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SYSTEMATIC LITERATURE REVIEW: WHAT DO THE STUDIES REVEAL ABOUT PROBLEM-BASED LEARNING IN PHYSICS EDUCATION?

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Abstract

Twenty-first century education demands the development of higher-order thinking skills (HOTS) such as critical thinking, creative thinking, and problem-solving. However, physics education often faces challenges due to its abstract nature and lack of visualization, which are worsened by the continued dominance of conventional teaching methods. Problem-Based Learning (PBL) emerges as a potential solution, especially when integrated with technology. This study is a Systematic Literature Review (SLR) of 57 selected articles from Scopus, Web of Science, and Google Scholar, aiming to analyze trends, effectiveness, challenges, and recommendations for the implementation of PBL in physics education. The findings reveal that PBL consistently enhances students' HOTS, with technological support such as Augmented Reality (AR), digital simulations, and e-scaffolding strengthening the understanding of abstract concepts. However, the implementation of PBL faces pedagogical challenges (lack of teacher training), technological challenges (limited infrastructure), and institutional challenges (rigid curricula).

Practical recommendations include the development of interactive digital teaching materials, teacher training, the combination of PBL with STEM or blended learning approaches, and the use of performance-based authentic assessments. These findings underscore the need for a holistic approach to optimizing technology-enhanced PBL in preparing students for 21st-century challenges.

Keywords:
Problem-Based Learning, Physics Education, HOTS, Technology Integration, Systematic Literature Review

1. Introduction

Education in the 21st century demands the development of critical thinking, creativity, and problem-solving skills as part of higher-order thinking skills (HOTS), which are essential for preparing students to face global challenges (OECD, 2019). However, achieving these goals remains challenging, particularly in science education such as physics, which is characterized by abstract concepts that are often difficult to visualize (Kanyesigye et al., 2022a).

Findings from international assessments such as the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) reveal that students in many countries, including Indonesia and Uganda, continue to struggle with higher-order thinking. Many students tend to memorize formulas rather than develop a deep conceptual understanding (NCES, 2020; OECD, 2019). This situation is further worsened by teaching practices still dominated by conventional methods.

In Uganda, students' limited conceptual understanding of physics topics such as mechanical waves and simple machines is strongly influenced by the dominance of conventional, teacher-centered methods that lack active student engagement (Gumisirizah et al., 2024; Kanyesigye et al., 2022b). Similarly, in Indonesia, challenges arise due to limited learning resources, low student motivation, and difficulties in adapting to online learning during the COVID-19 pandemic (Prahani et al., 2022; Suhirman & Prayogi, 2023).

Moreover, the use of conventional teaching methods in physics has not been able to significantly enhance students' learning motivation, even though there are indications of improvement in problem-solving skills (Argaw et al., 2017). Preliminary surveys in several Indonesian schools revealed that most of the students struggle to comprehend abstract physics concepts such as magnetic fields and fluid dynamics due to inadequate visualization (Muslimin, M., Handayanto, S. K., & Sari, 2024; Prahani et al., 2022).

Problem-Based Learning (PBL) has emerged as a potential solution to overcome these barriers in physics education. As a student-centered approach, PBL encourages learners to construct knowledge independently through contextual problem-solving, while fostering reflection and critical thinking skills essential for the 21st century (Nicholus et al., 2024).

Nevertheless, recent studies indicate that the application of PBL alone is often not fully optimal, particularly in abstract physics topics such as fluid dynamics, magnetic fields, and standing waves (Kanyesigye et al., 2022a; Prahani et al., 2022). This condition has prompted researchers to seek innovative strategies that can enhance the effectiveness of PBL through the integration of educational technologies.

Several studies have shown that integrating digital technology strengthens the effectiveness of PBL in physics education. For example, animation-based media and interactive digital books have been proven to help students grasp abstract concepts more easily through concrete visual representations (Nicholus et al., 2024; Prahani et al., 2022), In addition, the use of digital scaffolding, computer simulations, and Open Educational Resources (OER) not only supports conceptual understanding but also improves creativity, critical thinking, and students' confidence in solving contextual problems (Sedayu et al., 2024; Suhirman & Prayogi, 2023).

Other research also emphasizes that the integration of PBL with computer simulations strengthens the connection between problem-solving processes and the development of students' creativity (Simanjuntak et al., 2021). Collectively, these findings indicate that the combination of PBL and technology creates a more adaptive, collaborative, and meaningful learning ecosystem, aligning with the demands of 21st-century education. However, the effectiveness of such implementation is not always consistent, as institutional factors such as resource availability, teacher training, and learning culture also play significant roles (Gumisirizah et al., 2024).

Although numerous studies have investigated the effectiveness of PBL in physics education, the findings remain partial and fragmented. Most research has focused on specific contexts or technologies, and therefore, a comprehensive overview of the trends, effectiveness, challenges, and recommendations for PBL implementation in various physics education contexts is still lacking. Accordingly, this Systematic Literature Review seeks to address the following research questions:

1. RQ1. What are the key trends in the implementation of Problem-Based Learning (PBL) in physics education over the last decade?
2. RQ2. How effective is Problem-Based Learning (PBL) model in improving students' physics learning outcomes?
3. RQ3. What are the challenges and recommendations in implementing the Problem-Based Learning (PBL) model in physics education?

2. Method

This study employed a Systematic Literature Review (SLR) method to examine the trends, effectiveness, challenges, and recommendations of implementing Problem-Based Learning (PBL) in various contexts of physics education. The SLR approach was chosen because it enables the systematic and comprehensive identification, evaluation, and synthesis of findings from previous studies. The analytical process followed specific stages as outlined by Kitchenham, namely: formulating research questions, conducting database searches, establishing inclusion and exclusion criteria, selecting relevant articles, performing data analysis and extraction, summarizing and interpreting findings, and reporting the review (Kitchenham, 2004).

The literature search was conducted using *Publish or Perish 8* with relevant keywords and a publication range from 2016 to 2025. This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), a widely recognized framework for systematic reviews in the fields of social sciences, education, and health (Elmoazen, R., Saqr, M., Tedre, M., & Hirsto, 2022). The article selection process was visualized using a PRISMA flow diagram, as shown in Figure 1. The initial search yielded a total of 446 articles from various databases and registries. A total of 12 duplicate articles were identified and removed from the initial list. Subsequently, title and abstract screening was carried out, which eliminated 371 articles as they were irrelevant to the research focus. As a result, 63 articles remained for further evaluation.

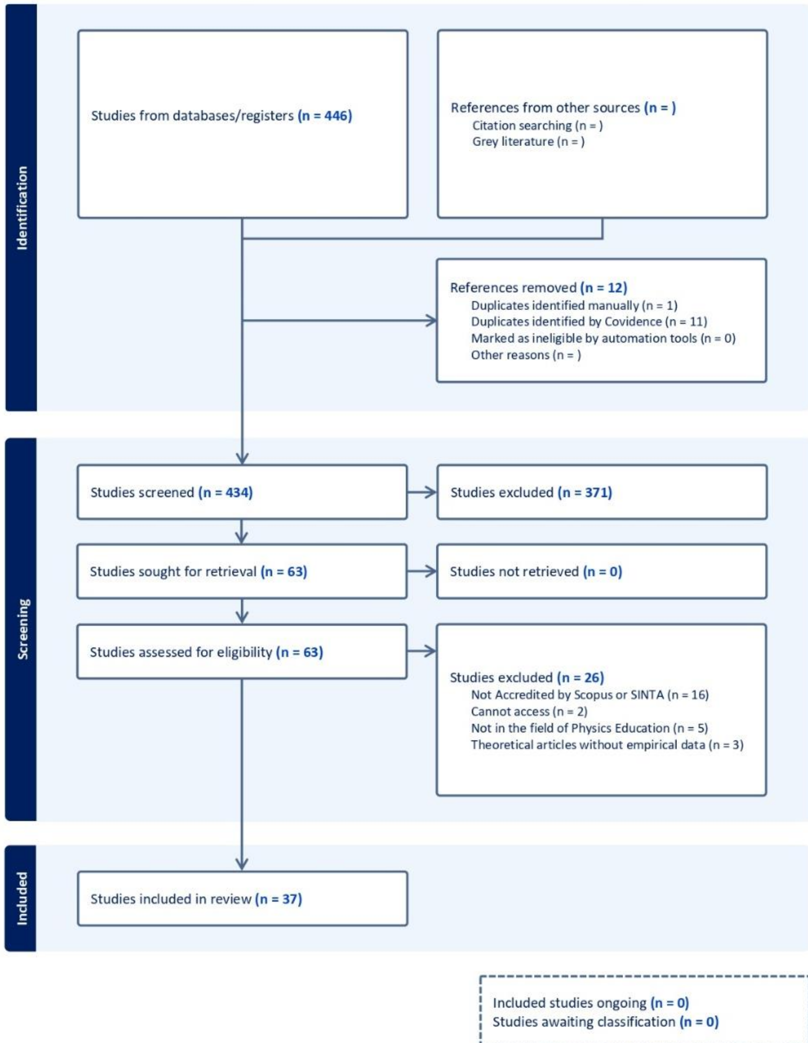

Figure 1: *PRISMA Flow Diagram*

The eligibility screening stage was carried out on the full texts of the remaining 63 articles. Each article was examined based on its introduction, methodology, results, and conclusions to ensure alignment with the scope of this study. Of the 63 reviewed articles, 5 were outside the field of physics, 2 were inaccessible, 16 were not indexed in Scopus or SINTA, and 3 were classified as non-empirical studies. In total, 37 articles met all inclusion criteria and were considered eligible for in-depth analysis.

To ensure the relevance and appropriateness of the analyzed articles, inclusion and exclusion criteria were systematically established based on the research objectives and the scope of the topic under investigation. The inclusion and exclusion criteria are presented in Table 2.1.

Table 2.1 *The Inclusion and Exclusion Criteria*

Aspect	Inclusion Criteria	Exclusion Criteria
Publication	Journal indexed by Scopus and SINTA	Other databases
Literature type	Journal Articles	Conference Reviews, Book Chapters, Short Survey, Books, Editorials, Conference Papers, and Reviews
Focused study	Discusses the implementation of Problem-Based Learning (PBL) in physics education	Does not discuss PBL, or discusses PBL in the context of other disciplines
Language	English	Other languages
Type of study	Empirical study	Literature Reviews, Theoretical Studies
Article access type	Open Access	Non-Open Access

To further guarantee the quality and credibility of the analyzed studies, a systematic quality assessment process was conducted. The purpose of this assessment was to evaluate the clarity of research objectives, methodological consistency, instrument validity, as well as the accuracy of data analysis and interpretation. The assessment instrument employed was based on the JBI Critical Appraisal Checklist, adapted to the context of physics education research. Consequently, only articles that were relevant, valid, and academically reliable were included as the foundation for synthesis in this study.

3. Results and Discussion

3.1 RQ1. What are the Recent Research Trends regarding the Implementation of Problem-Based Learning (PBL) in Physics Education over the Last Decade?

Based on the analysis of 37 selected articles, research on the implementation of Problem-Based Learning (PBL) in physics education over the past decade demonstrates clear and significant dynamics and trends. The landscape mapping of this research reveals interesting patterns in terms of geographical distribution, temporal development, technology integration, educational levels, and physics topics under investigation.

3.1.1 Geographical and Temporal Distribution

The geographical analysis reveals that research on PBL in physics education has been conducted in at least nine countries. The distribution, however, is highly uneven, as shown in Figure 2. Indonesia emerges as a dominant contributor, producing 24 articles (64.9%). Other countries such as Uganda (4 articles), Ethiopia and Turkey (2 articles each) also show significant interest, while the Netherlands, Peru, Thailand, Lithuania, and Mexico contribute one article each. This data highlights that interest in PBL within physics education is particularly strong in developing countries, especially across Asia and Africa.

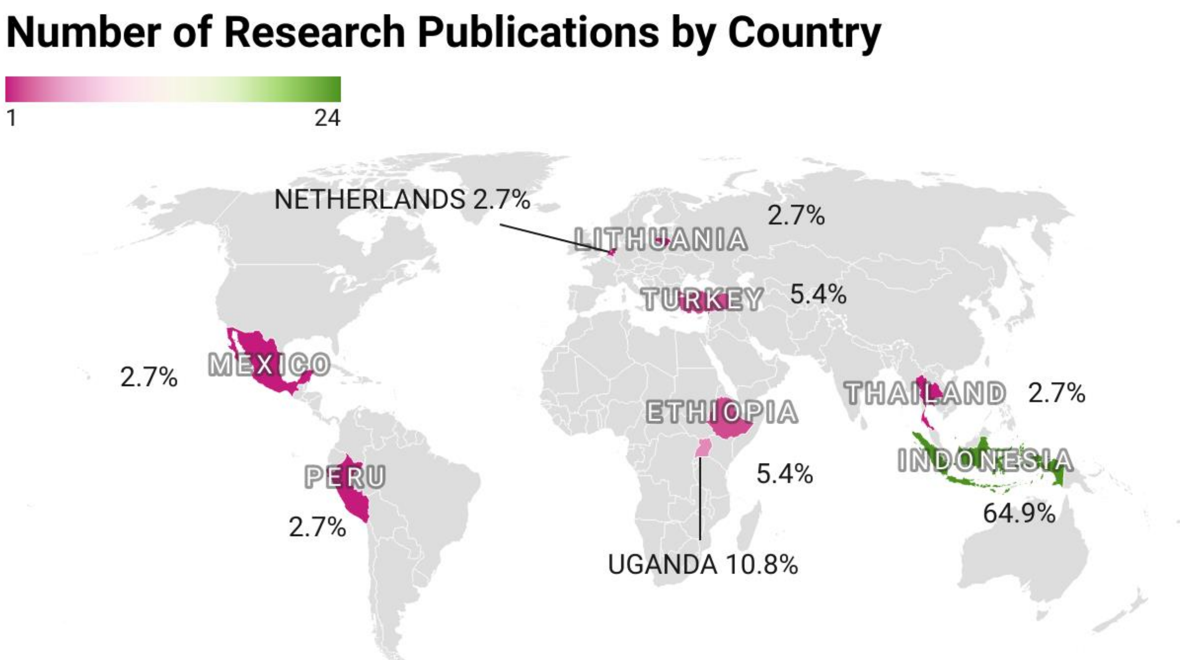

Figure 2: *Geographical Distribution of Countries of Origin of Publications*

Meanwhile, the temporal trend of publications between 2016 and 2025, as illustrated in Figure 3, indicates a remarkable upward trajectory. The volume of publications shows a steady and significant increase, with peaks in 2023 and 2024, each producing seven published articles. Overall, more than 50% of the articles were published within the last five years, reflecting the growing scholarly interest in this topic.

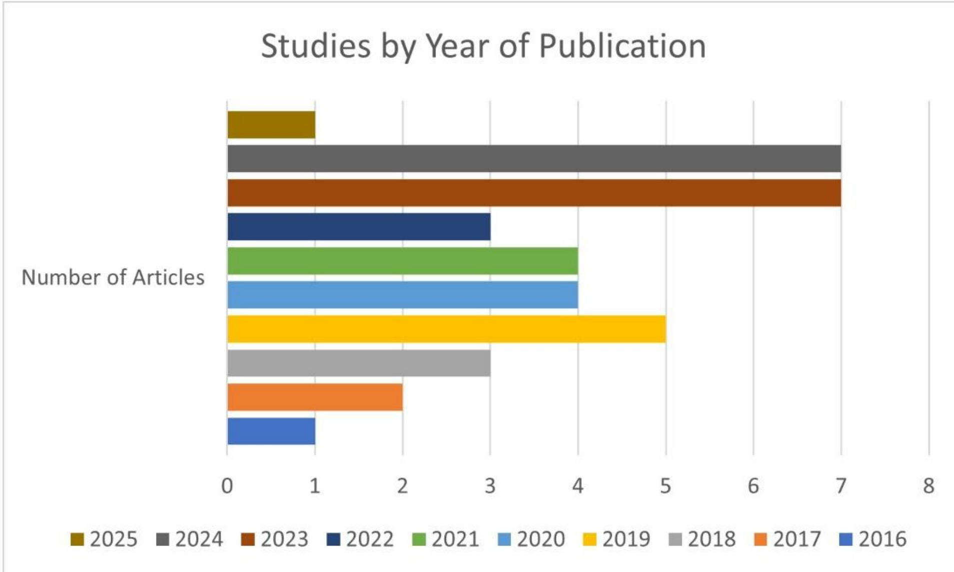

Figure 3: *Data Distribution by Year of Publication*

The geographical configuration, which is heavily dominated by Indonesia, suggests a strong correlation with the implementation of national curriculum policies emphasizing innovative learning approaches. On the other hand, the temporal trend, marked by a significant escalation in publication volume in recent years, peaking in 2023 and 2024 reflects an academic response to the disruption in education following the pandemic. This situation has accelerated the adoption of adaptive and relevant instructional models, including Problem-Based Learning (PBL).

3.1.2 Technology Integration and Educational Contexts

One of the most salient findings of this review is the diversity of technology integration in the implementation of PBL. The analysis identified several forms of technological innovations that function as enablers to facilitate and optimize problem-based learning processes, as presented in Table 3.1.

Table 3.1 *Categorization of Technological Innovations in the Implementation of PBL*

Category of Innovation	Specific Technologies Identified	Role of Technology in Supporting PBL
Augmented Reality (AR)	Augmented Reality, Physics Pocketbook integrating AR	Visualizing abstract concepts into real objects for problem analysis.
Interactive Simulation	PhET Simulation, Computer Simulation	Creating virtual environments for experimentation and solution testing.
E-Modules & Digital	Interactive Physics E-	Providing dynamic self-learning

Books	Module, Digital Book (E-Book) with 3D Animations	resources for the exploration stage.
Learning Management System (LMS)	Google Classroom, Moodle LMS	Managing learning flow, collaboration, and distribution of problem materials.
Learning Platforms	Flipped Classroom, Video Resources	Facilitating independent learning before problem discussion sessions.
Assessment Tools	Electronic Student Worksheet, E-scaffolding	Conducting formative assessments and providing feedback during the learning process.

These findings suggest that the current application of PBL is reinforced by technology, resulting in what can be described as Technology-Enhanced PBL. Innovations such as Augmented Reality (AR) and PhET simulations have been utilized to concretize abstract concepts, while Learning Management Systems (LMS) and flipped classroom models have been instrumental in supporting flexible PBL processes in the post-pandemic era.

Furthermore, the analysis of educational contexts reveals variations in PBL implementation, as shown in Figure 4. High Schools represent the most frequently investigated level, with 22 articles (59.5%), followed by Higher Education with 12 articles (32.4%), and Middle Schools with 3 articles (8.1%).

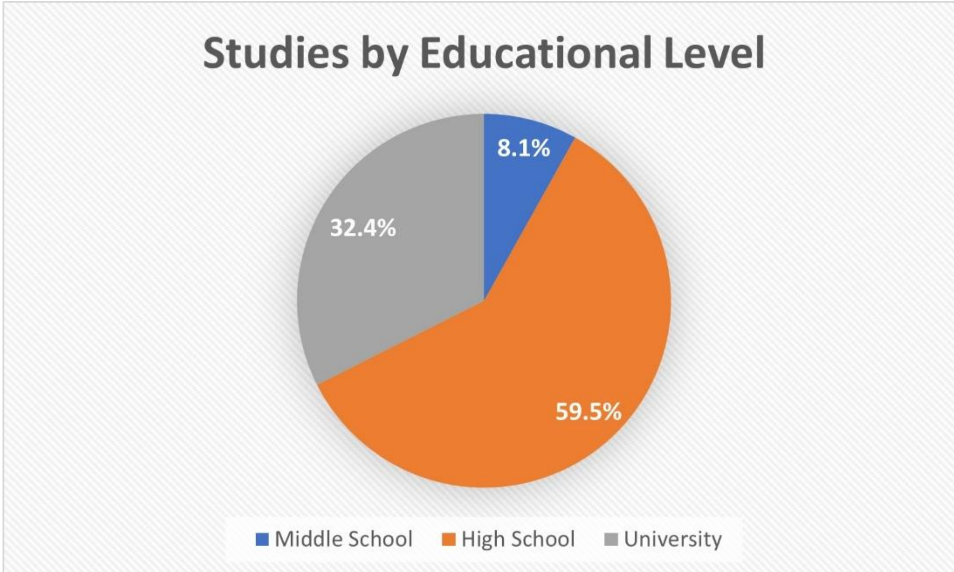

Figure 4: *Data Distribution by Educational Level*

The dominance of research at the High School level is highly logical, given the complexity and abstract nature of physics concepts at this stage (e.g., Electricity and Magnetism) that necessitate contextual approaches like PBL. Moreover, high school students are considered to possess sufficient cognitive maturity to engage in complex PBL processes. Conversely, the limited number of studies at the Middle School level indicates a gap in the literature, possibly linked to perceptions regarding students' cognitive readiness or the lack of modifications in PBL models tailored to younger learners.

3.1.3 Distribution of Physics Topics

The analysis of instructional topics reveals the strategic focus of researchers. After categorizing specific topics into broader domains, clear patterns emerge. As presented in Table 3.2, the Mechanics domain which includes Force and Motion, Newton's Laws, Kinematics, Simple Harmonic Motion, Momentum and Impulse, Work and Energy, Simple Machines, Elasticity, and Force Concept Inventory (FCI) is the most extensively researched area with 16 articles (43.2%). This is followed by Electricity & Magnetism, with 8 articles (21.6%).

Table 3.2 *Distribution of Physics Topics in PBL Research*

Topic Category	Number of Articles	Percentage
Mechanics	16	43.2%
Electricity & Magnetism	8	21.6%
Waves & Optics	6	16.2%

Thermodynamics	4	10.8%
Fluids	2	5.4%
Modern Physics	1	2.7%
Total	**37**	**100%**

The dominance of Mechanics as well as Electricity & Magnetism aligns with the inherent characteristics of these fields, which are known for their high levels of abstraction and persistent misconceptions. Researchers strategically employ PBL as a means of mitigating such misconceptions through contextualized approaches and real-world problem solving. The convergence between these findings and those concerning technology integration further strengthens this argument: computer simulations and AR technologies are specifically employed to visualize abstract concepts in these domains. In contrast, the relatively lower frequency of studies addressing topics such as Thermodynamics and Fluid Dynamics highlights an existing research gap and signals potential avenues for future research.

3.2 RQ 2. How Effective is the Problem-Based Learning (PBL) Model in Supporting various Aspects of Physics Learning Outcomes?

The analysis of 37 articles revealed that the effectiveness of Problem-Based Learning (PBL) in physics education was evaluated across multiple dimensions of learning outcomes. Overall, these dimensions can be categorized into three major domains: (1) cognitive learning outcomes and conceptual understanding, (2) process skills and 21st-century skills (problem-solving, critical thinking, collaboration, and creativity), and (3) affective aspects (students' motivation, interest, attitudes, and self-efficacy toward physics). Most studies measured more than one aspect simultaneously, indicating a comprehensive understanding of the multidimensional impact of PBL.

3.2.1 Effectiveness of PBL on Conceptual Understanding and Cognitive Learning Outcomes

Findings consistently demonstrate that PBL is effective in enhancing students' cognitive achievement and conceptual understanding. Several studies reported that students taught using PBL achieved significantly higher conceptual comprehension compared to those taught through conventional methods (Anwar et al., 2019; Batlolona et al., 2020; Fidan & Tuncel, 2019; Kanyesigye et al., 2022a; Nicholus et al., 2024). Similarly, Rusnayati et al. found that the integration of a Problem-Based Flipped Classroom in physics education significantly improved pre-service teachers' conceptual understanding of crystal structure, with an average N-Gain of 0.75 (high category) and a large effect size (d = 2.86), indicating a very strong impact on students' learning outcomes (Rusnayati et al., 2023). For instance, Mundilarto & Ismoyo reported that the average gain score of students' physics achievement in the experimental group was 0.63, compared to only 0.32 in the control group. PBL not only improved students' physics performance but also deepened their conceptual understanding (Mundilarto & Ismoyo, 2017). However, some studies suggested that in specific contexts (e.g., topics on Heat and Temperature), other instructional models such as ARIAS and PrBL demonstrated slightly higher effectiveness, although PBL still yielded positive impacts (Anwar et al., 2019; Milla Pino et al., 2024).

3.2.2 Effectiveness of PBL on Process Skills and 21st-Century Skills

The analysis further showed consistent evidence that PBL effectively fosters both scientific process skills and 21st-century competencies in physics education. This effectiveness is manifested through significant improvements in problem-solving, critical thinking, collaboration, and creativity. Specifically, PBL not only facilitates the acquisition of procedural knowledge through engagement with authentic problems but also acts as a catalyst for metacognitive development and higher-order thinking.

Evidence from previous studies further supports PBL's effectiveness in improving problem-solving skills. For example, Argaw et al. found that while students' motivation did not significantly increase, their problem-solving skills improved considerably ($p<0.05$) with a large effect size ($\eta^2 = 0.147$) (Argaw et al., 2017). Similarly, Suharlan et al. confirmed that PBL consistently outperformed discovery learning, regardless of students' levels of self-directed learning. The average problem-solving scores of students with high self-directed learning were 67.30 (PBL) and 60.20 (discovery learning), while students with low self-directed learning scored 62.70 and 56.30, respectively (Suharlan et al., 2023). These results emphasize that the primary strength of PBL lies in its use of authentic problems that stimulate logical reasoning, mathematical & graphical representation (Rahmasari & Kuswanto, 2023), and systematic metacognitive reflection, even for students with limited learning autonomy. Thus, the effectiveness of PBL in enhancing problem-solving is not merely contingent on students' intrinsic motivation but is embedded in its pedagogical framework, which structures learning experiences toward meaningful mastery of problem-solving.

PBL also significantly improves students' critical thinking in physics learning (Jatmiko et al., 2018; Mundilarto & Ismoyo, 2017). Studies demonstrated that PBL trains students to analyze problems, draw inferences, and construct structured scientific arguments (Salazar et al., 2023). Additionally, PBL has been proven to enhance students' critical and creative thinking skills, with experimental groups outperforming control groups (Anazifa & Djukri, 2017; Wenno et al., 2021). The integration of technology, such as interactive e-modules and PhET simulations, further amplifies this effect by visualizing abstract concepts (Marnita et al., 2020; Putranta et al., 2019; Suhirman & Prayogi, 2023; Sujanem & Putu Suwindra, 2023). Similarly, the use of digital media such as 3D animations and videos fosters creativity by providing interactive visual representations that stimulate students' imagination. Moreover, PBL's collaborative approach encourages group discussions and metacognitive reflection, contributing to holistic improvements in critical thinking. These findings highlight that PBL not only supports conceptual comprehension but also cultivates analytical skills essential for solving complex problems while promoting innovation and experimentation in physics learning. Consistent with these findings, Fauzi Bakri et al. confirmed that the integration of a WordPress-based e-learning model for PBL in Heat and Thermodynamics successfully facilitated independent learning, enhanced conceptual mastery, and fostered critical, creative, collaborative, and communicative competencies among high school students (Bakri et al., 2018).

3.2.3 Effectiveness of PBL on Motivation, Interest, Attitude and Self-Efficacy toward Physics

Beyond cognitive and skill-related outcomes, PBL also exerts a significant impact on students' affective dimensions, including motivation, interest, attitudes, and self-efficacy in learning physics. Implementing PBL with digital resources such as Open Educational Resources (OER) and electronic student worksheets creates more engaging, relevant, and empowering learning environments. Although self-efficacy is not solely determined by instructional models, students in OER-assisted PBL classrooms tended to report higher self-efficacy (Sedayu et al., 2024). Other studies similarly found that both PBL and PJBL (Project-Based Learning) effectively foster positive attitudes toward physics and students' responsibility for their own learning. While PJBL showed slightly greater improvements in problem-solving, both approaches contributed significantly to enhancing students' interest and motivation which are key foundations for affective engagement (Kan & Saka, 2021).

Moreover, Problem-Based Instruction (PBI) has been implemented in university-level physics courses (Lee et al., 2023). Despite challenges such as online learning during the pandemic, students expressed strong appreciation for opportunities to interact socially with peers and engage with laboratory equipment which are core elements of PBL. These active and contextual learning experiences strengthened students' confidence in their own abilities. Using the Colorado Learning Attitudes towards Science Survey (CLASS), Lee et al. also found that students showed shifts toward more expert-like epistemological beliefs in physics learning, particularly in the domains of problem-solving confidence, real-world connection, and conceptual understanding.

The effectiveness of PBL in creating deep learning experiences can be further optimized through appropriate media support. Nenggala et al. emphasized that developing PBL-based electronic worksheets (e-LKPD) was not only valid and practical but also highly effective in making physics learning more interactive and enjoyable (Nenggala et al., 2024). The integration of animations, videos, and simulations within e-LKPD facilitated students' comprehension of abstract concepts such as fluid dynamics while simultaneously enhancing their affective engagement. In summary, PBL especially when supported by digital resources (e.g., OER and e-LKPD) plays a critical role in fostering positive affective outcomes that underpin students' success in physics learning. This approach provides authentic, collaborative, and empowering learning experiences that ultimately enhance students' motivation, interest, attitudes, and self-confidence in learning physics.

3.3 RQ3. What are the Challenges and Recommendations in Implementing the Problem-Based Learning (PBL) Model in Physics Education?

From the synthesis of 37 research articles on the implementation of Problem-Based Learning (PBL) in physics education, several key challenges and recommendations have been identified. Together, these findings highlight critical aspects that must be considered for effective implementation. Table 3.3 summarizes the challenges along with the corresponding recommendations derived from the reviewed studies.

Table 3.3 *Challenges and Recommendations in Implementing PBL in Physics Education*

Category	Challenges	Recommendations
Students	Low motivation, difficulty adapting to student-centered learning,	Provide scaffolding (e-scaffolding, peer tutoring), use simulations

	misconceptions due to abstract concepts, weak group dynamics.	(PhET, AR) with hands-on experiments, structured group work, adequate time for synthesis.
Teachers	Lack of training, perception of PBL as complex and time-consuming, difficulty designing contextual problems, weak facilitation skills.	Continuous professional development, workshops on scenario design, facilitation, and digital tools, mentoring and peer support.
Resources & Infrastructure	Limited time allocation, insufficient facilities, weak access to labs and technology.	Flexible scheduling, hybrid models, alternative/low-cost resources, institutional investment in infrastructure.
Curriculum & Policy	Misalignment with rigid curricula and standardized assessments.	Curriculum flexibility, authentic assessment tools, integration of PBL into national curriculum frameworks.
Technology	Digital competence required, unstable internet, reluctance to adopt new tools.	Develop AR apps, PBL-based e-modules, LMS use, blended PBL models, integration with STEM and PjBL.

The most fundamental challenges stem from the learners, particularly their low initial motivation and unfamiliarity with student-centered learning structures. These often lead to difficulties in adapting, especially during the problem formulation and hypothesis development stages (Batlolona & Souisa, 2020; Shishigu et al., 2018). The inherently abstract nature of physics (e.g., the behavior of microscopic particles or wave superposition) further complicates this situation due to difficulties in visualization, which may foster misconceptions and highlight low levels of initial scientific literacy (Kanyesigye et al., 2022a; Parno et al., 2020). In addition, suboptimal group dynamics, characterized by unequal task distribution, internal conflicts, and passive communication become significant obstacles to the success of the collaborative learning that underpins PBL (Marcinauskas et al., 2024; Susbiyanto et al., 2019).

From the educators' perspective, the main challenges lie in the lack of preparation, training, and deep understanding of the philosophy and practice of PBL. Many teachers and lecturers perceive this model as a complex and time-consuming burden (Kan & Saka, 2021; Kanyesigye et al., 2022b). Common difficulties include designing contextual and relevant problem scenarios (Yuberti et al., 2019), effectively facilitating discussions and communication (Susbiyanto et al., 2019), and consistently managing all phases of the PBL process in a structured manner (Mundilarto & Ismoyo, 2017). These challenges are compounded by systemic and resource-related constraints. PBL inherently requires significant time allocation, both for educators to prepare and guide (Adamczyk et al., 2025) and for students to engage in the learning process (Shishigu et al., 2018). Limited access to project resources, technological infrastructure, and laboratory facilities also poses substantial barriers, especially in post-COVID-19 contexts (Fidan & Tuncel, 2019; Lee et al., 2023; Putranta et al., 2019).

At the institutional level, the success of PBL largely depends on administrative commitment and support to adapt rigid curricula and traditional assessment standards to accommodate flexible timelines. Although technology integration offers potential solutions, it simultaneously presents a paradox and unique challenges. On the one hand, technology is required to create resources such as e-worksheets and e-modules (Nenggala et al., 2024). On the other hand, it demands high levels of creativity and digital competence from educators. Technical issues such as unstable internet connections, large file sizes, and reluctance to adopt new tools further complicate the implementation landscape (Gumisirizah et al., 2024; Prahani et al., 2022; Rizal et al., 2021).

In response to these complex challenges, the literature proposes several strategic and multidimensional recommendations to enable more effective PBL implementation. The most fundamental recommendation is the establishment of robust support systems for students, particularly during the initial phases of PBL adoption. This can be achieved through e-scaffolding (Muslimin, M., Handayanto, S. K., & Sari, 2024), the use of virtual simulations such as PhET alongside hands-on experiments to visualize abstract physics concepts (Suhirman & Prayogi, 2023), and structured group work that fosters peer tutoring (Batlolona & Souisa, 2020). Adequate time allocation, including opportunities for students to synthesize knowledge, is also a critical success factor (Adamczyk et al., 2025).

At the educator level, investment in continuous and comprehensive professional development is the most frequently recommended strategy. Training should focus on enhancing teachers' competence in designing contextual problem scenarios (Yuberti et al., 2019), effectively facilitating PBL (Susbiyanto et al., 2019), utilizing technological tools (Nenggala et al., 2024; Putranta et al., 2019), and managing student-centered learning environments. These efforts must be supported by strong commitments from governments and school administrators to organize regular and widespread training programs (Kanyesigye et al., 2022b).

Parallel to this, strategic technology integration is strongly advised to address the inherent challenges of PBL. Concrete recommendations include developing and adopting interactive Augmented Reality (AR) applications (Fidan & Tuncel, 2019), utilizing PBL-based e-modules and e-worksheets as core instructional materials (Nenggala et al., 2024; Sujanem & Putu Suwindra, 2023), and leveraging LMS platforms to support collaboration and learning management (Salazar et al., 2023). The use of computer simulations is also highly recommended to enhance understanding of abstract topics (Simanjuntak et al., 2021). Moreover, hybridization and combination of models are encouraged to create more holistic learning experiences, such as integrating STEM approaches into PBL for direct engineering projects (Parno et al., 2020), incorporating elements of Project-Based Learning (PjBL) (Milla Pino et al., 2024), or implementing Blended PBL that combines the advantages of online and face-to-face learning (Marnita et al., 2020; Sujanem & Putu Suwindra, 2023).

For sustainability, curriculum and policy adjustments at both institutional and national levels are essential. This includes providing flexibility in time allocation and assessment, demonstrating strong commitment to adapting curricula that align with PBL philosophy, and even considering integrating this innovative model into national curriculum frameworks to promote the development of 21st-century skills (Simanjuntak et al., 2021). Finally, to further strengthen the empirical foundation of PBL, future research with larger and more diverse samples, more rigorous experimental designs, and broader exploration of dependent variables such as collaboration skills, problem-solving, and self-efficacy is highly recommended (Sedayu et al., 2024).

Overall, the synthesis of this literature underscores that the successful implementation of PBL in physics education is not a simple endeavor, but rather a systematic effort involving multiple stakeholders. The interconnected challenges at the student, teacher, and institutional levels require integrated and comprehensive solutions. The proposed recommendations cannot be implemented in isolation; scaffolding for students must be supported by adequate teacher training, which in turn requires supportive policies and flexible curricula. Thus, the transformation toward problem-based physics learning necessitates collective commitment and a holistic systemic approach to create a truly conducive learning ecosystem.

4. Conclusion

The implementation of Problem-Based Learning (PBL) in physics education has a significant impact on the development of conceptual understanding, 21st-century skills (problem solving, critical thinking, creativity, and collaboration), as well as students' affective aspects such as motivation, interest, and self-confidence. The majority of studies were conducted at the high school level, with a dominant focus on the topics of Mechanics and Electricity & Magnetism. The integration of technology such as computer simulations, Augmented Reality (AR), e-modules, and Learning Management Systems (LMS) has strengthened the effectiveness of PBL and fostered the formation of a more adaptive learning ecosystem in the post-pandemic era. However, the uneven distribution of research at the junior high school and higher education levels, as well as in topics such as thermodynamics, fluid mechanics, and modern physics, still leaves gaps that need further exploration. The main challenges in implementing PBL lie in students' readiness, teachers' capacity, resource limitations, and institutional support. Therefore, the success of PBL can only be achieved through a combination of scaffolding strategies, continuous teacher training, appropriate technology integration, and flexible, supportive curriculum policies.

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