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Effectiveness and Innovation of Problem-Based Learning in Physics Learning in a Decade: A Literature Analysis of Critical Thinking Development

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ABSTRACT

Purpose – This study examines the effectiveness of the PBL model in enhancing students' CTS in physics education. It explores recent innovations, including digital learning tools, authentic assessment, and local cultural contexts.

Methodology—This study uses a Systematic Literature Review (SLR) approach, guided by the PRISMA framework, to review 18 peer-reviewed articles published between 2014 and 2024. These studies focus on the impact of PBL on students' CTS in physics education.

Findings – The findings show that PBL consistently improves students' CTS, with N-Gain values ranging from moderate to high (0.36–0.73). PBL outperformed models like Discovery Learning, Reciprocal Learning, and Demonstration Methods, though the OR-IPA model performed better in some contexts, fostering higher-order thinking skills (HOTS). Innovations in PBL materials, such as worksheets, modules, E-LKPD, PhET simulations, and interactive multimedia, demonstrated high validity (0.82–0.93) and effectiveness in supporting Learning. PhET simulations and interactive multimedia helped students understand abstract physics concepts and enhanced critical thinking.

Contribution—This study highlights the importance of integrating technology, local wisdom, and web-based Learning in PBL to enhance its effectiveness. It also provides practical recommendations for educators, including developing technology-based materials, teacher training, and improved access to learning resources like computers and the Internet.

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INTRODUCTION

Developing critical thinking skills (CTS) is increasingly recognized as a core competency in 21st-century education. Critical thinking empowers students to scrutinize information, assess arguments, formulate rational conclusions, and resolve intricate problems grounded in evidence. These skills are essential for academic achievement and success in real-world contexts that demand adaptive and reflective thinking (Byhar et al., 2024; Pavlenko et al., 2024). In the context of science education, and particularly physics, critical thinking plays a pivotal role in helping students understand abstract concepts, draw logical inferences, and apply knowledge in diverse and dynamic situations.

Physics is one of the subjects that is often considered difficult by many students. This difficulty is caused by the many abstract concepts and theories that must be understood, such as force, motion, energy, and electricity, which demand higher-level thinking skills to analyze, connect, and apply them in real life (Nyoman et al., 2025). However, the physics learning process in schools is still dominated by conventional methods such as lectures and memorization. This method is unidirectional and fails to engage students actively, hence obstructing the cultivation of critical thinking and problem-solving abilities essential for comprehending physics content (Ranepa & Federation, 2024; Shivaleela et al., 2024). As a result, many students struggle to build conceptual understanding and apply physics knowledge in various contextual situations.

In response to the persistent challenges faced in physics education, the Problem-Based Learning (PBL) approach emerges as a pedagogical strategy that encourages students to engage with complex, real-world problems, requiring them to apply their knowledge, collaborate with peers, and engage in deep critical thinking. (Hung & Amida, 2020). By placing students at the center of the learning process, PBL shifts the focus from traditional teacher-centered methods to student-centered inquiry (Maistriuk, 2024). This model improves students' problem-solving skills and enhances their ability to think critically and analytically, which are vital skills in today's information-rich world (Ellianawati et al., 2025).

Over the past decade, PBL has gained recognition for its effectiveness in improving students' CTS, particularly in science education. Numerous studies have explored the impact of PBL on physics learning, demonstrating its potential to foster deeper understanding and better retention of knowledge (Hafizah et al., 2024; Verawati et al., 2024). By integrating technology, such as interactive simulations and multimedia tools, PBL has become even more effective in engaging students with abstract concepts, allowing them to visualize and manipulate complex physical phenomena (Xudayberdiyevna, 2024). Additionally, integrating local wisdom and collaborative online learning platforms has further enhanced the relevance and accessibility of PBL, providing students with a more holistic learning experience (Habibie et al., 2024; Zaki et al., 2024).

Despite its proven benefits, the implementation of PBL is not without challenges. Issues such as inadequate teacher training, limited access to technology, and the need for sufficient time and resources for collaborative work can hinder its widespread adoption (Abildinova et al., 2024; Eboi et al., 1 C.E.). However, the growing body of research over the last decade indicates that the potential of PBL to foster critical thinking and improve learning outcomes in physics remains strong (Dumbuya, 2024; Muftidafila et al., 2025). It is crucial to evaluate how PBL has evolved, its innovations, and the strategies that have made it successful in fostering critical thinking among students(Ali, 2019). Click or tap here to enter text.

Although numerous studies have examined the application of PBL in education, few have systematically explored its innovations and effectiveness in the context of technology integration and local wisdom within physics learning over the last decade. This represents a critical gap in the current literature.

Therefore, this study aims to analyze the effectiveness of PBL in enhancing students' CTS in physics education while also examining recent innovations in its implementation. These innovations include integrating digital learning tools, authentic assessment, and local cultural contexts. By reviewing relevant literature, this study seeks to provide insights into developing CTS through PBL, its integration with technology, and the lessons learned from its application in diverse educational settings. Ultimately, the goal is to offer practical recommendations for educators on how to maximize the potential of PBL to improve students' critical thinking abilities and better prepare them for future challenges.

METHODOLOGY

This study adopts a Systematic Literature Review (SLR) approach guided by the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) framework. This approach aims to systematically identify, evaluate, and synthesize research findings on the effectiveness and innovation of the Problem-Based Learning (PBL) model in enhancing students' CTS in physics education. The PRISMA method ensures transparency and replicability in selecting, screening, and analyzing relevant studies.

Data Sources

The data for this study were collected from several indexed academic journal databases, namely Google Scholar, Scopus, and Crossref. The selected articles focus on applying PBL in physics education and its impact on developing students' CTS. A systematic search strategy was employed using the keywords "Problem-Based Learning," "Critical Thinking," AND "Physics," combined with Boolean operators to refine the search results. The review included only peer-reviewed journal articles published between 2014 and 2024.

Article Selection Process

The article selection process follows the steps outlined in the PRISMA guidelines, which involve four main stages: identification, screening, eligibility, and inclusion of articles. Below is a detailed explanation of each stage:

Identification

Initially, an initial search yielded 2,031 articles from the databases used (Google Scholar, Scopus, and Crossref). These articles were then checked for relevance to the research topic.

Screening

Of the 2,031 articles identified, 1,615 unique articles were screened based on their abstracts and titles. At this stage, articles that did not meet the inclusion and exclusion criteria were removed. Six hundred twenty-nine articles were discarded as they were irrelevant to the research topic.

Eligibility

Next, 172 articles that met the inclusion criteria were selected for full-text review. At this stage, articles that did not meet the eligibility criteria, such as poor methodological quality, irrelevance to the topic, or other reasons, were eliminated. Of the 172 articles reviewed, 457 were excluded due to failure to meet the eligibility criteria.

Inclusion

The inclusion criteria for this study were articles published between 2014 and 2024, focusing on implementing Problem-Based Learning (PBL) in physics education and its relationship to critical thinking. Only articles written in English and published in peer-reviewed journals with a clearly defined research design were included. On the other hand, the exclusion criteria comprised articles that lacked a defined research methodology, such as opinion papers and editorials, and articles not indexed in major academic databases like Scopus, Crossref, and Google Scholar. Duplicate publications and articles with data irrelevant to the research focus were also excluded from the review. As a result of this selection process, 18 articles were included in the quantitative analysis. These articles are relevant and meet the rigorous methodological standards required for this systematic review.

PRISMA Flow Diagram

The PRISMA flow diagram clearly and systematically illustrates how the relevant articles were selected through several stages. Figure 2 presents the flow diagram of the research process, showing how articles were progressively selected for inclusion in the review.

Data Analysis

Once the articles that met the criteria were selected, the data obtained from each article were analyzed with a focus on the following aspects:

Effectiveness of PBL in improving students' CTS

Innovations in PBL applied in physics education include integrating technology, simulations, and interactive multimedia. Factors Affecting the Implementation of PBL, including challenges and obstacles educators face when applying PBL.

Analysis Framework

Each selected article was analyzed and compared based on the findings, then synthesized to gain broader insights into the effectiveness and innovation of PBL in physics education. The results of this analysis will be discussed further in the discussion section to provide practical recommendations for educators.

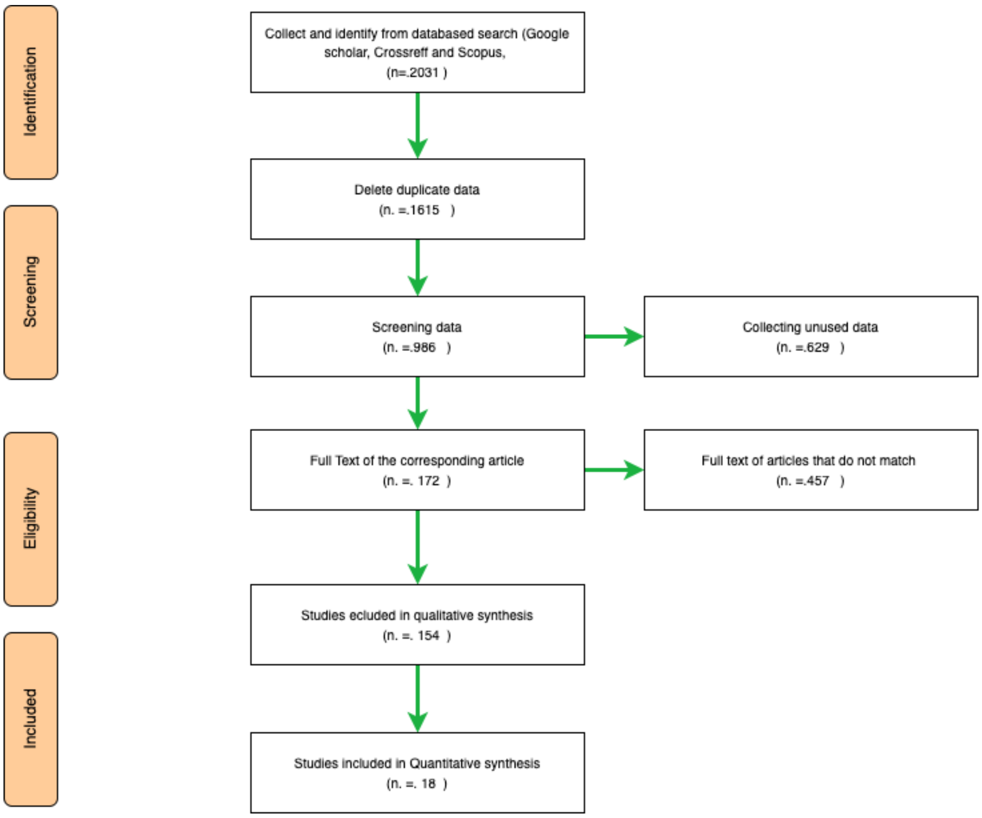

Figure 2. PRISMA Flow Diagram for Article Selection Process

FINDINGS

This study was conducted systematically following a systematic review protocol consisting of four main stages: identification, screening, eligibility assessment, and inclusion. In the identification stage, literature was collected from several search databases, namely Google Scholar, Crossref, and Scopus, which resulted in 2,031 articles. After removing duplicate data, 1,615 unique articles were obtained, which continued to the next stage. The screening stage was conducted by applying inclusion and exclusion criteria, resulting in 986 literature reviews that met the criteria, while the remaining 629 articles were excluded due to unsuitability. Next, in the eligibility assessment stage, the 986 screened articles were reviewed in-depth based on full-text screening, and only 172 articles were found eligible for further analysis.

In comparison, 457 articles were excluded for the reasons noted. At the inclusion stage, of the 172 articles that met the eligibility criteria, 154 articles were included in the qualitative synthesis. Of these, only 18 articles were quantitatively relevant and included in the quantitative synthesis. Thus, from a total of 2,031 articles identified in the initial stage, only 18 were finally included in the quantitative synthesis analysis, indicating a rigorous selection process to ensure valid and reliable results.

Table 1. PRISMA Selection Results Article Table

No	Category	Title	Author	Journal
1	Development of Learning Devices	The Development of Problem-Based Learning Worksheet to Train Student Critical Thinking Skills on Works and Energy Materials(Hamatun et al., 2018)	Hamatun et al.	International Journal of Advanced Research
2	Development of Learning Devices	Validation of the Physics E-Module Based on Problem-Based Learning as Independent Teaching Material to Improve Critical Thinking Skills of Class XI High School Students (Azriyanti, 2023)	Riza Azriyanti & Syafriani	Jurnal Penelitian Pendidikan IPA
3	Development of Learning Devices	The Effectiveness of Problem-Based Learning - Physics Module with Authentic Assessment for Enhancing Senior High School Students' Physics Problem-Solving Ability and Critical Thinking Ability (Suastra et al., 2019)	I Wayan Suastra et al.	Journal of Physics: Conference Series
4	Development of Learning Devices	Development of Physics Learning Material Based on Problem-Based Learning by Integrating Local Wisdom of West Sumatra to Improve the Critical Thinking Ability of Students (Oktavia et al., 2018)	Ridha Arahmi et al.	International Journal of Progressive Sciences and Technologies
5	Development of Learning Devices	Analysis of Physics E-LKPD Needs Based on Problem-Based Learning to Improve Students' Critical Thinking Skills (Larasati et al., 2023)	Yurika Usparianti L et al.	Jurnal Pendidikan Fisika dan Teknologi
6	Development of Learning Devices	The Implementation of Problem-Based Learning Toward Critical Thinking Skills of Students in General Physics I (Simanjuntak & Turnip, 2017)	Mariati Purnama Simanjuntak & Betty Marisi Turnip	Trends in science and science education
7	Model Comparison	The Effect of Problem-Based Learning Models and Interest in Learn Physics on Students' Critical Thinking Skills of Class XI Students at SMA Negeri 1 Selayar (Hasbi et al., 2024)	Ade Rezki Ramadayani Hasbi et al.	International Journal of Social Science and Human Research
8	Model Comparison	The Comparison of Orientasi IPA Teaching Model and Problem-Based Learning Model Effectiveness to Improve Critical Thinking Skill of Physics Teacher Candidates (Jatmiko et al., 2018)	Budi Jatmiko et al.	Journal of Baltic Science Education
9	Model Comparison	The Effect of Problem-Based Learning Teaching Method on Students' Critical Thinking Skills in Physics Lesson at SMA Negeri 4 Singaraja (Lisniandila et al., 2019)	Ni Putu Ayu Lisniandila et al.	Jurnal Pendidikan dan Pembelajaran
10	Model Comparison	The Influence of Problem-Based Learning Model and Critical Thinking Ability on Higher Order Thinking Skills (HOTS) of Physics Prospective	Nurhayati et al.	Journal of Physics: Conference Series

		Teachers Students (Nurhayati et al., 2021)		
11	Model Comparison	Physics Learning with a Metacognitive Approach through Problem-Based Learning (PBL) and Reciprocal Learning (RL) Model Viewed from Students' Critical Thinking Skills (Sulasih et al., 2018)	Sulasih et al.	International Journal of Pedagogy and Teacher Education
12	Model Comparison	Profile of Students' Physics Critical Thinking Skills and Prospect Analysis of Project-Oriented Problem-Based Learning Model (Suprapto et al., 2024)	Nadi Suprapto et al.	Journal of Educational and Social Research
13	Model Comparison	Effect of Problem-Based Learning on Improvement of Physics Achievement and Critical Thinking of Senior High School Students (Mundilarto & Ismoyo, 2017)	Mundilarto & Helmiyanto Ismoyo	Journal of Baltic Science Education
14	Technology Utilization	The Effects of Web-Assisted Problem-Based Learning Model of Physics Learning on High School Students' Critical Thinking Skills (Alandia et al., 2019)	Rahma Ghalda Alandia et al.	Journal of Physics: Conference Series
15	Technology Utilization	The Improvement of Student's Critical Thinking Skills on Motion System Material through Using Digital Book Based on Problem-Based Learning (Ernawati et al., 2022)	Yuliana Ernawati et al.	Journal of Innovative Science Education
16	Technology Utilization	Problem-Based Learning Approach with Supported Interactive Multimedia in Physics Course: Its Effects on Critical Thinking Disposition (Gunawan et al., 2019)	Gunawan et al.	Journal for the Education of Gifted Young Scientists
17	Technology Utilization	Critical Thinking Development in Physics Courses by Problem-Based Learning in Virtual Collaboration Environments (Salazar et al., 2023)	Laura Muñoz Salazar et al.	International Journal of Innovation in Science and Mathematics Education
18	Technology Utilization	Physics Learning by PhET Simulation-Assisted Using Problem-Based Learning (PBL) Model to Improve Students' Critical Thinking Skills in Work and Energy Chapters(Putranta & Wilujeng, 2019)	Himawan Putranta &Jumadi, Insih Wilujeng	Asia-Pacific Forum on Science Learning and Teaching

Based on the data table above, the findings of this study are as follows:

Table 2. Research findings

No	Research Conclusions	Author
1	Project-Based Learning significantly enhances students' critical thinking abilities in physics education across all educational tiers.	1. (Hamatun et al., 2018) 2. (Alandia et al., 2019) 3. (Azriyanti, 2023) 4. (Ernawati et al., 2022) 5. (Simanjuntak & Turnip, 2017)

		6. (Putranta & Wilujeng, 2019)
2	Integrating media and technology (such as PhET, interactive multimedia, and E-LKPD) strengthens the effectiveness of PBL in physics learning.	1. (Gunawan et al., 2019) 2. (Larasati et al., 2023) 3. (Putranta et al., 2019)
3	PBL with authentic assessment effectively improves students' critical thinking and problem-solving skills.	1. (Suastra et al., 2019)
4	Combining local knowledge with a PBL based method enhances students' critical thinking abilities and learning relevance.	1. (Oktavia et al., 2018) 2. (Salazar et al., 2023)
5	The PBL model is superior to other learning models, such as Reciprocal Learning (RL) or Discovery Learning, in improving students' CTS.	1. (Sulasih et al., 2018) 2. (Hasbi et al., 2024) 3. (Mundilarto & Ismoyo, 2017)
6	OR-IPA model is superior to PBL in improving the CTS of physics education students.	1. (Jatmiko et al., 2018)

This study shows that Problem-Based Learning (PBL) is proven effective in improving students' CTS in physics across various levels of education. PBL engages students in problem-based Learning, which allows them to collaborate, think analytically, and develop problem-solving skills. Several research confirm this conclusion, among which The Development of PBL Worksheets to Train Student CTS on Works and Energy Materials (Hamatun et al., 2018), The Impact of the Web Assisted PBL (Alandia et al., 2019), and Physics Education using PhET Simulation Assisted PBL (Putranta & Wilujeng, 2019), which demonstrate that PBL effectively enhances students' critical thinking in physics education.

Additionally, the findings indicate that integrating media and technology, such as PhET Simulations, E-LKPD, and interactive multimedia, strengthens the effectiveness of PBL in developing students' CTS. Technology provides students practical experiences that deepen their understanding of complex physics concepts. Studies supporting this include the Problem-Based Learning Approach with Supported Interactive Multimedia (Gunawan et al., 2019) and Physics Learning by PhET Simulation-Assisted Using PBL (Putranta et al., 2019), which highlight how integrating technology in PBL enriches the learning experience and enhances critical thinking.

Furthermore, the research also emphasizes that PBL with authentic assessment effectively improves students' critical thinking and problem-solving abilities. Authentic assessments provide students with the opportunity to solve real-world problems and receive relevant feedback on their learning outcomes, as demonstrated by studies such as The Efficacy of the PBL Physics Module Incorporating Authentic Assessment and the Efficacy of PBL with Authentic Assessment on Critical Thinking Abilities (Suastra et al., 2019). This suggests that PBL focuses on theory and engages students in practical, application-based Learning.

Moreover, the study indicates that PBL integrating local wisdom enhances learning relevance and students' CTS. By connecting learning materials with students' cultural contexts, the Learning becomes more meaningful and relevant, which increases students' motivation and understanding of physics content. Research supporting this conclusion include Development of Physics Learning Material Based on PBL by Integrating Local Wisdom of West Sumatra (Oktavia et al., 2018) and the enhancement of CTS in physics courses through a PBL approach conducted within virtual collaborative environments. (Salazar et al., 2023), which show that integrating local wisdom into PBL can boost students' engagement and comprehension of physics.

Furthermore, the findings also suggest that PBL outperforms other teaching models, such as Reciprocal Learning (RL) and Discovery Learning, in improving students' CTS. PBL encourages students to be more actively engaged in problem-solving. At the same time, other models tend to have limitations in structure and interaction, which can hinder the development of CTS. Articles supporting this finding include Physics Learning with Metacognitive Approach through PBL and RL (Sulasih et al., 2018), The Effect of Problem-Based Learning Models and Interest to Learn Physics (Hasbi et al., 2024), and the impact of PBL on the enhancement of physics achievement and CTS. (Mundilarto & Ismoyo, 2017).

Lastly, even though PBL is proven effective, this study also indicates that the OR-IPA model (Orientasi IPA) is more effective than PBL in improving students' CTS in physics education. OR-IPA focuses more on a scientific knowledge-based approach that is more structured, allowing students to grasp the fundamental concepts of physics better. However, further comparison between these two models regarding implementation and effectiveness is necessary for a clearer understanding. The study supports this finding by comparing OR-IPA and PBL effectiveness for pre-service physics teachers (Jatmiko et al., 2018).

DISCUSSION

In this study, the effectiveness of the PBL model was analyzed compared to several other learning models in improving students' CTS and physics learning outcomes. Table 3 summarizes the comparison results of various studies examining the effectiveness of PBL models with other learning models, such as Discovery Learning, Reciprocal Learning, OR-IPA, Demonstration Method, and conventional models. The results of this comparison show that, in general, PBL has an advantage in improving students' CTS, although in some cases, the OR-IPA model shows better results. The following summarizes the comparison results obtained from various related studies.

Compared to other learning models, PBL is more effective in improving students' CTS. Compared to Discovery Learning, PBL is more effective in training students' CTS, even in students with varying levels of learning interest. Compared to Reciprocal Learning, PBL provides better results in developing students' analysis, synthesis, and evaluation abilities, which are the main components of CTS.

However, compared with the OR-IPA model, especially in physics education students, OR-IPA shows superiority in training higher-order thinking skills (HOTS), such as creating creative solutions and abstract thinking, which is more prominent than PBL. Meanwhile, compared to traditional learning methods such as the Demonstration Method, PBL provides more significant results, with higher N-Gain values in CTS and student learning outcomes.

Table 3. Comparison results of the PBL model with other models

No	Author	Compared Models	Comparison Results	Conclusion
1	Riza Azriyanti & Syafriani (2023)	PBL vs. Discovery Learning	PBL leads to higher CTS among students engaged in Discovery Learning.	PBL model proves to be more effective for students regardless of whether they have high or low levels of learning interest.
2	Sulasih (2018)	PBL vs. Reciprocal Learning (RL)	PBL demonstrates superiority in enhancing student learning outcomes and CTS compared to RL.	There is no significant interaction effect between the learning model and students' CTS.
3	Budi Jatmiko (2018)	PBL vs. OR-IPA	OR-IPA produced a higher average N-Gain (0.63) than PBL (0.47).	The OR-IPA model is more effective than PBL in enhancing the CTS of physics education students.
4	Effect of Problem-Based Learning on Improvement of Physics Achievement and Critical Thinking of Senior High School Students	PBL vs. Demonstration Method	The N-Gain of the PBL group was higher (0.63) than the demonstration method (0.32).	PBL model effectively enhances students' CTS as well as their physics learning outcomes.

5	The Comparison of OR-IPA and PBL Effectiveness for Pre-Service Physics Teachers	PBL vs. OR-PA vs. Conventional	N-Gain: OR-IPA (0.63) > PBL (0.47) > Conventional (0.14).	OR-IPA is superior to PBL and conventional models in improving HOTS and critical thinking.

Compared to the conventional learning model, PBL was superior in almost all indicators of CTS. This includes thinking logically, solving problems, evaluating information, and making appropriate decisions. Thus, PBL is a potential approach to be applied in physics learning at various levels of education; the results of improving learning outcomes can be seen in Table 4.

Table 4. Learning outcomes using the PBL model

No	Author	Sample	Improvement Results
1	Humantun (2018)	25 grade X students at SHS State 10 Bandar Lampung	The experimental group's post-test average score (77.8) was higher than that of the control group (57.2), with an N-Gain value of 0.6.
2	Alandia (2019)	54 students of class XI (27 experimental, 27 control) SMAN 2 Yogyakarta	The mean post-test score of the experimental group (91) exceeded that of the control group (80), indicating a large effect size of 1.3.
3	Himawan Putranta &Jumadi, Insih Wilujeng (2019)	62 students of class X MAN 3 Sleman (32 modeling, 30 implementation)	Improvement in experimental post-test (39.4) compared to pre-test (28.4); N-Gain 0.61 (medium category).
4	I Wayan Suastra (2019)	78 students in class XII of SMA Negeri 4 Singaraja (39 experimental, 39 control)	The post-test PSA score of the experimental group (82.35) was higher than that of the control group (74.6), with the N-Gain falling into the high category.
5	Ridha Arahmi (2018)	31 students of class X SMK 1 Padang	The post-test average increased from 40.32 to 81.29; N-Gain 0.68 (medium category).
6	Mundilarto & Helmiyanto Ismoyo (2017)	64 high school 10th-grade students in Yogyakarta (32 experimental, 32 control)	The experimental N-Gain (0.63) was higher than the control (0.32).
7	Yuliana Ernawati (2022)	108 class XI students in Semarang	The average post-test increased from 48 to 67; N-Gain 0.36 (medium category).

In this study, the effectiveness of the PBL model is analyzed and compared with several other learning models in enhancing students' CTS and physics learning outcomes. Table 3 summarizes the comparison results from various studies that tested the effectiveness of the PBL model against other learning models, such as Discovery Learning, RL, OR-IPA, Demonstration Method, and conventional models. The comparison results show that, in general, PBL has an advantage in enhancing students' CTS. The OR-IPA model sometimes showed better results, especially in developing higher-order thinking skills (HOTS).

Compared to Discovery Learning, PBL produces higher CTS in students, even for those with varying levels of interest in Learning. This is demonstrated in the study by Hasbi (2024). on the effect of problem-based learning models and interest in learning physics on students' critical thinking skills. It shows that PBL is more effective in engaging students in real problem-solving and enhancing their CTS. Furthermore, compared with Reciprocal Learning (RL), PBL shows superiority in learning outcomes and CTS. In the study "Physics Learning with Metacognitive Approach through PBL and Reciprocal Learning (RL) Model" (Sulasih et al., 2018), PBL excels in providing students with opportunities to develop analysis, synthesis, and evaluation skills, which are the core of CTS.

However, compared to the OR-IPA model, especially in the context of physics education, OR-IPA shows an advantage in developing HOTS. The study by Budi Jatmiko (2018) found that OR-IPA produced a higher N-Gain (0.63) compared to PBL (0.47), indicating that OR-IPA is more effective in enhancing higher-order thinking skills such as creativity and abstract thinking. This indicates that OR-IPA is more suitable for teaching introductory physics concepts that require a strong theoretical understanding. At the same time, PBL is more effective in encouraging students to solve real-world problems with a more applied approach.

On the other hand, when compared to the demonstration method, PBL shows more significant results in improving students' CTS and physics learning outcomes. In the study Effect of Problem-Based Learning on Improvement Physics Achievement and Critical Thinking of Senior High School Students (Mundilarto & Ismoyo, 2017), the experimental group using PBL had a higher N-Gain (0.63) compared to the group using the demonstration method (0.32), indicating that PBL is more effective in enhancing CTS and understanding of physics concepts.

Although PBL has proven effective, the challenges in applying PBL to specific topics remain an important issue. Some basic physics topics, such as linear motion or dynamics of forces, are easier to teach using PBL because of their more structured nature and real-world problem-based approach. However, more abstract physics topics, such as quantum mechanics or thermodynamics, present greater challenges in applying PBL, as they require a strong theoretical understanding before students can engage in more complex problem-solving. Therefore, adjustments to the methods are necessary to teach these more abstract topics so that PBL can be applied effectively.

Furthermore, emerging technologies and media, such PhET Simulations and authentic assessment-based modules, are essential in augmenting the efficacy of PBL. This technology enables students to visualize intricate physics concepts via interactive simulations and engage in practical learning, so enhancing their comprehension. Authentic assessments integrated into PBL also allow students to engage in real-world problem-solving, making learning more meaningful and relevant. Thus, this innovative technology and media provide direct experiences that enhance the quality of physics learning.

However, besides the internal factors that influence the success of PBL, such as the quality of teaching, external factors that can affect students' learning outcomes also need to be considered. Student motivation, parental involvement, and social support can strengthen or even hinder the effectiveness of PBL in improving learning outcomes. For example, students with high intrinsic motivation tend to be more actively engaged in problem-based Learning, contributing to better learning outcomes. Therefore, further research is needed to explore the influence of these external factors on the success of PBL implementation.

CONCLUSION

This study shows that the Problem-Based Learning (PBL) approach effectively improves students' CTS in physics learning at various levels of education. The analysis shows that PBL produces higher CTS than traditional learning methods. In addition, integrating media and technology, such as PhET simulation, interactive multimedia, and E-LKPD, strengthens the effectiveness of PBL in physics learning. Using these media not only improves CTS but also the relevance of learning for students.

The importance of authentic assessment is also evident in this study, where PBL equipped with appropriate assessments showed significant improvements in students' CTS and problem-solving abilities. In addition, the PBL approach integrating local wisdom improved students' learning relevance and CTS, suggesting that local context can enrich the learning experience.

PBL proved superior to Reciprocal Learning (RL) and Discovery Learning in improving students' CTS compared to other learning models. However, the OR-IPA model showed superiority in training higher-order thinking skills (HOTS) in physics education students.

PBL also consistently improved student learning outcomes, with higher average post-test scores in the experimental group than in the control group. This improvement is reflected in the N-Gain category, which shows the ability of PBL to improve the understanding of physics concepts significantly.

Based on these findings, applying PBL in physics learning is highly recommended, especially with the support of innovative media and relevant assessments. Further research is needed to explore the application of PBL in various physics topics and other educational contexts. Thus, PBL is a potential approach to improve the quality of physics learning at various levels of education.

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