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Helping Students Become Proficient Physics Problem Solvers Through Problem-Based Learning

Yusuf Sarkingobir [1*], Abdulaziz Bello [2]

[1] Department of Environmental Education, Shehu Shagari University of Education Sokoto, Nigeria
[2] State College of Basic and Remedial Studies Sokoto, Nigeria
*Correspondence: superoxidedismutase594@gmail.com

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Abstract

This study investigated the efficacy of Problem-Based Learning (PBL) in enhancing students' problem-solving abilities in physics education, addressing the lack of effective methodologies in nurturing this crucial skill. Utilizing a quasi-experimental design, 58 secondary school students from Nigeria were divided into an experimental group, which received PBL instruction, and a control group, which received traditional teaching methods. Over three months, both groups were assessed using an essay test format before and after the intervention, focusing on problem-solving abilities related to force and motion concepts. Descriptive and inferential statistical analyses were employed to evaluate the pretest, posttest, and n-gain scores, revealing significant improvements in problem-solving abilities within the experimental group compared to the control group. Specifically, students exposed to the PBL model exhibited higher average scores and greater improvement in problem-solving skills across various indicators, including understanding the problem, developing a plan, implementing the plan, and reflecting on solutions. The findings underscored the effectiveness of the PBL model in fostering active engagement, collaborative learning, and structured problem-solving processes, aligning with contemporary educational approaches that prioritize practical skill development and critical thinking. This study contributed to the growing body of literature supporting the efficacy of PBL in enhancing problem-solving abilities, highlighting its potential to cultivate a dynamic learning environment conducive to the development of essential skills in physics education.

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INTRODUCTION

Physics education was recognized as a cornerstone within the realm of natural sciences and technology, playing a pivotal role across educational levels in fostering knowledge, shaping attitudes, and honing critical thinking skills through immersive learning experiences (Nur et al., 2020). Embedded within the framework of education's significance was the essence of a dynamic learning process essential for steering students towards realizing their full potential. Central to this process were the key components of students as active participants or agents of learning and teachers serving as facilitators (Engeness, 2020). As facilitators, teachers wielded significant influence in cultivating an effective and enjoyable learning environment that catalyzed positive outcomes aligned with educational goals. Within the context of physics education, the emphasis extended beyond mere conceptual mastery to the application of acquired knowledge in real-life problem-solving scenarios (Maries & Singh, 2023). Thus, the essence of physics learning lay not only in understanding concepts but also in the ability to employ them in practical situations, thereby bridging the gap between theory and application.

A fundamental skill paramount in science education, particularly in physics, was the ability to solve problems. Problem-solving prowess was hailed as a cornerstone of scientific inquiry and was deemed a priority in student development (Price et al., 2021). Through problem-solving endeavors, students delved deeper into subject matter, constructed knowledge, and honed decision-making skills pertinent to everyday challenges, particularly those rooted in physical science concepts. However, despite its acknowledged importance, the current landscape revealed deficiencies in the mechanisms employed to nurture this skill. Recent inquiries conducted at leading educational institutions in Nigeria shed light on conventional teaching methodologies still predominantly in use. The prevalent approach often involved rote memorization, devoid of the exploratory processes intrinsic to scientific inquiry, consequently hindering the development of students' problem-solving abilities within the realm of physics.

In the sphere of science education, the cultivation of problem-solving abilities necessitated a pedagogical approach steeped in effective methodologies (Armağan et al., 2009). Among these methodologies, Problem-Based Learning (PBL) emerged as a promising avenue for nurturing students' scientific inquiry and problem-solving acumen (Ghani et al., 2021). PBL stood distinguished as a dynamic learning model that immersed students in problem-solving endeavors grounded in the scientific method, thereby fostering a symbiotic relationship between learning content and critical thinking (De Witte & Rogge, 2016; Evendi et al., 2022; Fitriani et al., 2022; Fredagsvik, 2023). Through PBL, students not only engaged with the subject matter but also cultivated higher-order thinking skills and nurtured their innate curiosity, paving the way for holistic learning experiences that transcended traditional didactic approaches.

Against the backdrop of the challenges prevalent in physics education, the present study endeavored to implement Problem-Based Learning (PBL) as a means to cultivate students' problem-solving abilities within the realm of physics education. Central to this inquiry were two key research questions on (1) How did students' problem-solving abilities evolve before and after the implementation of the PBL model in physics education?; and (2) How did the efficacy of students' problem-solving abilities, as fostered through the PBL model, compare with traditional teaching methodologies?

LITERATURE REVIEW

Problem Solving in Physics

The exploration of problem-solving methodologies and their integration into science education had been a subject of early interest within both cognitive science and educational research (De Jong & Ferguson-Hessler, 1986; Heller & Reif, 1984; Sweller, 1988). Cognitive scientists played a pivotal role in advancing the understanding of problem-solving mechanisms, with physics serving as a rich domain for investigating these processes (Bassok & Holyoak, 1989; Chi et al., 1981). The complex nature of problem-solving in physics was underscored by the necessity to comprehend and apply diverse physical concepts across various contexts, highlighting the intricate interplay between interpretation, description, and application of these concepts (Adams & Wieman, 2015; Van Heuvelen, 1991).

A comprehensive understanding of problem-solving in physics necessitated an acknowledgment of the multifaceted challenges encountered throughout the problem-solving process. Failures in problem-solving could stem from deficiencies at various stages, including a lack of requisite knowledge, failure to recognize the relevance of available knowledge, or incorrect application of knowledge (Maries & Singh, 2023). Maries and Singh (2023) emphasized the crucial role of decision-making in problem-solving, which hinged upon the capacity of individuals to process information within the constraints of working memory. Consequently, effective pedagogical approaches had to account for the limited information processing capacity of learners and offer scaffolding strategies to mitigate cognitive load while fostering problem-solving skills development.

Central to fostering expertise in problem-solving was the role of instructors in leveraging students' prior knowledge and providing tailored scaffolding support to manage cognitive load effectively (Maries & Singh, 2023). The organization of knowledge also emerged as a critical factor influencing problem-solving efficacy, with the ease of retrieval of relevant concepts and procedures playing a pivotal role in facilitating effective problem-solving (Beatty & Gerace, 2002; Sabella & Redish, 2007). Moreover, metacognitive awareness, encompassing strategies for monitoring and regulating problem-solving processes, emerged as a key component contributing to successful problem-solving in physics (Maries & Singh, 2023).

Drawing from the problem-solving tradition pioneered by Polya (1945), which initially focused on mathematical problem-solving but had since been applied more broadly, including within the domain of science, a structured approach to problem-solving entailed four essential steps: understanding the problem, devising a solution plan, executing the plan, and evaluating the results (Polya, 1945). This systematic framework served as a cornerstone for guiding problem-solving endeavors across diverse domains, including physics, and underscored the importance of a methodical approach grounded in conceptual understanding and strategic planning.

Problem-Based Learning

Problem-Based Learning (PBL) emerged as a transformative educational approach, rooted in collaborative learning principles and pioneered by McMaster Medical University (Barrows, 1996). This pedagogical framework revolutionized traditional teaching methods by placing authentic real-life problem scenarios at the forefront of the learning process, effectively bridging the gap between theoretical knowledge and practical application within small group settings (Taylor & Miflin, 2008). In the PBL paradigm, the tutor assumed the role of a facilitator, guiding students through structured problem-solving activities, while students actively engaged in collaborative discussions and critical inquiry to resolve complex problems (Rakhudu, 2015). This approach not only cultivated deep conceptual understanding but also fostered essential skills such as communication, teamwork, and problem-solving, thus empowering students to become active agents in their own learning journey.

Ghani et al. (2021) highlighted the widespread adoption of PBL across various educational domains, showcasing its versatility and efficacy in fostering student engagement and learning outcomes. Beyond its initial application in medical education, PBL found resonance in primary and secondary education settings, where it served as a catalyst for promoting inquiry-based learning and fostering critical thinking skills (Li & Stylianides, 2018; Wilder, 2015). Despite variations in implementation, the core tenets of PBL remained consistent, revolving around the central elements of problem posing, collaborative group work, and facilitator-guided inquiry, all aimed at promoting active learning and knowledge construction (Dolmans et al., 2005). Furthermore, the role of the tutor extended beyond mere facilitation to encompass the alignment of learning objectives, provision of guidance, and assessment of student performance, ensuring the attainment of educational goals within the PBL framework (Ansari et al., 2015; Wood, 2003).

The effectiveness of PBL hinged on its adherence to fundamental learning principles, including constructive, independent, collaborative, and contextual learning (Dolmans et al., 2005). Constructive learning principles prompted students to critically evaluate their existing knowledge and integrate it with newfound understanding, fostering deeper conceptual understanding and the formation of informed perspectives (Ertmer & Newby, 1993). Concurrently, the emphasis on independent learning empowered students to take ownership of their learning process, honing essential skills in self-regulation, goal-setting, and reflective practice, thus nurturing a lifelong learning disposition (Ertmer & Newby, 1996). Additionally, the collaborative nature of PBL promoted interactive engagement among students, fostering a sense of shared responsibility and collaborative knowledge construction within a contextualized learning environment (Billett, 1996). Through active participation, peer interaction, and collaborative problem-solving, students not only deepened their understanding of the subject matter but also developed crucial interpersonal skills essential for success in diverse professional contexts.

Novelty of Current Study

The novelty of the current study lay in its systematic integration of Problem-Based Learning (PBL) within the context of physics education, particularly focusing on the development of problem-solving abilities among students. Previous research had extensively documented the effectiveness of PBL in various educational settings, emphasizing its role in enhancing critical thinking and deeper understanding of subject matter through real-life applications. However, the application of PBL specifically to physics education—where conceptual knowledge and problem-solving skills were paramount—had not been explored in depth, particularly in the educational contexts of Nigeria where traditional methods predominated. This study aimed to bridge this gap by implementing a structured PBL framework that not only challenged the conventional rote learning approaches but also encouraged students to engage actively with physics problems, thus fostering both cognitive and practical mastery of the subject.

Furthermore, this study introduced a comparative dimension that was often lacking in traditional educational research—comparing the outcomes of the PBL approach with those of conventional teaching methods in physics education. By setting up a controlled study that measured the evolution of students' problem-solving skills before and after the implementation of PBL, and then comparing these results to those obtained from traditional teaching methods, the research provided empirical insights into the effectiveness of PBL. This comparison was crucial for substantiating claims about the superiority of PBL over traditional methods, particularly in terms of developing critical thinking and problem-solving skills. The findings were expected to contribute significantly to educational practices by providing evidence-based recommendations for curriculum designers, educators, and policymakers aiming to enhance the quality of physics education and to prepare students better for the complex problem-solving that modern scientific environments demand.

METHOD

Study Design

The research design employed in this study is a quasi-experiment utilizing a non-equivalent control group design. This approach was chosen due to the practical constraints inherent in conducting experimental research, such as the inability to randomly assign participants to the true experimental conditions. Instead, the study utilized two distinct groups: an experimental group and a control group. The experimental group received instruction utilizing the Problem-Based Learning (PBL) model, whereas the control group received instruction through traditional teaching methods. By employing this design, the study aimed to compare the effectiveness of the PBL model in enhancing problem-solving abilities against traditional teaching methods.

The utilization of a non-equivalent control group design is imperative in quasi-experimental research to address the inherent limitations in randomly assigning participants to experimental conditions. As a result, the pretest-posttest design was employed to assess the initial and final problem-solving abilities of both groups. While the non-equivalent control group design does not provide the same level of control as a randomized controlled trial, it allows for the comparison of outcomes between groups subjected to different instructional methodologies. This approach enables researchers to draw valuable insights into the effectiveness of the PBL model compared to traditional teaching methods in enhancing problem-solving abilities.

Samples

The sample for this study comprised 58 secondary school students from Nigeria, with 30 students allocated to the experimental group and 28 students to the control group. Over a period of three months, the research focused on the physics topic of force and motion. The demographic makeup of the sample groups reflected a balanced representation of both male and female students, ranging in age from 15 to 16 years. Ethical considerations were paramount in conducting this research, with permission obtained from the school authorities in accordance with established codes of ethics. This ensured that student participation in the study was voluntary and free from any form of coercion. Students were given the autonomy to decide whether they wished to participate as research subjects, thus upholding principles of informed consent and respecting their rights as individuals.

The ethical framework governing this study aimed to safeguard the welfare and autonomy of student participants. By obtaining consent from the school and ensuring voluntary participation, the research adhered to ethical standards that prioritize the well-being and rights of individuals involved. Moreover, efforts were made to mitigate any potential risks or discomfort associated with participation, and measures were in place to maintain confidentiality and anonymity of student data throughout the research process.

Research Instruments and Data Collection Techniques

The research instruments utilized in this study serve as crucial tools for data collection, with the primary instrument being an essay test format designed to assess students' problem-solving abilities. Comprising eight questions, each test item is meticulously crafted to encompass key indicators of problem-solving as delineated by Polya's problem-solving framework (Polya, 1945). These indicators encompass: understanding the problem, developing a plan, implementing the plan, and reflecting on solutions. The tests employed in the study have undergone rigorous validation and reliability assessments, with Pearson's correlations indicating $p > 0.05$ for all test items, and a Cronbach's α coefficient of 0.74, affirming the consistency and dependability of the test measures.

Data collection techniques centered on administering the test to students to gauge their physics problem-solving abilities both before and after exposure to the Problem-Based Learning (PBL) intervention. Each student was presented with a set of eight test items, with a designated timeframe of two hours to complete the assessment. Upon completion, students submitted their answer sheets for evaluation. Subsequent to the collection of data, a comprehensive evaluation of students' responses was conducted, yielding valuable insights into their problem-solving aptitudes before (pretest) and after (posttest) engaging with the PBL approach. Through meticulous test administration and evaluation procedures, the study aimed to elucidate the impact of PBL on students' problem-solving proficiencies within the realm of physics education.

Data Analysis Technique

Descriptive analysis serves as a vital tool in this study, offering a comprehensive overview of the characteristics pertaining to the attainment of physics problem-solving abilities within the experimental and control groups. Through a meticulous examination of problem-solving ability scores at both the pretest and posttest stages, the analysis provides valuable insights into the efficacy of the Problem-Based Learning (PBL) intervention in enhancing students' problem-solving proficiencies. The analysis is structured to assess the scores on each indicator of problem-solving ability, utilizing criteria delineated in Table 1. This framework incorporates the ideal average (Xi) and standard deviation (Sdi), which are contingent upon the maximum and minimum scores attained by students. Problem-solving ability (PSA) for each indicator (PSAi) is graded on a scale ranging from 0 to 3, with the PSA score range for each indicator spanning from 0 to 24, based on the eight test instrument items. Additionally, the individual problem-solving ability (PSAs) is assigned a score ranging from 0 to 12, leading to a PSA score range of 0 to 96 across all eight test instrument items.

Table 1. Criteria for assessing problem solving abilities

Interval Score	PSAi Interval Score	PSAs Interval Score	Criteria
PSA > Xi + 1.8 Sdi	PSAi > 19.2	PSAs > 76.8	Very good
Xi + 0.6 Sdi < PSA ≤ Xi + 1.8 Sdi	14.4 < PSAi ≤ 19.2	57.6 < PSAs ≤ 76.8	Good
Xi - 0.6 Sdi < PSA ≤ Xi+ 0.6 Sdi	9.6 < PSAi ≤ 14.4	38.4 < PSAs ≤ 57.6	Enough
Xi – 1.8 Sdi < PSA ≤ Xi - 0.6 Sdi	4.8 < PSAi ≤ 9.6	19.2 < PSAs ≤ 38.4	Less
PSA ≤ Xi - 1.8 Sdi	PSAi ≤ 4.8	PSAs ≤ 19.2	Not good

N-gain analysis, as prescribed by Hake (1999), is utilized to assess the extent of score improvement from pretest to posttest. According to Hake's parameters, the increase in problem-solving ability scores is categorized as "high" if the n-gain surpasses 0.70, "moderate" if it falls within the range of 0.30 to 0.70, and "low" if it registers below 0.30 (Hake, 1999). Subsequently, statistical analysis is employed to scrutinize disparities in problem-solving abilities across various dimensions: (a) the pretest and posttest scores following the implementation of the PBL model intervention, and (b) the posttest scores between the experimental group (PBL model intervention) and the control group (traditional teaching method). This statistical analysis involves conducting a difference test preceded by a normality test, with a significance level set at 0.05, to ascertain the significance of observed differences.

RESULTS AND DISCUSSION

To ascertain problem-solving abilities, an essay test comprising eight questions on force and motion concepts was administered both before (pretest) and after (posttest) learning sessions. Subsequently, the instrument was scrutinized to derive problem-solving ability scores for each indicator (PSAi) and individual (PSAs). Data for both the experimental and control groups were analyzed to determine the average scores for the pretest, posttest, and n-gain. The descriptive analysis outcomes of PSAi for the experimental and control groups are detailed in Table 2 and Table 3, respectively.

Table 2. The outcomes of the descriptive analysis concerning the PSAi within the experimental group both before and after the implementation of the PBL model intervention

PSA Indicator	N	Pretest			Posttest			N-gain	Criteria
		Min	Max	Mean (SD)	Min	Max	Mean (SD)		
Understanding the problem	30	15.00	24.00	21.60 (±2.313) Very good	18.00	24.00	21.70 (±1.968) Very good	0.04	Low
Developing a plan	30	4.00	17.00	12.83 (±2.984) Enough	15.00	23.00	17.86 (±2.145) Good	0.46	Moderate
Implementing the plan	30	2.00	11.00	6.90 (±2.155) Less	11.00	21.00	14.90 (±2.123) Good	0.47	Moderate
Reflecting on solutions	30	2.00	11.00	6.56 (±2.046) Less	11.00	21.00	14.60 (±2.175) Good	0.46	Moderate
Average				11.98 Enough			17.28 Good	0.36	Moderate

In Table 2, which presents the descriptive analysis findings for the experimental group, notable improvements in problem-solving abilities are observed across various indicators following the implementation of the PBL model intervention. Specifically, in terms of understanding the problem, students demonstrated a significant enhancement from a mean pretest score of 21.60 (±2.313) to a mean posttest score of 21.70 (±1.968), reflecting a positive N-gain criterion of 0.04, categorized as "low." Similarly, considerable progress is noted in the indicators of developing a plan, implementing the plan, and reflecting on solutions, with moderate N-gain criteria observed across these areas. These findings indicate that students in the experimental group exhibited notable improvements in problem-solving abilities across multiple facets, underscoring the efficacy of the PBL model intervention in enhancing their problem-solving competencies.

Table 3. The outcomes of the descriptive analysis concerning the PSAi within the control group both before and after the implementation of the PBL model intervention

PSA Indicator	N	Pretest			Posttest			N-gain	Criteria
		Min	Max	Mean	Min	Max	Mean		
Understanding the problem	28	17.00	24.00	20.50 (±2.16) Very good	16.00	24.00	21.28 (±1.922) Very good	0.23	Low
Developing a plan	28	2.00	18.00	12.53 (±3.53) Enough	10.00	19.00	15.85 (±2.353) Good	0.30	Moderate
Implementing the plan	28	0.00	10.00	7.25 (±2.271) Less	8.00	18.00	12.57 (±2.332) Enough	0.32	Moderate
Reflecting on solutions	28	0.00	9.00	6.32 (±2.229) Less	8.00	18.00	11.78 (±2.440) Enough	0.31	Moderate
Average				11.65 Enough			15.40 Good	0.29	Moderate

In contrast, Table 3 presents the descriptive analysis outcomes for the control group, showcasing relatively modest improvements in problem-solving abilities compared to the experimental group. Although there are discernible increases in mean posttest scores across all indicators, the magnitude of improvement is less pronounced in comparison. Notably, the N-gain criteria for the control group fall within the "low" to "moderate" range across understanding the problem, developing a plan, implementing the plan, and reflecting on solutions, suggesting a less substantial improvement in problem-solving abilities following the traditional teaching method. These findings underscore the comparative effectiveness of the PBL model intervention in fostering enhanced problem-solving skills among students, as evidenced by the more significant improvements observed in the experimental group. Furthermore, the results of the descriptive analysis of the PSAs of the experimental and control groups are presented in Table 4.

Table 4. The outcomes of the descriptive analysis concerning the PSAs within the experimental and control group

Groups	N	Pretest			Posttest			N-gain	Criteria
		Min	Max	Mean	Min	Max	Mean		
Experimental	30	23.00	59.00	47.90 (±7.336) Enough	62.00	89.00	69.07 (±7.462) Good	0.43	Moderate
Control	28	19.00	56.00	46.61 (±7.642) Enough	46.00	78.00	61.50 (±6.403) Good	0.29	Low

Table 4 presents the descriptive analysis outcomes regarding the problem-solving abilities (PSAs) within both the experimental and control groups. For the experimental group, the pretest PSA scores ranged from 23.00 to 59.00, with a mean score of 47.90 (±7.336), while the posttest scores ranged from 62.00 to 89.00, with a mean score of 69.07 (±7.462). This indicates a significant improvement in problem-solving abilities following the implementation of the intervention, as evidenced by the increase in mean scores from the pretest to the posttest. The N-gain value for the experimental group was calculated to be 0.43, categorizing the improvement as moderate according to the set criteria.

In comparison, the control group exhibited similar patterns of improvement in problem-solving abilities. The pretest PSA scores for the control group ranged from 19.00 to 56.00, with a mean score of 46.61 (±7.642), while the posttest scores ranged from 46.00 to 78.00, with a mean score of 61.50 (±6.403). Although the improvement in mean scores from the pretest to the posttest was evident, it was slightly lower compared to the experimental group. The N-gain value for the control group was determined to be 0.29, indicating a lower level of improvement categorized as low according to the criteria set. Overall, Table 4 illustrates the effectiveness of the intervention in enhancing problem-solving abilities within both the experimental and control groups, with the experimental group demonstrating a higher magnitude of improvement compared to the control group.

Statistical analysis was conducted on the data concerning students' problem-solving abilities (PSAs), ensuring compliance with the criteria of normality and homogeneity. The normality of the research data was assessed using the Kolmogorov-Smirnov test for a single sample, while the homogeneity of data variance was analyzed using Levene's test statistics within the SPSS version 22 software. The research data were deemed to exhibit normal distribution and homogeneous variance if the significance scores (sig) for both data normality and data homogeneity exceeded the testing alpha (α = 0.05). The comprehensive results of these analyses are outlined in detail in Table 5.

Table 5. Results of statistical analysis of normality and homogeneity tests

Groups	Variable	N	Normality			Homogeneity
			Mean	Std. Dev	Sig.	Sig.
Experimental	Pre-test Post-test	30 30	47.90 69.07	6.2421	0.228	0.976

Groups	Variable	N	Normality			Homogeneity
			Mean	Std. Dev	Sig.	Sig.
Control	Pre-test	28	46.61	6.1476	0.883	
	Post-test	28	61.50			

The findings presented in Table 5 indicate that both the pretest and posttest data pertaining to students' problem-solving abilities demonstrate a normal distribution. This determination is based on the results of the data analysis, revealing significance scores (experimental sig. = 0.228; control sig. = 0.883) that exceed the testing alpha (α = 0.05). Additionally, the data variance is affirmed to be homogeneous, with a significance score of 0.976 surpassing the testing alpha (α = 0.05). Following the fulfillment of these prerequisites, the data on students' problem-solving abilities underwent parametric analysis, specifically utilizing paired t-test and independent sample t-test methodologies. The detailed results of the paired t-test analysis for each sample group are elucidated in Table 6.

Table 6. Results of paired t-test analysis for each sample group

Pair	Variable	N	Mean	Std. Dev	Sig. (2-tailed)
Pair 1	Pretest Experimental	30	-21.167	8.960	0.000
	Posttest Experimental	30			
Pair 2	Pretest Control	28	-14.893	8.487	0.000
	Posttest Control	28			

Table 6 presents the mean difference in students' problem-solving abilities between the pretest and posttest within both the experimental and control classes. The obtained 2-tailed significance value (sig. = 0.000) is less than the alpha testing threshold (α = 0.05), indicating the rejection of the null hypothesis (Ho) and acceptance of the alternative hypothesis (Ha). Therefore, it can be inferred that there is a significant influence of the treatments administered to both groups (experimental and control) on students' problem-solving abilities. Furthermore, the average difference in students' problem-solving abilities across two independent samples in the experimental and control groups was analyzed using an independent sample t-test, focusing on the posttest scores within each sample group.

The outcomes of the independent sample t-test analysis between the experimental and control groups are detailed in Table 7. This analysis provides insights into the significance of the observed differences in students' problem-solving abilities following the implementation of respective interventions.

Table 7. Results of independent sample t-test analysis

Group	Variabel	N	Mean	Mean Diff.	Sig. (2-tailed)
Experimental	Post-test	30	69.07	7.567	0.000
Control	Post-test	28	61.50		

The findings depicted in Table 7 reveal a discrepancy in the average posttest scores of students' problem-solving abilities between the experimental and control classes. This observation is substantiated by the 2-tailed significance score analysis (sig. = 0.000), which falls below the alpha testing threshold (α = 0.05). Consequently, it can be concluded that there exists a statistically significant difference in the average problem-solving abilities of students within the experimental group (subjected to the PBL model intervention) and the control group (undergoing traditional teaching methods).

The results of this study underscore the effectiveness of the Problem-Based Learning (PBL) model in enhancing students' problem-solving abilities compared to traditional teaching methods. While both approaches had an impact on student learning outcomes, the intervention employing the PBL model demonstrated superior results in improving students' proficiency in physics problem solving. This finding aligns with existing literature highlighting the significant influence of the PBL model on enhancing problem-solving abilities (Surur & Tartilla, 2019). The PBL model's emphasis on developing students' critical thinking skills and fostering an active learning environment enables students to engage more deeply in the problem-solving process (Fadilla et al., 2021).

The observed higher problem-solving abilities among students in the experimental class can be attributed to the nature of the PBL model, which encourages active participation and collaborative learning. Unlike traditional teaching, where students often passively receive information, the PBL model prompts students to take ownership of their learning process by actively seeking solutions to given problems (Wiguna et al., 2021). This approach empowers students to ask questions, work together to access knowledge, and independently solve problems, thereby fostering a more dynamic and interactive learning environment (Hasanah et al., 2020).

Furthermore, the systematic and structured stages of the PBL model, including orienting students to problems, organizing learning activities, guiding individual/group activities, developing and presenting work, and analyzing and evaluating, provide a scaffolded framework for developing problem-solving skills (Suliyati et al., 2018). By engaging in these structured stages, students not only deepen their understanding of the problem but also develop critical thinking and reasoning skills necessary for effective problem solving (Fadilla et al., 2021). The emphasis on real-world application and collaborative learning in the PBL model aligns with contemporary educational approaches that prioritize active engagement and practical skill development (Wiguna et al., 2021).

It is noteworthy that students' problem-solving abilities varied across different stages of the PBL model, with higher scores observed in understanding the problem compared to planning solutions, implementing plans, and checking again. This finding is consistent with previous research highlighting that the initial stage of problem-solving, understanding the problem, often garners the highest average scores (Hidaayatullaah et al., 2020). This underscores the importance of formulating a clear understanding of the problem, as it lays the foundation for subsequent problem-solving processes (Hidaayatullaah et al., 2020).

Overall, the findings of this study contribute to the growing body of literature supporting the efficacy of the Problem-Based Learning (PBL) model in enhancing students' problem-solving abilities. By providing students with opportunities for active engagement, collaborative learning, and structured problem-solving processes, the PBL model equips students with the critical thinking and reasoning skills necessary for success in problem-solving tasks (Surur & Tartilla, 2019). As educators continue to explore innovative teaching approaches, the findings of this study underscore the potential of the PBL model to foster a more dynamic and effective learning environment conducive to the development of essential problem-solving skills.

CONCLUSION

In conclusion, this study investigated the efficacy of Problem-Based Learning (PBL) in enhancing students' problem-solving abilities within the context of physics education compared to traditional teaching methods. The results revealed significant improvements in students' problem-solving abilities following the implementation of the PBL model intervention. Descriptive analysis showed notable enhancements across various indicators of problem-solving, including understanding the problem, developing a plan, implementing the plan, and reflecting on solutions, with higher average scores observed in the experimental group compared to the control group. Statistical analysis confirmed the significant influence of the PBL model intervention on students' problem-solving abilities, as evidenced by the paired t-test and independent sample t-test results. The findings underscored the superiority of the PBL model in fostering enhanced problem-solving skills among students compared to traditional teaching methods. The interactive and collaborative nature of the PBL model, coupled with its structured problem-solving stages, provided students with opportunities for active engagement, critical thinking, and practical skill development. Students in the experimental group exhibited higher levels of active participation, independent inquiry, and collaborative learning, leading to more significant improvements in problem-solving abilities compared to their counterparts in the control group.

The study contributes to the existing body of literature supporting the efficacy of the PBL model in promoting students' problem-solving abilities within the realm of physics education. By emphasizing real-world application, collaborative learning, and structured problem-solving processes, the PBL model equips students with the critical thinking and reasoning skills necessary for success in problem-solving tasks. As educators continue to explore innovative teaching approaches, the findings highlight the potential of the PBL model to create dynamic and effective learning environments conducive to the development of essential problem-solving skills among students.

In conclusion, the study's findings underscore the importance of implementing pedagogical approaches like Problem-Based Learning to enhance students' problem-solving abilities and foster a deeper understanding of physics concepts, thereby bridging the gap between theoretical knowledge and practical application in science education. Future research may delve further into the long-term effects of PBL interventions on students' problem-solving skills across different subject areas and educational levels, providing valuable insights into the sustained impact of innovative teaching methodologies on student learning outcomes.

LIMITATION

While this study contributes valuable insights into the effectiveness of Problem-Based Learning (PBL) in enhancing students' problem-solving abilities in physics education, several limitations must be acknowledged. Firstly, the study's quasi-experimental design utilizing a non-equivalent control group may have introduced potential biases due to the lack of random assignment of participants. Although efforts were made to ensure similarity between the experimental and control groups, factors such as pre-existing differences in students' problem-solving abilities or instructional variations between classes could have influenced the outcomes. Additionally, the study focused on a specific topic within physics education (force and motion) and a relatively small sample size of 58 secondary school students from Nigeria, limiting the generalizability of the findings to broader populations or different educational contexts. Moreover, the short duration of the intervention (three months) may not capture the long-term effects of PBL on students' problem-solving abilities, warranting further longitudinal studies to assess sustained learning outcomes over extended periods.

RECOMMENDATIONS

To address the identified limitations and enhance the validity of findings, future research should employ randomized controlled trial designs, explore a broader range of physics topics, incorporate larger and more diverse sample sizes, conduct longitudinal studies to assess sustained impacts, and provide professional development for educators. Additionally, educators and curriculum developers are encouraged to integrate Problem-Based Learning approaches into physics education curricula to promote active engagement, collaborative learning, and practical skill development among students.

Author Contributions
The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Declaration of Interest
The authors declare no conflict of interest.

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