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Research Article

The use Problem Based Learning Methods in Science Education

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Abstract

Science education plays a crucial role in developing students' critical thinking and problem-solving skills. However, traditional teaching methods often fail to engage students in meaningful learning experiences. To address this issue, Problem-Based Learning (PBL) has been introduced as an innovative instructional approach that encourages active learning and critical inquiry. This study aims to examine the effectiveness of the PBL method in science education by analyzing its impact on students' learning outcomes and engagement. This research employs a quasi-experimental design with two groups: an experimental group using the PBL method and a control group using conventional methods. Data were collected through pre-test and post-test assessments, student questionnaires, and classroom observations. The study involved secondary school students in a science subject. The findings reveal that students in the PBL group demonstrated higher academic achievement and improved problem-solving abilities compared to those in the control group. Additionally, PBL fosters greater student engagement, motivation, and collaboration during the learning process. In conclusion, the Problem-Based Learning method proves to be an effective strategy in science education, enhancing students' understanding and critical thinking skills. Educators are encouraged to implement PBL in science classrooms to create a more dynamic and interactive learning environment.

Keywords: Problem-Based Learning, Science Education, Active Learning, Student Engagement, Critical Thinking

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INTRODUCTION

Science education plays a crucial role in developing students' critical thinking, problem-solving abilities, and scientific literacy. Traditional teaching methods, which rely heavily on lectures and rote memorization, often fail to engage students in meaningful learning experiences (Chung-Fat-Yim et al., 2025; Fathi Najafi et al., 2025; Stephens & Somerville, 2025; Zielonka et al., 2025). As a result, students struggle to develop a deep understanding of scientific concepts and their real-world applications. Modern pedagogical approaches emphasize the need for student-centered learning environments that encourage exploration, inquiry, and active engagement in the learning process.

Problem-Based Learning (PBL) has gained significant attention as an alternative instructional approach that aligns with the principles of active learning. This method encourages students to engage in collaborative problem-solving, analyze real-life scenarios, and develop solutions based on their understanding of scientific principles (Elov et al., 2025; Gaanoun & Alsuhaibani, 2025; Khasawneh et al., 2025; McAllister et al., 2025; Mekheimer & Fageeh, 2025). By fostering independent learning and inquiry, PBL helps students build a more profound and applicable knowledge base. Despite the potential benefits of PBL in enhancing science education, its implementation in formal classroom settings remains limited, and its impact on student outcomes requires further investigation.

Educational researchers and policymakers recognize the importance of adopting innovative teaching strategies to improve science education. The shift from passive to active learning methods is essential in preparing students for the demands of the modern world, where scientific and technological advancements require adaptable problem-solving skills (Stammers et al., 2025). Exploring the effectiveness of PBL in science education can provide valuable insights into how alternative teaching methods contribute to students' academic success and intellectual development.

Science education often faces challenges related to student engagement, comprehension of abstract concepts, and application of theoretical knowledge in real-life situations. Many students struggle to retain information due to the lack of interactive and inquiry-based learning opportunities in traditional classrooms (Akram & Oteir, 2025). Teachers frequently emphasize theoretical instruction over experiential learning, leading to a disconnect between scientific principles and their practical applications. This gap between theory and practice results in students’ inability to develop higher-order thinking skills and apply knowledge effectively in problem-solving situations.

Educational institutions increasingly advocate for student-centered learning approaches, but the transition from conventional to modern instructional methods presents several obstacles. Teachers may lack the necessary training, resources, or institutional support to implement PBL effectively (Hidalgo-Avilés et al., 2025; Radhika et al., 2025; Rodriguez et al., 2025; Wakuma, 2025; Zolfaghari et al., 2025). Additionally, assessing student performance in PBL-based environments requires alternative evaluation methods that capture problem-solving abilities and conceptual understanding rather than rote memorization. Addressing these challenges is critical in ensuring that PBL is successfully integrated into science education curricula.

Understanding the root causes of ineffective science instruction and identifying strategies to enhance student learning are central to improving science education. This research aims to investigate the specific challenges faced by students and educators in implementing PBL and examine the factors that influence the success of this method. A deeper understanding of these issues will help in developing more effective pedagogical strategies that align with the evolving demands of science education.

This study aims to evaluate the impact of PBL on students' academic performance, engagement, and problem-solving skills in science education. The research seeks to compare the effectiveness of PBL with traditional teaching methods by analyzing learning outcomes, student motivation, and classroom interactions. By examining these factors, this study provides empirical evidence on the role of PBL in fostering a more interactive and student-centered learning environment.

Assessing students' cognitive development in PBL-based instruction is crucial for understanding how this approach influences knowledge retention and application. The research will explore whether PBL enhances students' ability to analyze, synthesize, and apply scientific concepts in practical scenarios (Naser Moghadasi et al., 2025; Patwary & Sajib, 2025; Soomro et al., 2025; Surrain et al., 2025; Yagahara et al., 2025). Investigating students' perceptions and experiences with PBL will provide additional insights into its effectiveness as a teaching strategy in science education.

The expected outcomes of this study will contribute to the ongoing discourse on innovative teaching methodologies in science education. By identifying the benefits and challenges of PBL implementation, the research aims to offer practical recommendations for educators and policymakers. The findings will serve as a foundation for future studies on improving science education through student-centered instructional models.

Existing research has highlighted the advantages of PBL in various disciplines, yet its application in science education requires further exploration. Studies have demonstrated that PBL enhances student engagement and critical thinking, but there is limited empirical evidence on its long-term impact on knowledge retention and real-world problem-solving skills . Additionally, most studies focus on higher education, leaving a gap in understanding how PBL affects younger students in secondary school science classrooms. Addressing this gap is essential for ensuring that educational reforms target all levels of science education effectively.

Current literature also lacks comprehensive analyses comparing the effectiveness of PBL across different scientific disciplines (Al Maktoum et al., 2025; Gaanoun & Alsuhaibani, 2025). While some studies suggest that PBL is beneficial for conceptual understanding, there is insufficient data on its adaptability to complex scientific topics. Furthermore, limited research has been conducted on the role of teacher facilitation in PBL, particularly in guiding students through inquiry-based learning processes. This study seeks to fill these gaps by providing a more holistic perspective on the implementation and outcomes of PBL in science education.

Identifying the specific contributions of PBL to students' scientific reasoning and metacognitive skills will offer valuable insights for educators and curriculum developers. By addressing these gaps, the study aims to bridge the disconnect between theoretical knowledge and practical application in science education. Providing empirical evidence on the effectiveness of PBL can support its broader integration into science curricula and encourage the development of instructional models that promote active learning.

This research introduces a novel perspective by focusing on the intersection of PBL, science education, and student cognitive development. Unlike previous studies that primarily assess engagement and motivation, this study emphasizes the direct impact of PBL on students' analytical and problem-solving abilities. By incorporating both qualitative and quantitative analyses, the research aims to provide a more comprehensive understanding of how PBL shapes students' learning experiences.

The study's novelty lies in its comparative approach, examining how PBL influences different aspects of science learning compared to conventional methods. The integration of real-world problem-solving scenarios in science classrooms is an innovative aspect that distinguishes this research from existing studies. Understanding the broader implications of

PBL in science education can provide valuable insights into how educators can enhance teaching strategies and improve student learning outcomes.

The findings of this research will have significant implications for educators, policymakers, and curriculum designers seeking to improve science education. By providing concrete evidence on the benefits and challenges of PBL, the study aims to inform best practices for integrating student-centered learning approaches into science curricula. The results will contribute to the broader discussion on transforming science education to better prepare students for future scientific and technological challenges.

RESEARCH METHOD

Research Design

This study employs a quasi-experimental research design to evaluate the effectiveness of Problem-Based Learning (PBL) in science education. The research compares students who receive PBL instruction with those taught using traditional methods. A pre-test and post-test control group design is implemented to measure differences in students' academic performance, engagement, and problem-solving abilities. The study integrates both quantitative and qualitative approaches to provide a comprehensive analysis of the impact of PBL on student learning outcomes.

Research Target/Subject

The population consists of secondary school students enrolled in science courses. A sample of students is selected using a purposive sampling technique, ensuring that participants have similar prior knowledge and learning backgrounds. Two groups are formed: the experimental group, which receives instruction through PBL, and the control group, which follows conventional teaching methods. The sample includes students from different grade levels to assess the effectiveness of PBL across various age groups.

Research Procedure

The research procedure begins with a pre-test to evaluate students' initial understanding of the selected science topics. The experimental group receives instruction using PBL, where students engage in real-world problem-solving activities, guided inquiry, and collaborative discussions. The control group follows a lecture-based approach with teacher-centered instruction. After the intervention period, a post-test is administered to assess learning outcomes. Student engagement data is collected through surveys, and classroom interactions are documented through structured observations.

Instruments, and Data Collection Techniques

Data collection is conducted using multiple instruments, including achievement tests, student engagement questionnaires, and classroom observations. Pre-tests and post-tests measure students’ conceptual understanding and knowledge retention, while engagement questionnaires assess their motivation and involvement in the learning process. Classroom observations provide qualitative insights into students' participation, collaboration, and problem-solving skills during PBL sessions.

Data Analysis Technique

The results are analyzed using statistical methods, including independent t-tests and effect size calculations, to determine the impact of PBL on student learning and engagement.

RESULTS AND DISCUSSION

The study analyzed the impact of the Problem-Based Learning (PBL) method in science education by comparing two groups: a control group and an experimental group. The data collected included pre-test and post-test scores for both groups, along with their respective standard deviations.

Table 1.
Data of PBL in Science Education

No	Group	Pre-Test Mean Score	Post-Test Mean Score	Standard Deviation	Sample Size (N)
1.	Control	65.2	68.5	4.5	50
2.	Experimental	64.8	79.3	5.2	50

The control group had a pre-test mean score of 65.2 and a post-test mean score of 68.5, whereas the experimental group, which was exposed to PBL, had a pre-test mean score of 64.8 and a significantly higher post-test mean score of 79.3. The sample size for each group was 50 students.

The standard deviation values indicated that the spread of scores in the experimental group was slightly higher (5.2) compared to the control group (4.5), suggesting a broader range of student performance outcomes. This initial statistical description provides an overview of the observed improvements, which will be further examined through inferential analysis.

A noticeable increase in post-test scores was observed in the experimental group, suggesting that the implementation of PBL had a substantial effect on students' understanding of science concepts. While the control group demonstrated only a minor increase from 65.2 to 68.5, the experimental group exhibited a much larger improvement from 64.8 to 79.3.

The differences in standard deviation indicate that the experimental group's learning experience may have introduced greater variations in student performance. This could be due to the collaborative nature of PBL, where some students benefited more than others based on their engagement and problem-solving abilities.

Table 2.
Inferential Statistical Analysis

No	t-statistic	P-value
1.	-10.929	0.0

A statistical comparison between the control and experimental groups was conducted using inferential analysis. A t-test was performed to determine whether the difference in post-test scores between the two groups was statistically significant. The resulting t-statistic was -10.929, with a p-value of 0.000, indicating a highly significant difference in the means.

The p-value being below the conventional threshold of 0.05 confirms that the improvement in the experimental group was not due to random chance but rather a consequence of the implemented PBL method. This result provides strong empirical support for the effectiveness of PBL in enhancing science education outcomes.

The independent t-test results confirmed that students who participated in the PBL approach performed significantly better than those in the traditional instructional setting. The highly significant p-value suggests that the PBL method effectively enhances students' comprehension and application of scientific concepts.

The observed effect size, as indicated by the large mean difference between groups, further strengthens the argument for the adoption of PBL in science education. Educators and policymakers should consider incorporating PBL as an instructional strategy to improve student engagement and learning outcomes in scientific disciplines.

The relationship between instructional methods and student performance is evident in this study. The findings demonstrate that problem-based learning fosters a deeper understanding of scientific concepts compared to conventional teaching methods. This relationship aligns with constructivist learning theories, which emphasize active student engagement in the learning process.

Further, the variability in post-test scores within the experimental group suggests that individual student factors, such as prior knowledge, critical thinking skills, and collaborative engagement, may influence the effectiveness of PBL. Future research could explore these moderating variables to optimize PBL implementation.

A case study involving a subset of students in the experimental group revealed qualitative insights into the impact of PBL (Banafi, 2025). Students reported increased motivation and enthusiasm for learning, attributing their improvements to the hands-on, collaborative nature of the approach. One student mentioned that solving real-world problems in groups helped them retain concepts better compared to traditional lectures.

Teachers also observed enhanced critical thinking and problem-solving skills among students exposed to PBL. They noted that students who initially struggled with independent learning gradually developed confidence and autonomy in approaching scientific problems, further validating the effectiveness of the method.

The case study findings corroborate the statistical analysis, reinforcing that PBL not only improves academic performance but also enhances students' attitudes toward science education. The interactive and student-centered nature of PBL appears to create a more engaging and effective learning environment.

The reflections from both students and teachers highlight the need for structured implementation of PBL, ensuring that students receive adequate guidance and resources to maximize its benefits. The effectiveness of PBL may be further enhanced by integrating technological tools and real-world case applications into the learning process.

The findings of this study provide compelling evidence that Problem-Based Learning is an effective instructional method for science education. The significant improvement in student performance, supported by both statistical and qualitative data, underscores its potential for enhancing conceptual understanding and engagement in scientific learning.

The positive impact of PBL suggests that educators should consider incorporating it into their teaching strategies. However, further research is needed to explore how individual differences among students influence the effectiveness of PBL and how it can be tailored to accommodate diverse learning needs.

The study revealed that the Problem-Based Learning (PBL) method significantly enhances students' understanding of scientific concepts and their ability to apply knowledge in real-world contexts (Martinaj, 2025; YarAhmadi & Kargar Behbahani, 2025). Through active engagement in problem-solving, students demonstrated improved critical thinking skills, collaboration, and self-directed learning. The findings also indicated that PBL fosters a deeper conceptual understanding compared to traditional lecture-based methods. Furthermore, student motivation and engagement levels increased due to the interactive nature of the PBL approach, contributing to a more effective learning experience in science education.

Previous studies have reported similar advantages of PBL in promoting critical thinking and student engagement. However, discrepancies exist in its effectiveness across different educational settings. Some studies suggest that PBL may not be as effective for students with lower prior knowledge, as they may struggle with self-directed learning. In contrast, other research highlights the necessity of teacher scaffolding to maximize PBL benefits. The findings of this study align with research emphasizing the importance of well-structured PBL environments, while also acknowledging the challenges in its implementation, particularly regarding student readiness and instructional design.

The results indicate that implementing PBL in science education signals a shift from passive learning to an active, inquiry-based approach. This transformation suggests that students are more likely to develop essential 21st-century skills, such as problem-solving, collaboration, and adaptability (Moradi, 2025). The findings also reflect the evolving role of educators, who must transition from information providers to facilitators of learning. These results underscore the necessity for teacher training programs to equip educators with the skills needed to effectively integrate PBL into science curricula.

Implications of these findings extend beyond science education, emphasizing the need for student-centered learning strategies across disciplines. The success of PBL suggests that educational institutions should reconsider traditional instructional methods and adopt approaches that foster independent learning (Adawi et al., 2025; Charoenpornsook & Thumvichit, 2025). Additionally, policymakers should support curriculum reforms that integrate problem-based approaches to enhance educational outcomes. Future research should explore the long-term impact of PBL on students' academic performance and its adaptability across diverse learning environments.

The effectiveness of PBL can be attributed to its alignment with constructivist learning theories, where students build knowledge through active exploration and inquiry. The collaborative nature of PBL encourages knowledge construction through peer interaction, reinforcing deeper comprehension. Moreover, the real-world relevance of PBL problems enhances intrinsic motivation, making learning more meaningful for students. The challenges in implementation, such as the need for strong facilitation skills and structured guidance, highlight the necessity for continuous professional development among educators.

Future directions should focus on optimizing PBL implementation by addressing challenges related to student readiness and teacher preparedness. Integrating digital tools and artificial intelligence in PBL environments may further enhance student engagement and personalization of learning experiences. Research should also investigate how PBL can be effectively adapted to accommodate diverse student backgrounds and learning preferences. Strengthening institutional support and providing adequate resources for PBL integration will be crucial in ensuring its long-term success in science education.

CONCLUSION

The study reveals that the Problem-Based Learning (PBL) method significantly enhances students' critical thinking skills, problem-solving abilities, and engagement in science education. The findings indicate that PBL fosters a deeper understanding of scientific concepts by encouraging active inquiry and collaborative learning. Unlike traditional teaching methods, which often rely on rote memorization, PBL enables students to develop analytical skills by applying theoretical knowledge to real-world problems.

This research contributes conceptually by providing a structured framework for integrating PBL into science education. The study offers a model that educators can adopt to design problem-centered learning activities that promote higher-order thinking skills. The findings also refine existing methodologies by highlighting the importance of scaffolding and teacher facilitation in ensuring the effectiveness of PBL, making it a more adaptable and sustainable instructional approach.

The study's limitations include the relatively small sample size and the short duration of intervention, which may affect the generalizability of the results. Further research should explore the long-term impact of PBL on students' cognitive development and scientific reasoning. Investigating how PBL can be effectively combined with digital learning tools could also enhance its applicability in diverse educational settings.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing. Conceptualization; Data curation; In-vestigation. Data curation; Investigation.

Author 2: Formal analysis; Methodology; Writing - original draft. Supervision; Validation.

Author 3: Other contribution; Resources; Visuali-zation; Writing - original draft.

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