test

Independent Sample T-Tes		
		t-test Equality of Means Sig. (2-tailed)
Conceptual understanding	Equal variances assumed	0,00
	Equal variances not assumed	0,00

3.2 Discussion

The findings of this study indicate a statistically significant difference in conceptual understanding between the experimental group taught using the Problem-Based Learning (PBL) model and the control group taught using a cooperative learning model. The independent samples t-test revealed a *p*-value of 0.00 < 0.05, confirming the rejection of the null hypothesis and the acceptance of the alternative hypothesis. With a mean posttest score of 88.54, the experimental group outperformed the control group, which scored an average of 78.72. These results demonstrate that PBL has a positive and significant effect on improving students' understanding of scientific concepts in the basic science course.

This finding aligns with previous research suggesting that PBL enhances students' conceptual understanding by engaging them in active problem-solving and real-world applications (Zahara Syarifah et al., 2021). Unlike traditional methods that emphasize rote memorization, PBL encourages learners to construct meaning through collaboration, exploration, and reflective thinking (Hmelo-Silver, 2004). This model helps students develop the ability to connect theory with practice, analyze problems from multiple perspectives, and develop more robust mental models (Zakaria et al., 2019).

Moreover, this study supports the argument that PBL fosters higher-order thinking skills such as creativity, critical thinking, and problem-solving (Kasuga et al., 2022). These cognitive processes are essential in science education, where students must be able to evaluate evidence, draw conclusions, and apply concepts to new contexts. PBL facilitates this by requiring students to take responsibility for their learning, investigate authentic problems, and collaborate with peers to develop solutions (Yew & Goh, 2016).

Research by Ikstanti and Yulianti (2023) also found that PBL significantly improved students' understanding of scientific content by enabling integrative and meaningful learning experiences. The ability to promote deep learning—learning that is both applicable and enduring—is one of the key strengths of the PBL approach. Similarly, Golightly and Raath (2015) highlighted that when implemented effectively, PBL supports transformative learning that reshapes students' understanding and self-perception as learners.

This study's findings are consistent with evidence from various educational levels. For instance, Djumhana (2017) reported a substantial increase in conceptual understanding among students using PBL, with scores improving from 61.29% to 82.88% across instructional cycles. Wardana et al. (2024) also observed enhanced conceptual mastery among junior high school students through the use of PBL strategies, while Faiza et al. (2023) demonstrated the model's effectiveness in high school science education. These consistent findings across educational stages suggest that PBL is a versatile model that can be successfully adapted to different learning environments.

Despite its advantages, the implementation of PBL is not without challenges. As noted by Colliver (2000), although PBL is often praised for its innovation, empirical evidence regarding its consistent superiority over traditional models remains mixed. One major limitation is the resource-intensive nature of the approach. Effective PBL requires not only time and preparation but also supportive infrastructure, access to appropriate learning materials, and skilled facilitators (Dolmans et al., 2005). Teachers must be well-trained in facilitation techniques, capable of guiding inquiry without overtaking the learning process, which demands a pedagogical shift from directive instruction to learner-centered mentoring.

Furthermore, PBL can impose high cognitive demands on learners, especially those lacking sufficient prior knowledge. According to Kirschner, Sweller, and Clark (2006), minimally guided instructional approaches like PBL may overload working memory, potentially leading to reduced learning effectiveness. Kirschner et al. (2009) extended this critique by highlighting how collaborative problem-solving, when poorly scaffolded, may increase cognitive load rather than reduce it. These findings point to the importance of careful instructional design and gradual scaffolding to support student success in PBL environments.

Another concern relates to assessment practices. As noted by Komariah et al. (2024), traditional assessment tools may not adequately capture learning outcomes such as collaboration, critical thinking, and self-directed learning—skills central to the PBL model. Thus, the development of authentic, performance-based assessments is essential to evaluate the full impact of PBL on student learning. Moreover, Jayanto et al. (2024) emphasized that institutions must provide structured evaluation tools and teacher training to ensure consistent and fair implementation of PBL.

Given these considerations, it is important to acknowledge the limitations of this study. The research was conducted over a short period (three sessions) and focused only on a single topic (static electricity) within a specific academic context. Additionally, the sample was drawn from a single institution, which may limit the generalizability of the findings. Future studies should explore the long-term impact of PBL across broader subjects, different institutions, and varied student populations. Furthermore, mixed-method approaches that integrate quantitative outcomes with qualitative insights (e.g., student reflections, teacher observations) could provide a more comprehensive understanding of PBL's effectiveness.

In conclusion, the results of this study reinforce the value of the PBL model in enhancing students' conceptual understanding in science education. When implemented with adequate support and thoughtful design, PBL offers a powerful means to engage students in meaningful learning and develop the cognitive skills necessary for success in the 21st century. However, institutional readiness, teacher competence, and robust assessment mechanisms remain crucial for the model's sustainable and effective integration into educational practice.

4. CONCLUSION

The results show that the based learning paradigm can improve students' conceptual comprehension skills, which aligns with the study's objectives. Students in the experimental class and the control class had substantially different conceptual understanding skills, as evidenced by the sig (2-tailed) value of 0.00 < 0.05. Following this, there was a larger average difference in the conceptual understanding abilities of the experimental class and the control class. Tests of Problem-Based Learning's (PBL) adaptability across a variety of universities with a wide range of demographic and geographic origins, covering educational levels from elementary school to college, and spanning many disciplines, need more investigation.

Longitudinal study can evaluate the long-term effects on concept understanding and critical thinking skills, while a mixed-methods approach will provide a thorough knowledge of its effectiveness. The study may use educational technology to examine implementation challenges and evaluate the effect of digital platforms or gamification on PBL success. PBL can be adjusted to fit the needs of different circumstances thanks to the global viewpoint provided by cross-cultural study in different educational systems.

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