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Problem-Based Learning for Physics Conceptual Understanding: A Quasi-Experimental Study of Pressure and Static Electricity

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Abstract

Conceptual understanding of physics is essential for explaining natural phenomena, yet students often experience difficulties understanding pressure and static electricity. This study examined the effect of Problem-Based Learning (PBL) on junior high school students' conceptual understanding of these topics. A quasi-experimental pretest–posttest control-group design involved 65 eighth-grade students from SMP Negeri 14 Ambon: 33 in the experimental group and 32 in the control group. The experimental group received PBL instruction, whereas the control group received conventional instruction. The intervention duration should be specified according to the actual number of meetings and instructional time. Students' conceptual understanding was measured using a conceptual-understanding test. Analysis of covariance (ANCOVA) compared posttest scores while controlling for pretest scores. The results indicated a statistically significant group effect, $F(1, 62) = 4.567$, $p = .037$, partial $\eta^2 = .069$, subject to verification against the original statistical output. The effect size indicates that group membership accounted for approximately 6.9% of the adjusted variance in posttest scores. However, statistical significance alone does not establish which group performed better; the adjusted group means must be checked to determine the direction of the difference. Therefore, the findings are interpreted in relation to conceptual understanding only and do not support claims about critical thinking, communication, collaboration, problem-solving, or other outcomes that were not directly measured. This study contributes evidence relevant to evaluating PBL for teaching pressure and static electricity in junior high school science.

Keywords: Problem-Based Learning; Conceptual Understanding; Physics Education; Pressure; Electrostatics

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INTRODUCTION

Physics is one of the fundamental branches of science that plays a strategic role in supporting a country's economic growth. Its contribution is reflected in its capacity to drive innovation, foster technological advancement, and enhance the competitiveness of various industrial sectors. In the United Kingdom, for example, physics-based industries employed more than 2.33 million full-time workers in 2019. This represented nearly 86% of the total workforce in the UK's physics sector and accounted for approximately 10.1% of total national employment. Furthermore, employment in physics-related industries grew at an average annual rate of 1.4% (IOP, 2021). Physics also plays a crucial role in societal development across numerous fields. In electronics, for instance, advances in physics have enabled the development of transistors, diodes, and integrated circuits (ICs), which serve as the foundation for radio transmitters and receivers, televisions, audio devices, and many other electronic technologies. Likewise, modern medical equipment, such as X-ray imaging systems, has been developed through the application of fundamental principles of physics (Abubakar, 2012). Despite its

substantial contributions to scientific and technological development, physics as an academic discipline has not received adequate attention in Ethiopia (Shishigu et al., 2018). Several studies have reported that students' interest in learning physics remains relatively low (Semela, 2010; Argaw et al., 2017).

This lack of interest is reflected in the limited number of students who choose physics as their field of study at colleges and universities. Moreover, students admitted to physics programs generally come from lower academic achievement groups. One factor contributing to this situation is the limited employment opportunities available to physics graduates outside the teaching profession (Semela, 2010). At teacher education institutions, such as Bonga College of Teacher Education—the site of the present study—all graduates are prepared to pursue careers as educators. Nevertheless, enrollment in mathematics and science education programs remains lower than that in many other academic disciplines. This suggests that attracting students to physics-related fields continues to be a significant challenge, even within institutions specifically established to prepare future science teachers. The declining interest in studying physics is not unique to Ethiopia but has also become a concern in many countries worldwide. Osborne et al. (2003) reported a downward trend in both enrollment and graduation rates in physics across various educational levels in the United States, the United Kingdom, Germany, and the Netherlands. These findings indicate that the declining interest in physics represents a global educational challenge requiring serious attention from policymakers, educators, and other stakeholders. Similar findings have also been reported in Ethiopia, where many students experience difficulties in understanding complex physics concepts, resulting in poor academic performance and low achievement. These learning difficulties substantially influence students' decisions when selecting their academic majors, contributing to the declining interest in physics as a field of study (Abuna et al., 2026).

In modern education, one of the primary goals of instruction is to develop individuals who are capable of acquiring knowledge, understanding scientific concepts, and applying them to solve real-world problems. Achieving this objective largely depends on the quality of the learning environment, which should support students in constructing and internalizing new knowledge by building upon their prior understanding (Şenyiğit, 2021). Students acquire knowledge and develop their understanding of natural phenomena through learning experiences in both formal and informal educational settings (Soeharto et al., 2019). However, their prior knowledge is not always consistent with scientifically accepted concepts (Duit, 2003). A substantial body of research has shown that students frequently hold non-scientific conceptions across various science topics, including electric circuits (Peşman & Eryilmaz, 2010; Tahir et al., 2020), force and motion (Azita & Mora, 2015; Anggoro et al., 2019), plane mirrors (Harman & Yenikalayci, 2022), and the concepts of temperature and heat (Alwan, 2011). These alternative conceptions often persist despite formal instruction and present significant obstacles to meaningful learning. One of the major factors contributing to students' difficulties in understanding physics concepts is the discrepancy between scientifically accepted concepts and their existing prior knowledge. Scientific concepts frequently differ from, or even contradict, the intuitive beliefs and explanations that students develop through their everyday interactions with the physical world (Carey, 2000; Savion, 2009). As a result, students enter the classroom with a wide range of preconceptions that may hinder their acceptance of scientific explanations presented by teachers. Consequently, they may reject or disregard these explanations, or construct hybrid conceptions that combine elements of scientific and intuitive reasoning but remain inconsistent with scientifically accepted principles (Lichtenberger et al., 2025).

Physics education aims not merely to help students memorize physical laws and equations, but also to develop their ability to construct coherent conceptual understandings and use scientific models to explain and predict physical phenomena. Accordingly, physics instruction should emphasize consistent relationships among concepts, mathematical

representations, and observable phenomena, enabling students to understand the underlying physical meaning rather than simply perform mathematical procedures (Hestenes, 1987; Wells et al., 1995). Conceptual understanding enables learners to identify relationships among variables, interpret evidence, and apply principles when they encounter unfamiliar situations. In this sense, success in physics cannot be judged solely by students' ability to substitute values into formulas or reproduce worked examples (Chase et al., 2019). Learners also need to explain why a relationship holds, identify the conditions under which it applies, and connect symbolic representations with observable phenomena (Batlolona, 2025). Recent research in physics education continues to show that conceptual understanding requires explicit attention in instruction and assessment, rather than being assumed from procedural performance alone (Lichtenberger et al., 2024; Batlolona et al., 2024). This distinction is particularly important in school physics, where students are expected to use abstract principles to interpret observable events rather than rely exclusively on memorized definitions or formulas (Gjerde et al., 2021). Conceptual understanding therefore provides a meaningful basis for evaluating whether instruction supports transferable learning (Mestre, 2002). One persistent challenge is that students enter science classrooms with prior ideas developed through everyday experience, informal explanations, and earlier learning (Vosniadou, 2007). These ideas may be useful in familiar situations but can conflict with accepted scientific explanations. When learners rely on such alternative conceptions, they may misinterpret a physical event and misunderstand the relationships among the concepts used to explain it (Kotsis, 2023). Research on physics learning has therefore examined not only the incorrect answers students give but also the reasoning and conceptual resources underlying those answers. For example, recent work on electric circuits has shown that students' ideas are diverse and context-dependent, suggesting that instruction should elicit and build on learners' thinking rather than treating all errors as identical (Bauman et al., 2024). These ideas are not always arbitrary errors; they may be reasonable interpretations based on everyday experiences, although they do not fully align with accepted scientific explanations. For this reason, instruction needs to make students' initial reasoning visible and provide opportunities to examine the strengths and limitations of their explanations (Vosniadou, 2019).

These difficulties become particularly pronounced when understanding physical phenomena requires students to integrate interrelated concepts rather than merely recall definitions or equations. For example, understanding pressure requires students to explain how force and surface area determine pressure in solids and how depth and fluid density influence hydrostatic pressure. Research has documented persistent misconceptions about hydrostatic pressure, indicating that students may struggle to apply fundamental principles consistently across different physical contexts (Wijaya et al., 2016). Similarly, understanding static electricity requires students to distinguish electric charge from other properties of matter and explain how charge transfer and redistribution account for electrical attraction and repulsion. Previous research has demonstrated that students may retain misconceptions about static electricity, while conceptual change-oriented instruction can improve their understanding of these concepts (Başer & Geban, 2007). Taken together, these findings indicate that difficulties in learning physics involve more than recalling factual information; they also reflect challenges in establishing coherent relationships among concepts to construct scientifically accurate explanations of physical phenomena. Therefore, diagnosing and addressing students' prior conceptions is essential for promoting conceptual restructuring and enabling students to apply scientific principles consistently across different physical contexts. Conceptual change involves more than replacing an incorrect answer with a scientifically accepted one; it requires learners to examine their initial explanations, evaluate them against empirical evidence, identify inconsistencies, and construct more scientifically adequate explanatory models. In physics education, this process requires an understanding of how students organize and use their existing knowledge, including the intuitive resources that may support the development

of more sophisticated conceptual reasoning. A resources-oriented analysis of students' explanations of electric circuits illustrates the importance of examining the reasoning underlying students' responses rather than evaluating their understanding solely in terms of correctness or incorrectness (Bauman et al., 2024). These findings highlight the need for instructional practices that make students' thinking explicit and provide structured opportunities to critically evaluate and revise their explanations. Such conceptual development requires sufficient time, purposeful feedback, and opportunities to compare alternative explanations against relevant evidence. By articulating the reasoning behind their answers and revising their interpretations in response to evidence, students can develop more coherent scientific understanding rather than merely replacing one memorized statement with another.

Concepts constitute the fundamental building blocks of knowledge in every scientific discipline. Therefore, strong conceptual understanding is essential for enabling students to develop well-organized knowledge structures, apply concepts accurately in problem-solving, and acquire the competencies and expertise required within their respective fields of study (Streveler et al., 2008). Nevertheless, misconceptions and conceptual misunderstandings remain prevalent, particularly among novice learners. Such misconceptions often lead to fragmented or inaccurate knowledge structures, which in turn negatively affect academic achievement and problem-solving performance across various disciplines (Liu & Fang, 2016). The presence of concepts that are inconsistent with scientifically accepted explanations can hinder the development of accurate conceptual understanding. Consequently, the influence of misconceptions must be minimized to ensure that learning objectives are achieved effectively. However, reconstructing incorrect understandings into scientifically accurate concepts is neither straightforward nor automatic. Conceptual change refers to the process of revising or replacing misconceptions, allowing students to develop a deeper and more scientifically accurate understanding of a concept (Siantuba et al., 2023; Kotsis, 2024; El Fathi et al., 2025). Therefore, identifying and addressing misconceptions is a crucial step in helping students construct valid scientific knowledge (Leinonen et al., 2013). Selain itu, kesalahpahaman dalam satu atau lebih konsep dasar dapat memiliki efek berantai pada pemahaman siswa tentang fisika. When students hold misconceptions about the concepts used to explain a physical phenomenon, they tend to misinterpret not only the phenomenon itself but also the relationships among the underlying concepts (Bozkurt & Yıldırım, 2022). This highlights the importance of instructional approaches that actively facilitate conceptual change and support students in reconstructing their existing knowledge in accordance with scientific principles.

Instructional approaches that rely solely on traditional lecture-based teaching have been shown to be ineffective in addressing students' misconceptions (Chen et al., 2020; Martin-Alguacil et al., 2024). In other words, when physics is taught primarily through conventional teacher-centered methods, students often struggle to connect newly acquired concepts with real-life phenomena. Consequently, more effective instructional strategies are needed to facilitate conceptual change and promote meaningful learning. One instructional approach that has demonstrated considerable potential in addressing these challenges is Problem-Based Learning (PBL). Through PBL, students are encouraged to critically examine the validity of their existing conceptions and revise them whenever they are found to be inconsistent with scientifically accepted explanations. Moreover, PBL provides opportunities for students to construct knowledge systematically through inquiry, investigation, and problem-solving processes grounded in the scientific method. As a result, this approach is considered highly effective in fostering deeper conceptual understanding and supporting lasting conceptual change. The effectiveness of PBL in promoting conceptual change can be explained by its emphasis on active learning. Rather than passively receiving information, students engage in authentic investigations and experiments that require them to explore scientific concepts independently and collaboratively (Batlolona et al., 2019; Rachman et al., 2026). This learning process encourages students to question their prior knowledge, evaluate evidence, and refine

their understanding through scientific reasoning. Consequently, PBL promotes critical thinking, problem-solving abilities, and deeper engagement with the subject matter, leading to stronger conceptual understanding and improved long-term retention of scientific principles (Leasa et al., 2023).

Previous studies have demonstrated that the implementation of PBL enhances teamwork, presentation skills, and critical thinking in physics education. In contrast, traditional instructional methods have been found to be more effective in promoting independent learning and strengthening students' mastery of theoretical physics concepts. Conventional instruction may also be more appropriate when learning outcomes are primarily assessed through closed-ended examinations (Marcinauskas et al., 2024). Beyond improving conceptual learning, PBL has been shown to foster critical thinking, problem-solving, communication skills, and lifelong learning competencies (Ali, 2019). This approach requires students to examine problems from multiple perspectives and communicate their ideas effectively through both oral and written forms. Another notable advantage of PBL is its use of small cooperative learning groups, which provide opportunities for all students to actively participate in discussions, exchange ideas, and express diverse viewpoints (Almagribi et al., 2024). Problem-Based Learning is widely recognized as an effective instructional strategy for achieving intended learning outcomes. Its effectiveness is supported by three key components: the presentation of challenging and authentic problems, collaborative learning in small groups, and the sharing of knowledge among students. Through these elements, PBL creates learning experiences that stimulate higher-order thinking, reinforce understanding of fundamental concepts, and increase students' confidence in discussing and defending their ideas (Almasarweh & Khudairat, 2021; Xie et al., 2026). Furthermore, PBL is regarded as a student-centered instructional approach that emphasizes reflection throughout the learning process. Students actively engage in solving real-world problems by following systematic inquiry and problem-solving procedures (Abeysuriya et al., 2026). In addition to improving academic achievement, PBL contributes significantly to the development of students' social competencies. PBL classrooms create authentic opportunities for communication and collaboration, enabling students to strengthen their interpersonal and social skills (Saleh et al., 2022).

Through these experiences, students are expected to develop more effective interpersonal communication, greater self-directed learning abilities, and enhanced competence in solving complex problems (Schmidt et al., 2006). Moreover, PBL is implemented through collaborative work in small groups focused on solving contextual problems, complemented by independent learning activities. This combination enables students to develop the professional competencies required throughout their higher education and future careers (Saqr et al., 2020). Although PBL has been examined in science and physics education, evidence from a particular topic or student population cannot automatically be generalized to other settings. Studies of conceptual reasoning also indicate that students' explanations can vary with the context of a question, reinforcing the need for focused empirical comparisons. A relevant gap is therefore the need to examine whether PBL is associated with differences in junior high school students' understanding of both pressure and static electricity, compared with conventional instruction, while accounting for students' initial performance. Addressing this gap can provide context-specific evidence for teachers deciding how to structure physics lessons and how to use contextual problems to address students' conceptual difficulties. In particular, findings from other educational settings cannot automatically be generalized to every school context, because students' prior knowledge, classroom practices, and opportunities to engage with scientific ideas may differ. Evidence from the present setting can therefore contribute context-specific information while helping identify questions for further research on PBL in school physics. Therefore, this study aims to investigate the effect of Problem-Based Learning on junior high school students' conceptual understanding of physics, particularly in the topics of pressure and static electricity.

METHOD

Research Design

This study employed a quantitative approach using a quasi-experimental design to examine the effect of PBL on students' conceptual understanding of physics. A quasi-experimental method was selected because random assignment of individual participants was not feasible; therefore, existing classroom groups were used as the research samples. The study adopted a pretest–posttest control group design, involving two groups: an experimental group, which received instruction through the PBL model, and a control group, which received conventional teacher-centered instruction. Prior to the intervention, both groups completed a pretest to assess their initial conceptual understanding and to establish baseline equivalence for subsequent comparisons. During the intervention, the experimental group participated in learning activities based on the PBL instructional framework, which emphasizes solving authentic contextual problems through inquiry, collaborative discussion, investigation, and reflection. In contrast, the control group received conventional instruction that primarily focused on teacher explanations and direct knowledge transmission. Upon completion of the instructional intervention, both groups were administered a posttest using the same instrument as the pretest to measure students' conceptual understanding after the treatment. The differences in posttest performance between the two groups, while controlling for students' initial conceptual understanding, were used to evaluate the effectiveness of PBL in improving students' conceptual understanding of physics.

Population and Sample

The population of this study consisted of all eighth-grade students at SMP Negeri 14 Ambon during the academic year in which the study was conducted. The population comprised 10 classes, all of which studied pressure and static electricity in accordance with the prescribed curriculum. The sample was selected using a cluster random sampling technique, in which intact classes rather than individual students were selected randomly. This technique was appropriate because students had already been assigned to classes by the school, making individual random assignment impractical. From the 10 available classes, two classes were randomly selected to participate in the study. One class, consisting of 33 students, was assigned to the experimental group, while the other class, consisting of 32 students, served as the control group, resulting in a total sample of 65 students. The experimental group received instruction using the PBL model, whereas the control group received conventional instruction. Both groups studied the same physics topics under comparable curricular conditions. This sampling procedure enabled a comparison of students' conceptual understanding between the two instructional approaches while maintaining the existing classroom structure.

Research Instrument

The instrument used in this study was a researcher-developed physics conceptual understanding test consisting of 20 multiple-choice items, comprising 10 items on pressure and 10 items on static electricity. The items were developed based on the learning outcomes and conceptual indicators for both topics, including the identification of relevant physical quantities, understanding of conceptual relationships, application of physics principles, and interpretation of physical phenomena. The test blueprint and complete instrument are provided as supplementary materials. The assessment followed the dichotomous scoring principles of the Force Concept Inventory (FCI) developed by Hestenes et al. (1987). The FCI is a multiple-choice conceptual assessment designed to identify students' understanding of force and motion based on Newtonian mechanics and their intuitive beliefs that may conflict with Newtonian concepts. Each correct response received one point, whereas incorrect or unanswered items received zero points. Total scores ranged from 0 to 20 and were converted into percentages. Although the scoring principles were informed by the FCI, the present instrument was not the original FCI because it assessed pressure and static electricity rather than force and motion.

Content validity was evaluated by three experts, comprising two physics education experts and one pure physics expert. The experts assessed the relevance of the items to the learning objectives, the accuracy of the physics content, the clarity of the questions, and their alignment with the conceptual indicators. Following expert review, the instrument was pilot-tested with students who had characteristics similar to those of the main research participants but were not included in the study sample. The pilot test was intended to examine item validity, difficulty, discrimination, and internal consistency. Items were retained or revised according to the established assessment criteria and the results of the instrument evaluation. The same instrument was administered as both the pretest and posttest to examine changes in students' conceptual understanding following the implementation of the PBL model. Reusing the same items may introduce testing or recall effects. This potential limitation should be considered when interpreting the findings. Parallel test forms were not reported as part of the study procedures. Furthermore, misconceptions were interpreted only when supported by distractors designed to represent alternative conceptions and by analysis of students' response patterns. Otherwise, the results were interpreted as measures of conceptual understanding rather than definitive diagnoses of misconceptions.

Research Procedure

The research procedure was carried out through a series of systematically designed stages to ensure alignment with the study objectives. The initial stage involved a preliminary study to identify problems in physics instruction, particularly those related to pressure and static electricity. Subsequently, the researchers developed the instructional materials, including lesson plans, teaching materials, student worksheets, and a physics conceptual understanding test. All instructional materials and research instruments were evaluated by experts to assess their content, construct, and language appropriateness. Based on the validators' feedback, the materials and instruments were revised before implementation. Before the intervention, both the experimental and control groups completed a pretest to assess their initial conceptual understanding of physics. The pretest scores were subsequently used as a covariate in the statistical analysis. Following the pretest, the experimental group received instruction using the PBL model, which followed five instructional phases: orienting students to the problem, organizing students for learning, assisting independent and group investigation, developing and presenting work, and analyzing and evaluating the problem-solving process (Arends, 2015). Students explored contextual problems related to pressure and static electricity, worked collaboratively to plan and conduct investigations, gathered and analyzed relevant information, presented their findings, and reflected on their problem-solving processes. Throughout these activities, the teacher acted as a facilitator who guided students in developing evidence-based explanations and constructing physics concepts, consistent with the student-centered principles of PBL. In contrast, the control group received conventional instruction based on six instructional stages: (1) reviewing previously learned material; (2) presenting new material; (3) providing guided practice; (4) giving feedback and correcting errors; (5) providing independent practice; and (6) conducting periodic reviews (Rosenshine, 1995). In the lessons on pressure and static electricity, the teacher reviewed prior knowledge, explained new concepts and relevant formulas, demonstrated worked examples, guided students through exercises, provided corrective feedback, and assigned independent practice and review activities (Rosenshine & Stevens, 1986). Both groups studied the same physics topics and received the same number of class meetings and equivalent instructional time to support a fair comparison of the two instructional approaches. Upon completion of the intervention, both groups took a posttest using the same instrument administered at pretest. The pretest and posttest scores were compiled and analyzed using Analysis of Covariance (ANCOVA), with the pretest score as the covariate, to examine differences in students' conceptual understanding between the PBL and conventional instruction groups.

Data Analysis

The data collected in this study were analyzed quantitatively using IBM SPSS Statistics Version 16. Data analysis was conducted in several stages to assess the statistical assumptions before hypothesis testing. The first stage involved descriptive statistical analysis to summarize the characteristics of the research data. Descriptive statistics included the mean, maximum score, minimum score, and standard deviation of the pretest and posttest scores for the experimental and control groups. This analysis provided an overall description of students' conceptual understanding before and after the instructional intervention. Before conducting inferential statistical analyses, the assumptions underlying analysis of covariance (ANCOVA) were examined. Normality was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests, supplemented by residual histograms, normal Q–Q plots, skewness, and kurtosis. Levene's test was used to assess the homogeneity of error variances between the experimental and control groups. Additional diagnostics examined the linearity between pretest and posttest scores, homogeneity of regression slopes, independence of observations, and potential outliers or influential cases. The reliability and suitability of the pretest scores as a covariate were also considered. The research hypotheses were tested using one-way analysis of covariance (ANCOVA). This statistical technique was selected to examine differences in students' conceptual understanding between the instructional groups while controlling for differences in their prior knowledge. In the ANCOVA model, the posttest score served as the dependent variable, the instructional condition PBL versus conventional instruction) was treated as the independent variable, and the pretest score was included as the covariate. By statistically adjusting for students' initial conceptual understanding, ANCOVA enabled a comparison of posttest outcomes between the experimental and control groups.

Hypothesis testing was conducted at a significance level of $\alpha = 0.05$. The null hypothesis was rejected when the p-value was less than 0.05, indicating a statistically significant difference in adjusted posttest scores between the two instructional groups. The results were reported using the F statistic, degrees of freedom, exact p-value, and partial eta squared (η^2_p). The unadjusted pretest and posttest means and standard deviations, as well as the adjusted posttest means, standard errors, and 95% confidence intervals, were reported to clarify baseline performance, the direction of the group differences, and the precision of the estimated effect. In addition to statistical significance, partial eta squared (η^2_p) was calculated to estimate the magnitude of the instructional-group effect within the ANCOVA model. The effect size was interpreted cautiously by considering the adjusted mean difference, its 95% confidence interval, and the potential educational relevance of the findings. Statistical significance alone was not considered sufficient evidence of educational importance. Given the quasi-experimental design, potential baseline differences and threats to internal validity were considered when interpreting the findings. If each instructional condition involved only one intact class, the potential confounding of class membership and instructional condition was acknowledged as a limitation when interpreting the effectiveness and generalizability of PBL (Cohen, 1988).

RESULTS AND DISCUSSION

The results of this study begin with the presentation of the assumption tests conducted to ensure that the data satisfied the statistical requirements prior to hypothesis testing. The prerequisite analyses included the homogeneity of variance test using Levene's Test and the normality test using the Kolmogorov–Smirnov test. After these assumptions were verified, the research hypotheses were tested using Analysis of Covariance (ANCOVA) to examine the effect of PBL on students' conceptual understanding of physics while controlling for differences in their prior knowledge. The results of the homogeneity of variance test are presented in Table 1. The results of this study are presented through a sequence of preliminary statistical analyses and hypothesis testing. First, assumption checks were conducted to assess

whether the data met the requirements for the planned analysis of covariance (ANCOVA). These checks included the homogeneity of error variances, examined using Levene's test, and the normality of the ANCOVA residuals, examined using the Shapiro–Wilk test. After presenting these diagnostic results, ANCOVA was used to examine whether students' posttest conceptual-understanding scores differed between the Problem-Based Learning (PBL) and conventional-instruction groups while controlling for their pretest scores. The results of each analysis are presented in a separate table, followed by an explanation of the relevant statistical findings. The homogeneity of error variances was examined using Levene's test for the posttest conceptual-understanding scores. The results are presented in Table 1.

Table 1. Levene's Test of Equality of Error Variances

Dependent variable	F	df1	df2	p
Posttest conceptual understanding	1.387	1	63	.243

As shown in Table 1, Levene's test was not statistically significant, $F(1, 63) = 1.387$, $p = .243$. Because the p-value was greater than .05, there was no statistically significant evidence of unequal error variances between the instructional groups. Therefore, the homogeneity-of-variance assumption was considered acceptable based on this test. The normality of the ANCOVA residuals was then assessed using the Shapiro–Wilk test. This test was used to evaluate whether the residual distribution showed a statistically significant departure from normality. The results are presented in Table 2.

Table 2. Shapiro–Wilk Normality Test for ANCOVA Residuals

Residual variable	W	df	p
ANCOVA residuals	.971	65	.134

As shown in Table 2, the Shapiro–Wilk test was not statistically significant, $W = .971$, $p = .134$. Since the p-value exceeded the .05 significance level, the null hypothesis of normality was not rejected. Thus, the ANCOVA residuals did not show a statistically significant deviation from a normal distribution according to this test. This result should also be considered alongside graphical inspection of residuals and the other assumptions required for ANCOVA. The descriptive statistics were analyzed to provide an overview of students' conceptual understanding of physics following the instructional intervention. The analysis focused on the posttest scores of the experimental group, which received PBL and the control group, which received conventional instruction. The mean, standard deviation, and number of students in each group are presented in Table 3.

Table 3. Descriptive Statistics of Students' Conceptual-Understanding Scores

Group	Test	N	Mean	SD
Experimental	Pretest	33	42.83	13.44
	Posttest	33	68.28	8.35
Control	Pretest	32	39.79	14.22
	Posttest	32	58.75	10.77

Following the assumption checks, ANCOVA was conducted to examine the effect of instructional group on posttest conceptual understanding while controlling for pretest scores. The posttest score was treated as the dependent variable, instructional group (PBL or conventional instruction) as the independent variable, and pretest score as the covariate. The ANCOVA results are presented in Table 4.

Table 4. ANCOVA for Posttest Conceptual Understanding

Source	Type III SS	df	MS	F	p	Partial η^2
Corrected model	3271.994	2	1635.997	22.059	< .001	.416
Pretest score	1736.663	1	1736.663	23.416	< .001	.274
Instructional group	338.712	1	338.712	4.567	.037	.069
Error	4598.221	62	74.165	—	—	—
Corrected total	7870.215	64	—	—	—	—

Note. Dependent variable: posttest conceptual understanding. $R^2 = .416$; adjusted $R^2 = .397$.

H_0 : The PBL model has no significant effect on junior high school students' conceptual understanding of physics compared with conventional instruction.

H_1 : The PBL model has a significant effect on junior high school students' conceptual understanding of physics compared with conventional instruction.

From Table 4, it can be seen that the significance value for the class effect is 0.037, which is lower than the significance level of $\alpha = 0.05$. Therefore, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_a) is accepted. This indicates that there is a statistically significant difference in the conceptual understanding of junior high school students who were taught using the PBL model compared with those who received conventional instruction. In other words, the findings demonstrate that the PBL model has a significant positive effect on students' conceptual understanding of physics. These findings suggest that successful physics learning is determined not only by the amount of content delivered by the teacher but also by the extent to which students actively construct their own knowledge throughout the learning process. In conventional instruction, physics concepts are typically introduced through teacher explanations followed by practice exercises. Such an instructional approach tends to position students as passive recipients of information, thereby providing limited opportunities for them to examine, revise, and refine their conceptual understanding. In contrast, PBL offers a fundamentally different learning experience by engaging students with authentic, real-world problems from the outset. Throughout the learning process, students are required to identify the information needed to solve the problem, connect relevant scientific concepts, evaluate alternative solutions, and draw conclusions based on the evidence they have gathered. These learning activities encourage students to actively construct rather than merely memorize scientific concepts, resulting in deeper and more meaningful conceptual understanding. This finding is consistent with the work of Wijnia et al. (2024), who argue that **PBL** is a student-centered instructional approach in which learning occurs through independent inquiry, critical analysis, and systematic problem-solving activities.

The PBL model is characterized by several interrelated components. First, the learning process begins with the presentation of an authentic contextual problem designed to activate students' prior knowledge while simultaneously stimulating their interest in learning. For example, in the topic of pressure, students may be asked to explain why shoes with wide soles are more comfortable for walking on sand than high-heeled shoes, or why the base of a dam is constructed thicker than its upper sections. Similarly, in the topic of static electricity, students may investigate why hair stands on end after being rubbed with a balloon or why lightning is more likely to strike tall buildings. These real-world problems serve as the starting point for students to identify the physics concepts required to explain and solve the phenomena. Second, learning is centered on students' active participation, enabling them to construct knowledge through inquiry, information gathering, simple experiments, collaborative discussions, and evidence-based reasoning. Rather than passively receiving information, students actively investigate scientific phenomena and develop conceptual understanding through the process of discovery. Third, learning takes place through collaboration in small groups, typically consisting of five to twelve students, allowing participants to exchange ideas, test hypotheses,

evaluate evidence, and collectively construct conceptual understanding. Such collaborative interactions promote deeper learning by encouraging students to articulate, defend, and refine their scientific reasoning. Fourth, the teacher serves as a facilitator rather than the primary source of knowledge. In this role, the teacher provides guidance, poses thought-provoking questions, monitors students' progress, and offers support whenever difficulties arise during the inquiry process, while allowing students to maintain responsibility for their own learning. Finally, students are provided with sufficient opportunities for self-directed learning, enabling them to explore concepts related to pressure and static electricity in greater depth before presenting and discussing their findings with other groups. This combination of contextual problem-solving, collaborative inquiry, guided facilitation, and independent learning constitutes the core of the PBL approach and contributes to the development of meaningful conceptual understanding (Barrows, 1996; Hmelo-Silver, 2004; Schmidt et al., 2009).

The problems used in PBL can be presented in a variety of formats, including case studies, narratives, visual illustrations, experimental demonstrations, and natural phenomena that require scientific explanation (Barrows, 1996). For example, in the topic of pressure, teachers may present a case involving a diver experiencing changes in water pressure at different depths or the operation of a hydraulic jack used to lift a vehicle. In the topic of static electricity, students may be asked to investigate phenomena such as lightning, photocopying machines, electrostatic painting, or the interactions between electrically charged objects commonly encountered in everyday life. These problems are designed with an appropriate level of complexity to challenge students' thinking and encourage them to connect physics concepts with authentic real-world situations. When supported by effective teacher facilitation, such contextual problems can enhance students' self-confidence, engagement, learning motivation, and problem-solving abilities (Belland et al., 2013). Therefore, the implementation of PBL in teaching the topics of pressure and static electricity not only helps students develop a deeper understanding of physics concepts but also promotes the development of essential 21st-century skills, including critical thinking, collaboration, communication, and problem-solving. These competencies enable students to apply scientific knowledge more effectively in explaining and addressing real-world phenomena.

The improvement in students' conceptual understanding observed in this study can also be explained by the conceptual change process that occurs during the implementation of PBL. One of the major challenges in physics education is that students often enter the classroom with misconceptions formed prior to formal instruction. These prior conceptions are frequently derived from everyday experiences and intuitive reasoning, which do not always correspond to scientifically accepted explanations. Under conventional instruction, such misconceptions often persist because students primarily receive new information without sufficient opportunities to examine whether their existing understanding is scientifically accurate. In contrast, PBL deliberately creates learning situations that promote conceptual change. The contextual problems presented by the teacher generate cognitive conflict, as students' intuitive explanations are often insufficient to account for the observed phenomena. This cognitive disequilibrium motivates students to seek additional evidence, discuss their ideas with group members, critically evaluate alternative explanations, and revise their existing conceptions whenever inconsistencies are identified. Such a process represents the core mechanism of conceptual change, enabling students to construct more accurate and scientifically valid understandings. Conceptual change involves more than the acquisition of new information; it requires learners to critically reconsider and reorganize their existing knowledge in light of new evidence and meaningful learning experiences. From this perspective, changes in students' conceptual understanding should not be attributed merely to the adoption of PBL as an instructional model. Instead, such changes may be understood as the outcome of learning experiences that encourage students to examine their initial conceptions, confront

inconsistencies in their thinking, and reconstruct their understanding in accordance with scientifically accepted explanations (Jamaludin & Batlolona, 2021).

PBL can promote students' conceptual understanding by positioning them as active participants in the construction of scientific knowledge. Through engagement with contextual problems, students are encouraged to investigate phenomena, identify relevant principles, evaluate evidence, and develop explanations that connect theoretical concepts with observable experiences. This process enables students to move beyond memorizing definitions and equations toward understanding the relationships underlying physical phenomena. In particular, PBL provides opportunities for students to examine their initial conceptions, identify inconsistencies in their reasoning, and refine their explanations through investigation and discussion. Yew & Goh (2016) highlighted the potential of PBL to support knowledge application and longer-term retention, emphasizing the importance of the learning process rather than the mere presentation of information. Evidence from physics education also supports this perspective. Kanyesigye et al. (2022), in a study involving 239 students from 19 secondary schools, found that problem-based instruction improved students' understanding of several mechanical-wave concepts, including wave propagation, reflection, and standing waves, although the results varied across concepts. This finding suggests that the contribution of PBL to conceptual learning may depend partly on the specific concepts being taught and the difficulties students experience. A systematic review by Nicholus et al. (2023) likewise reported generally positive contributions of PBL to physics learning outcomes across the studies reviewed, including conceptual understanding and academic achievement. Together, these studies provide a relevant basis for interpreting the present findings: PBL may support conceptual development by engaging students in contextual inquiry, evidence-based reasoning, and the active construction of explanations.

In addition to improving individual conceptual understanding, PBL strengthens the learning process through meaningful social interaction among students. During group discussions, each member has the opportunity to express ideas, provide scientific reasoning, critically evaluate peers' arguments, and collaboratively identify the most appropriate solutions to the problems presented. These interactions create a dynamic learning environment in which students learn not only from the teacher but also through the exchange of ideas and perspectives with their peers. When differences of opinion arise, students are encouraged to seek stronger evidence to support their claims, thereby improving the quality of their scientific reasoning and argumentation. Furthermore, explaining concepts to others helps students clarify and reorganize their own knowledge structures. Consequently, group discussions function not only as a means of communication but also as an effective mechanism for deepening conceptual understanding. PBL fosters authentic communication among students, making collaborative learning more meaningful while simultaneously promoting self-directed learning, interpersonal communication, and problem-solving skills that collectively contribute to the development of academic competence (Markula & Aksela, 2022). Therefore, physics instruction should no longer focus solely on solving numerical problems. Instead, it should provide students with broader opportunities to explore scientific phenomena, formulate questions, develop hypotheses, conduct investigations, and construct scientific explanations based on empirical evidence. Through such learning experiences, students not only arrive at correct answers but also develop a clear understanding of the scientific principles underlying those answers. This ability is a key indicator of deep conceptual understanding and equips students to apply physics concepts effectively in a variety of contexts and real-world situations. Accordingly, Problem-Based Learning represents an effective alternative instructional strategy for enhancing the quality of physics education, particularly in topics that involve highly abstract concepts and are prone to generating misconceptions. Its emphasis on inquiry, collaboration, and evidence-based reasoning enables students to develop scientifically accurate conceptual understanding

while acquiring the higher-order thinking skills required for learning and problem-solving in the twenty-first century.

CONCLUSION

This study concludes that the implementation of PBL has a positive effect on students' conceptual understanding of physics, particularly in the topics of pressure and static electricity. By initiating learning with authentic contextual problems, students are encouraged to identify problems, conduct investigations, engage in collaborative discussions, and construct knowledge based on the evidence they obtain. This learning process enables students to develop a deeper conceptual understanding than that achieved through conventional teacher-centered instruction. In addition to enhancing conceptual understanding, the implementation of PBL provides more meaningful learning experiences by actively engaging students throughout the learning process. Such active participation promotes the development of critical thinking, scientific communication, collaboration, and problem-solving skills, all of which are essential competencies for physics learning in the twenty-first century. Therefore, PBL can be considered an effective instructional strategy for helping students develop a more comprehensive understanding of physics concepts while reducing the likelihood of misconceptions. The findings of this study are expected to serve as a valuable reference for educators in designing more innovative, student-centered physics instruction that effectively connects scientific concepts with phenomena encountered in everyday life.

RECOMMENDATION

PBL is recommended as an effective alternative instructional strategy for physics education to help students develop a deeper conceptual understanding, particularly in topics that are abstract and prone to misconceptions. To maximize its effectiveness, teachers should design authentic and contextually relevant problems, provide opportunities for students to conduct both independent and collaborative investigations, and facilitate discussions and reflective activities that promote the construction of scientifically accurate concepts. Furthermore, learning environments that are active and student-centered should be continuously fostered so that instruction not only emphasizes content mastery but also cultivates critical thinking, communication, collaboration, and problem-solving skills. For future research, it is recommended that the effectiveness of PBL be investigated across a wider range of physics topics, different educational levels, and more diverse student populations to provide a more comprehensive evaluation of the model's effectiveness. Future studies may also explore the integration of PBL with other innovative instructional approaches and digital technologies to gain broader insights into effective strategies for enhancing the quality of physics education. In addition, employing more diverse research designs, such as mixed-methods or longitudinal studies, is recommended to provide a deeper understanding of how students develop conceptual understanding over time and to examine the long-term impact of Problem-Based Learning on students' learning outcomes and conceptual development.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
John Rafafy Batlolona	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Jamaludin	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	
Gazali Rachman	✓		✓	✓			✓			✓	✓		✓	✓
A.B.P. Dulhasyim	✓		✓	✓			✓			✓	✓		✓	✓

Conflict of Interest Statement

The authors declare no conflict of interest and The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Informed Consent

We have obtained informed consent from all individuals included in this study.

Data Availability

The data that support the findings of this study are available from the corresponding authorupon reasonable request.

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