

The Role of Problem-Based Learning with The Help of Virtual Laboratory in Physics Learning: A Systematic Literature Review

Muizzatul Islamiyah, Sujito*, and Nasikhudin

Physics Education Study Program, State University of Malang, Malang, Indonesia

sujito.fmipa@um.ac.id

Article Info	Abstract
Article history: Received: May 15, 2025 Accepted: June 18, 2025 Published: July 7, 2025 Keywords: Physics learning Problem based learning Systematic literature review Virtual laboratory This article is licensed under a creative commons attribution-share alike 4.0 international license © 2025 Jurnal ilmiah Pendidikan Fisika	The abstract nature of physics concepts and the low level of student interest often present significant challenges in the learning process. The integration of Problem-Based Learning (PBL) with virtual laboratories is believed to offer a promising solution; however, comprehensive and systematic studies on this integration remain scarce. This study aims to conduct a systematic review of the trends, methods, and key findings of studies integrating the Problem-Based Learning model with virtual laboratories in physics education in Indonesia. Using the PRISMA guidelines and a systematic literature review (SLR) approach, we analyzed 28 articles selected from the Scopus, Semantic Scholar, and Google Scholar databases using content analysis methods and visualized the results with VOSviewer software. The results of the review indicate that integrating PBL and virtual laboratories consistently improves student learning outcomes, especially critical thinking, problem-solving, scientific processes, and physics concept understanding. These results confirm that PBL supported by interactive simulations creates a more active, exploratory learning environment. Most studies employed experimental and developmental approaches, indicating a focus on testing effectiveness and developing innovative teaching tools. These findings imply the necessity of further research on other technology-based PBL approaches, such as STEM or web-based PBL, as well as the development of authentic assessment tools that can support adaptive and sustainable physics learning in the digital age.
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INTRODUCTION

Physics learning is an important component in science education as it provides a conceptual and practical foundation in understanding natural phenomena and technology. Physics learning not only supports the development of theoretical knowledge but also practical skills that are needed in today's modern era. However, many challenges are faced in learning physics, including its abstract, complex nature, which requires a deep understanding of concepts. This often causes low student interest and motivation ([Alfiah & Dwikoranto, 2022](#); [Flamboyant et al., 2018](#)), because many students find physics lessons very difficult. So there needs to be innovation in learning methods to invite students to actively participate, think critically, and understand concepts deeply ([Royantoro et al., 2018](#)).

One innovative learning approach that can help overcome this challenge is the Problem Based Learning (PBL) model. According to [Dewa et al. \(2020\)](#), [Şahin & Kılıç \(2024\)](#),

[Siregar et al. \(2025\)](#), [Sujanem & Putu Suwindra \(2023\)](#), this learning model places an emphasis on problem solving as the focal point of learning and encourages students to experiment with problem solving, critical thinking, teamwork, and better learning motivation. Because many abstract physics concepts may be presented in the context of real issues that students must solve, PBL is a very relevant tool for teaching physics ([Astuti et al., 2019](#); [Marcinauskas et al., 2024](#)).

The learning process is significantly impacted by technological innovation in addition to educational approaches. One prominent technology is virtual laboratories, which are computer-based simulations of experiments that allow students to conduct scientific explorations anywhere and anytime that may be difficult to do in traditional laboratories in a safe, interactive, and flexible environment ([Hendri et al., 2022](#); [Lucía Asencios-Trujillo et al., 2024](#); [Suarni et al., 2022](#)). Virtual laboratories have many advantages, such as cost savings, accessibility, and enhanced student engagement in the learning process, particularly when real experimentation is not feasible ([Kholis, 2019](#); [Utama & Kristin, 2020](#)). Virtual laboratory is a media that can be integrated in problem-based learning models to improve learning effectiveness, especially in physics learning ([Lutfi & Sukarmin, 2019](#); [Sulistina et al., 2024](#)).

The use of the virtual laboratory problem-based learning model in physics education fosters innovation and mutual improvement. This is supported by research by [Serungke et al. \(2020\)](#) which found that problem-based learning with virtual laboratories enhances students' critical thinking abilities and academic performance. These two approaches are also anticipated to improve students' comprehension of physics topics, foster the growth of their scientific abilities, and encourage greater student participation in the educational process ([Alfiah & Dwikoranto, 2022](#); [Dewa et al., 2020](#); [Royantoro et al., 2018](#)). Previous studies have shown positive results related to the implementation of PBL and the use of virtual labs separately ([Akçay & Benek, 2024](#); [Ali et al., 2022](#)). However, there are still very limited systematic reviews specifically examining the integration of the two that summarize these findings thoroughly, making it important to investigate further ([Suarni et al., 2022](#); [Sulistina et al., 2024](#); [Wang et al., 2024](#)).

Although several studies have examined the effectiveness of the problem-based learning model and the use of virtual laboratories in physics education separately, few have specifically and systematically evaluated their integration into a single learning framework. Previous studies have primarily focused on applying each approach without considering the potential synergy between PBL and virtual laboratories. Therefore, integrating both approaches can create a unified method that strengthens PBL as a pedagogical strategy and virtual laboratories as a means of supporting scientific exploration. A comprehensive review of these two approaches is needed to strengthen the scientific basis for evaluating how they interact and support effective physics learning. Thus, a systematic literature review is necessary to identify trends and key findings and to guide future research. ([Sulistina et al., 2024](#); [Utama & Kristin, 2020](#); [Zulfa et al., 2022](#)).

This systematic review is significant for the development of physics education practices, especially in the context of technology-based learning and strengthening 21st-century skills. This study aims to provide strategic direction for educators, curriculum developers, and researchers in designing more relevant, interactive, and effective physics learning experiences by summarizing and analyzing research findings related to the integration of project-based learning and virtual laboratories. Additionally, the findings can serve as a foundation for developing instructional materials, assessment tools, and learning models that adapt to students' needs in the digital age. This study uses a systematic literature review (SLR) approach to analyze current research trends, identify the methods used, and evaluate the main findings related to the application of PBL and virtual labs in physics education in

Indonesia. The SLR follows PRISMA guidelines and uses VOSviewer visualization, which is expected to contribute significantly to developing more effective, innovative learning models.

METHODS

The type of research used is a Systematic Literature Review (SLR). The analysis method used is content analysis. The stage used to select articles is PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) ([Haddaway et al., 2018](#)). This PRISMA stage consists of 4 stages, namely identification, screening, eligibility and including ([Latifah et al., 2024](#)). The PRISMA stages in article selection are shown in Figure 1.

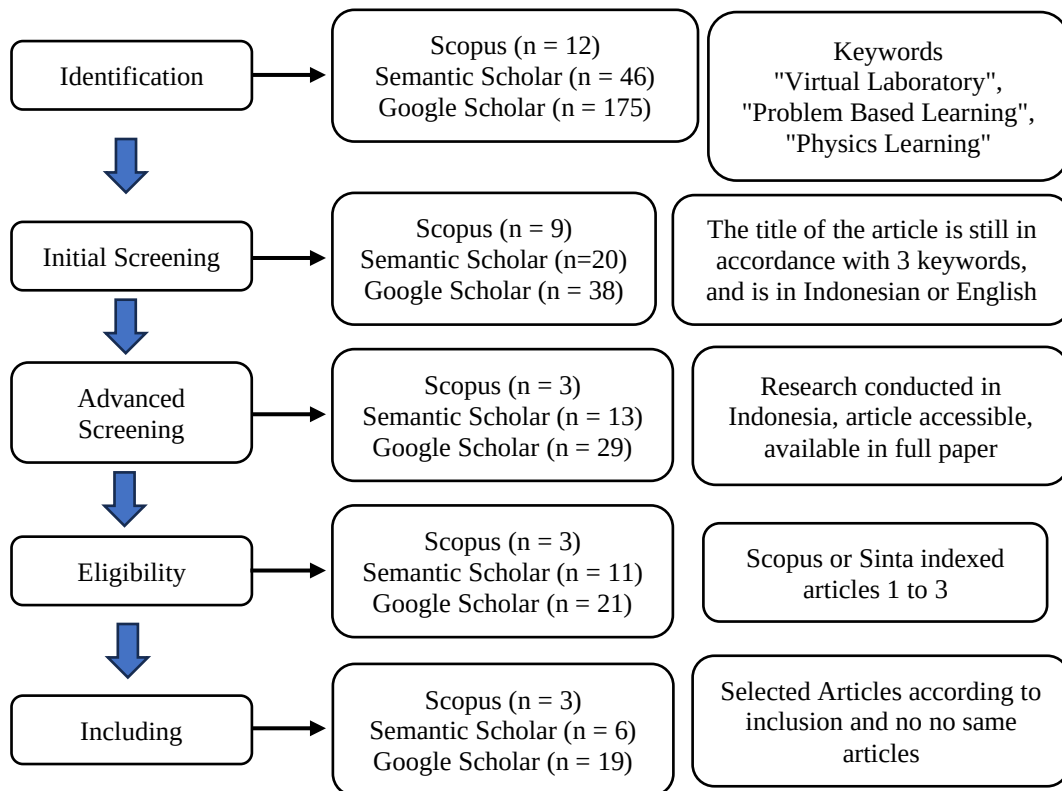


Figure 1 Diagram of PRISMA stages

Literature search using publish or perish (POP) application with scopus, semantic scholar, and google scholar databases. At the identification stage, the keywords used in the article search include: virtual laboratory, problem-based learning, and physics learning, with a range of article publications from 2016 to 2024. Followed by the screening stage, screening is carried out based on the title that matches the 3 keywords in the previous stage, articles written in Indonesian or English, research conducted in Indonesia, accessible and available in full paper. Eligibility is the stage of selecting articles that meet the predetermined inclusions. Selected articles will be described in accordance with the research needs included in the including stage. The criteria for selected articles are shown more clearly in Table 1 below.

Table 1 Article inclusion and exclusion criteria

Inclusion	Exclusion
Publication of articles 2016-2025	Article Publication (< 2016)
Scopus or Sinta index 1-3	Not Indexed by Scopus or Sinta 1-3
Article in Inonesian or English	Article not in Inonesian or English
Article available in full paper	Article not available in full paper
Article is open access	Article not accessible
Place of research in Indonesia	Research site outside of Indonesia

In addition to the inclusion and exclusion criteria specified in Table 1, the relevance and quality of the articles were evaluated based on how well the topics of the articles aligned with the research focus: the integration of problem-based learning and virtual laboratories in physics education.

During the identification phase, the articles collected from the search results using the Publish or Perish application were visualized using VOSviewer software. This program generates a bibliometric map that shows relationships between terms (co-occurrence) within the articles. The bibliometric map consists of nodes (points); larger nodes indicate terms that appear more frequently. Relationships between terms are depicted by connecting lines that indicate the strength of the association. This visualization is important for showing interconnections among trending research topics and identifying research focuses and topics frequently studied together in physics education literature. The articles selected in the inclusion stage will be categorized according to the research objectives based on publication year, research method, dependent variables, and main results.

Limitations of the article search strategy include being restricted to three databases (Scopus, Semantic Scholar, and Google Scholar); limited use of keywords; geographical context restrictions; including only articles conducted in Indonesia; and availability of access. Articles not available in full text or open access were not analyzed further.

RESULTS AND DISCUSSION

The results of the article search obtained were 233 articles at the identification stage, 67 articles at the initial screening stage, 45 articles at the advanced screening stage, 35 articles at the eligibility stage and 28 articles at the including stage. As for the identification stage, the relationship between terms that often appear in articles, visualized using the VOSviewer application as in Figure 2.

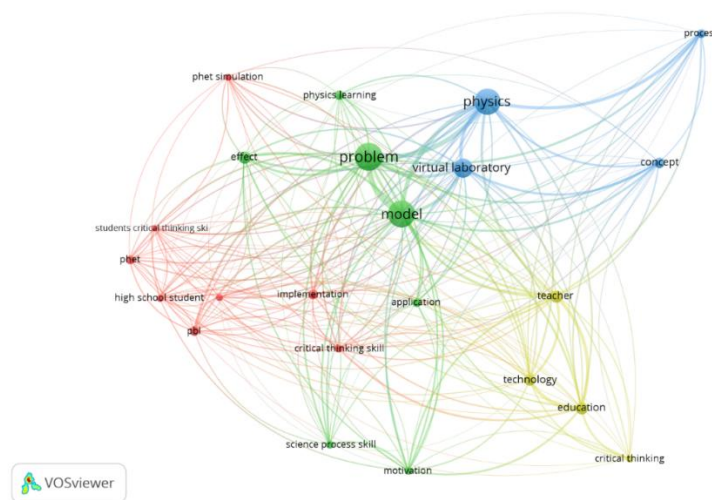


Figure 2 Visualization of Vosviewer

The visualization of Figure 2, generated from the VOSviewer application, was taken from the POP application, which has three sites: Google Scholar, Semantic Scholar, and Scopus. Image retrieval was taken by searching using three keywords, namely virtual laboratory, problem based learning, and physics learning, with a range of article publications from 2016 to 2024 found as many as 233 articles.

Figure 2 shows the VOSviewer visualization results of the identification stage. These are bibliometric maps that illustrate the relationships between keywords (co-occurrence) in related scientific articles grouped into specific clusters (marked with different colors). The following is an explanation of each cluster:

- The green cluster is the central core because it contains the most nodes of all the clusters. The largest nodes in this cluster are "problem" and "model," indicating high frequency and connectivity with many other words.
- The blue cluster focuses on topics such as "physics," "virtual laboratory," "concept," and "process," illustrating the relationship between physics concepts, the use of virtual laboratories, learning processes, and conceptual understanding.
- The yellow cluster focuses on how educators use technology and innovative approaches to promote critical thinking in physics education.
- The red cluster focuses on the central topics: "PBL," "PhET," "high school student," "critical thinking skill," and "implementation." This cluster focuses on using PhET simulations and the PBL approach to enhance critical thinking skills among high school students.

Thus, it can be concluded that the bibliometric map reflects research trends oriented toward problem-based physics learning, virtual laboratory technology, and strengthening 21st-century skills, including critical thinking.

There are 28 articles included in the including stage where the highest number of publications in 2024 with a total of 7 articles. Whereas in 2020 there was only 1 and no article publications in 2016 from three databases namely scopus, semantic scholar, and google scholar. This can be seen in the bar chart in Figure 3.

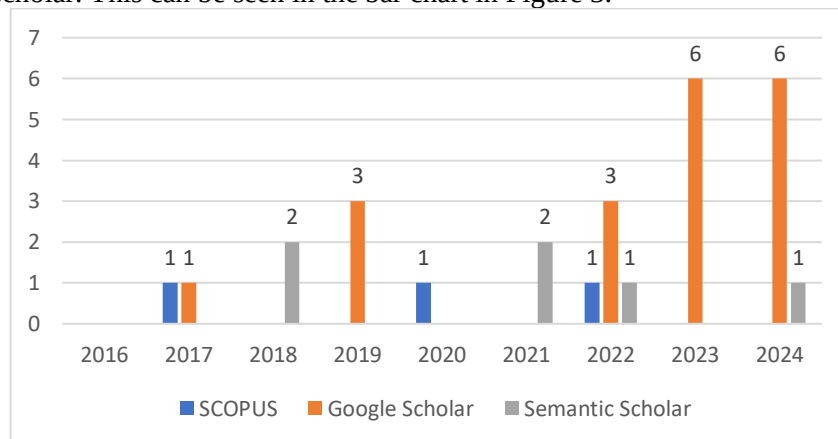


Figure 3 Bar Chart of Article Publication from 2016 - 2024

The least number of article publications in the SCOPUS database is 3 articles each in 2017, 2020, and 2022. Meanwhile, the Google Scholar database has the most article publications, totaling 19 articles with 1 article in 2017, 3 articles in 2019 and 2022, and 6 articles in 2023 and 2024. Figure 3 shows that the publication of articles has increased since 2020, peaking in 2024, indicating a growing interest in the use of virtual laboratories and PBL models.

As for the methods used in the research, which are categorized into three types of methods, namely development, experimentation, and literature study, can be seen in the pie chart in Figure 4.

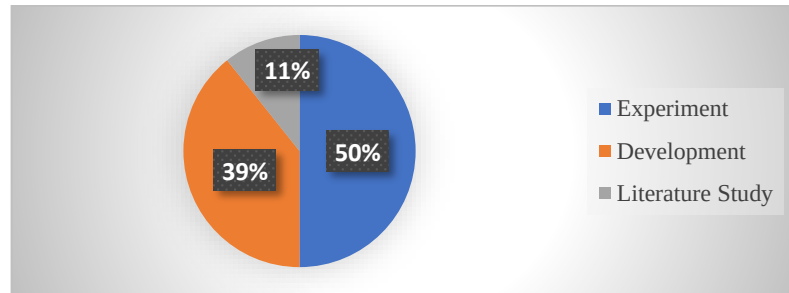


Figure 4 Circle Diagram of Research Methods Used in the Article

As shown in Figure 4, the most dominant research method is the experimental method, accounting for 50% of the 28 articles. This shows that almost half of the studies analyzed used an experimental approach, which is usually done to test hypotheses or cause-and-effect relationships under controlled conditions. Furthermore, the development method occupies the second position with a percentage of 39%, indicating that many studies also focus on product development, such as media, models, or learning tools. Meanwhile, literature review was only used in 11% of the studies, indicating that conceptual approaches or theoretical studies are still relatively in demand. Overall, these results illustrate that most studies tend to use practical and applicable approaches rather than theoretical approaches.

The dominance of experimental methods suggests that many researchers aim to evaluate the practical effectiveness of implementing PBL and virtual laboratories in the classroom. This shows a strong tendency to test the effectiveness of learning media or approaches on student learning outcomes directly. Teachers and educational practitioners can use these results to inform their choice of learning strategies proven to improve understanding of physics concepts and 21st-century skills, particularly the use of media such as simulations or virtual laboratories. However, the dominance of experimental methods also reflects a tendency to focus on quantitative results. Consequently, more reflective, theoretical, and long-term development-based approaches are less explored. This results in a lack of new, structured learning innovations and limited use of literature studies as a basis for designing more comprehensive learning practices. Thus, while experimental methods significantly contribute to proving effectiveness in the classroom, a balance with development methods and literature studies is necessary to ensure learning innovations are theoretically relevant and sustainable across various educational contexts.

The achievement of research results in each article, as indicated by the expected dependent variable based on the development method, is presented in Table 2.

Table 2 Details of research results with development methods

Article Author	Dependent Variable	Research Results
Fatmaryanti, 2022	Inquiry, social communication, and scientific communication skills of physics teacher candidates	A virtual laboratory built on inquiry skills and scientific and social communication is supported by the task model.
Dewi, 2020	Mastery of student physics concepts	With the aid of a virtual laboratory, a generative learning model enhances students' comprehension of physics ideas.
Manurung, 2017	Problem solving skills in physics learning	Needs analysis and development of interactive multimedia tools for problem solving-based physics learning.

Article Author	Dependent Variable	Research Results
Kua et al., 2021	Feasibility of virtual physics laboratory products	Ngada local wisdom-based physics virtual laboratory products are feasible to be applied in Basic Physics Practicum courses and can support student independent practicum.
Wibowo et al., 2022	Critical thinking skills	Increase in Gain score after the use of OVL: 0.66 (medium category) Optics Virtual Laboratory (OVL) Based on Physics Independent Learning (PIL) can improve students' critical thinking skills.
Amelia, 2024	Feasibility of digital teaching materials based on problem-based learning integrated with virtual laboratories	PBL + virtual lab-based digital teaching materials on electricity material for PGMI students are declared valid and feasible to use in science learning.
Yusuf et al., 2024	Quality of physics learning tools (in terms of validity, practicality, effectiveness, and student learning outcomes)	PBL-based physics learning tools with PhET simulation are feasible to use for students of class X SMK Negeri 1 Sentani.
Oksaviona et al., 2023	Feasibility and practicality of PBL interactive multimedia using Lumi on sound wave material	PBL-based interactive multimedia using Lumi is seen both practical and viable to utilize by both teachers (93.30) and students (90.46) (Aiken validity score = 0.86; very high category).
Azizahwati et al., 2023	Feasibility and practicality of emodules to improve students' concept understanding on dynamic electricity material	Valid (3.57) and practical (3.67-3.71), suitable for use in grade IX.
Lestari et al., 2022	Students' problem solving ability	PBL-based learning tools integrated with science literacy were declared valid with an average score of: syllabus 3.97; lesson plan 3.84; LKPD 3.70; test instrument 3.60. The device is declared feasible to use to improve students' problem solving ability
Jiniarti et al., 2019	Generic science skills of students	The developed PBL-based physics learning tools are valid, practical, and effective; students are in the "skilled" and "highly skilled" categories in generic science skills

A review of a number of studies based on Table 2, shows that the integration of virtual laboratories in physics learning has a positive impact on various aspects, such as improving concept mastery, critical thinking skills, inquiry skills, and scientific and social communication. The problem-based learning model combined with virtual laboratories is valid, practical, and effective in improving students' problem-solving skills and generic science skills. Furthermore, the virtual laboratory can be tailored to local contexts, such as Ngada local wisdom, and facilitates inclusive learning for kids with special needs. Digital platforms, such as PhET and Lumi, also enhance the quality of teaching tools and the effectiveness of independent and group learning.

The achievement of research results in each article, in accordance with the expected dependent variable based on the literature study method, is presented in Table 3.

Table 3 Details of research results with literature study method

Article Author	Dependent Variable	Research Results
Rahmadita et al., 2021	Students' critical thinking skills	Students' critical thinking skills are in the medium category, with 17 students in the low category, 53 medium, and 30 high. Practice questions are needed for improvement.
Ajizah et al., 2024	The trend of incorporating problem-based learning (PBL) into laboratory practicum exercises	The research is growing, with the United States as a major contributor. There is a lot of emphasis to the use of PBL in enhancing critical and applied thinking skills in the laboratory setting, as seen by the six major clusters of research issues that tend to centre on learning systems, sophomores, curriculum, and problem-solving abilities.
Pristianti & Prahani, 2022	Students' problem solving ability on gas kinetic theory material	Most students (159 out of 162) had low problem solving skills, especially only answering at the E (Execute) stage. A web-based PBL model is recommended to improve this skill.

Based on Table 3 of the results of the literature study, students' critical thinking skills are still classified as moderate, with a varied distribution of achievements and indicating the need for continuous question practice ([Rahmadita et al., 2021](#)). [Ajizah et al., 2024](#) showed that incorporating PBL into laboratory practicums is an increasingly popular research trend that emphasizes improving students' critical thinking and problem-solving abilities. The majority of students struggled to solve issues based on gas kinetic theory, according to ([Pristianti & Prahani, 2022](#)), hence it was suggested that a website-based PBL model be used to address the inadequate problem-solving skills.

The achievement of research results in each article according to the expected dependent variable based on the experimental method can be seen in Table 4 below.

Table 4 Details of research results with experimental method

Article Author	Dependent Variable	Research Results
Ranti et al., 2024	Students' motivation to learn physics and their proficiency with the scientific method	From cycle I to cycle II, students' enthusiasm to learn and their proficiency with the scientific method were successfully raised using the Problem Based Learning (PBL) approach.
Diani et al., 2018	The level of student misconceptions on fluid material	Physics learning using the PDEODE model assisted by a virtual laboratory (PhET simulation) succeeded in reducing student misconceptions in all subconcepts of fluid material. It can be concluded that physics learning based on virtual laboratory is effective in remediating students' misconceptions.
Yusuf & Widyaningsih, 2018	Science Process Skills (KPS) & Student perceptions of virtual laboratory-based physics learning	KPS of lecture observation results: $86.4\% \pm 12.7$ (very good category) KPS results of student worksheet analysis: $77.5\% \pm 5.9$ Overall KPS: 81.95% (very good category) Student perception: $78.53\% \pm 4.9$ (very good category)

Article Author	Dependent Variable	Research Results
Nurita et al., 2017	Students' problem solving ability in optical wave course	There was an increase in problem-solving ability scores in 15 students, indicating an increase in ability after treatment.
Isbah & Adi, 2024	HOTS (Higher Order Thinking Skills) of grade VI students on electrical circuit material	The enhancement of students' HOTS is significantly impacted by the Problem Based Learning approach, which is aided by PhET simulation. This is evidenced by the t-test results which show a significance value of 0.00
Aldila et al., 2024	Critical thinking skills of students on global warming material	Students' critical thinking abilities are significantly enhanced in both modeling and implementation classes when physics e-books are used in conjunction with interactive PhET simulations that are based on problem-based learning (medium category). Students' interest in physics is also increased by e-books.
Alandia et al., 2019	Critical thinking skills	Students who learn using the web-assisted PBL paradigm have significantly different critical thinking skills than those who learn normally; this difference is huge (high effect size).
Gunawan et al., 2019	Critical thinking disposition	Both male (N-gain 35.5) and female (36.4) students' critical thinking dispositions are positively impacted by the use of interactive multimedia.
Syam et al., 2024	Critical thinking skills	The Problem-Based Learning learning model assisted by a virtual laboratory can improve students' critical thinking skills. The N-Gain test results show that the increase in critical thinking skills is in the high category.
Pratiwi & Hariyono, 2022	Student learning outcomes and critical thinking skills	There was an increase in critical thinking skills with n-gain values of 0.87 and 0.83 (high category); there was no significant difference between classes; student response was 82% (very good category).
Susilawati & Doyan, 2023	Learning goals for students studying wave content (in the psychomotor and affective domains)	The psychomotor domain (3.43) and affective domain (3.34 vs. 3.13), respectively, have higher average student learning results in the experimental class than in the control class (3.06). The t test results show that the PBL model with PhET support has a significant impact on student learning outcomes (t count = 6.45 > t table = 2.00).
Imaniah et al., 2023	Student learning outcomes on wave material	The experimental class (using PBL + PhET) had greater average student learning outcomes (79.65) than the control group (69.77). The PBL model with PhET support had a significant impact on student learning outcomes, according to the t test results, which showed t count = 6.45 > t table = 2.0017.
Adhelacahya et al., 2023	Students' critical thinking skills on	A significant difference between the pretest and posttest (sig.<0.05) in the t-test results and an N-Gain score of 0.76 (high category)

Article Author	Dependent Variable	Research Results
	mechanical wave characteristics	demonstrate that the learning model that uses physics e-modules based on Problem-Based Learning linked with STEM has a positive impact on students' critical thinking skills.
Sebastiana et al., 2023	Students' visual representation ability on optical instrument material	The use of PBL-based flip-book media assisted by virtual laboratory simulation proved effective in improving students' visual representation skills, with an N-Gain value of 0.828 (high category).

Based on the results of experimental research on table 4, the application of the Problem-Based Learning model combined with virtual laboratories consistently shows effectiveness in improving various student competencies. Among them, there are significant improvements in critical thinking skills, written communication skills, HOTS, science process skills, and student learning outcomes, both in the cognitive, affective, and psychomotor domains ([Isbah & Adi, 2024](#); [Ranti et al., 2024](#); [Susilawati & Doyan, 2023](#)). PhET simulations and STEM-based e-modules also support the reduction of misconceptions and increase visual representations and learning interest ([Adhelacahya et al., 2023](#); [Diani et al., 2018](#)). In addition, students' positive perceptions of virtual laboratory-based physics learning indicate that this model is not only effective, but also well received by students ([Yusuf & Widyaningsih, 2018](#)).

A review of the literature reveals a prevailing trend in physics education toward integrating Problem Based Learning and virtual laboratories, with an emphasis on cultivating 21st-century skills, including critical thinking, problem solving, and conceptual mastery. While most studies demonstrate positive outcomes, there are variations in results across studies, particularly regarding the effectiveness of implementing the PBL model in different contexts. Some studies demonstrate significant improvements in students' skills, while others reveal more modest effects. For instance, the research conducted by [Ajizah et al. \(2024\)](#) and [Pristianti & Prahani \(2022\)](#) indicates that, even after implementing the PBL method, students continue to struggle with problem-solving questions. This suggests a discrepancy between the model and its implementation. These findings suggest opportunities for further exploration of variables influencing the effectiveness of this integration, such as the roles of teachers and students and the types of media used.

This study shows that integrating the Problem-Based Learning model with virtual laboratories has a consistently positive impact on students' critical thinking skills, understanding of physics concepts, scientific process skills, and learning motivation (see Tables 2, 3, and 4). Findings from the literature review have strong practical implications for physics classrooms, particularly regarding the development of problem- and technology-based curricula and instructional strategies.

- Physics learning curricula should accommodate contextual, student-centered, problem-based approaches that integrate the use of virtual laboratories as an alternative to direct experiments.
- Instructional strategies should incorporate a combination of exploratory activities through simulations (e.g., PhET, Lumi) and project- or real-world scenario-based problem solving.
- The use of virtual laboratories increases access to and flexibility in experimental practices, which supports schools with limited laboratory equipment or practice spaces.
- The development of PBL- and virtual lab-based teaching materials and learning tools (e.g., e-modules, interactive multimedia, and student worksheet) can improve the

quality of physics learning and make it more applicable and adaptive to technology, as part of school policy.

As demonstrated in the articles by [Amelia \(2024\)](#) and [Yusuf et al. \(2024\)](#), developing PBL-based instructional materials and virtual laboratories is valid, practical, and effective. These findings reinforce the recommendation that curriculum developers and physics teachers begin integrating interactive technology and constructivist approaches into their daily instructional designs.

These findings have important implications for educators and policymakers designing progressive physics learning policies. To prepare students for global challenges, the integration of technology, such as virtual laboratories, and active learning models, such as problem based learning, should be part of physics education reform. Policymakers must provide training and infrastructure that support the use of technology in learning and encourage applied research in schools. Teachers must also be empowered to develop and implement innovative learning strategies continuously. As education becomes increasingly digitized, this finding underscores the need to transform physics learning into innovative, interactive approaches.

This study has several limitations that should be noted. First, the selection of articles was limited to three main databases (Scopus, Semantic Scholar, and Google Scholar), which may introduce bias and cause the researchers to overlook other relevant sources. Additionally, the study's focus on the Indonesian context limits the generalization of findings to a global level. The study's methodology, including limitations in the literature review and the dominance of experimental methods, indicates that it has not fully encompassed theoretical or reflective approaches. Therefore, broader and more in-depth studies are needed to improve our understanding of the development of physics education. Considering these limitations, future research should not only focus on the use of virtual laboratories, but also explore alternative problem-based learning approaches, such as STEM-integrated, web-based, or locally oriented ones. Additionally, valid and reliable assessment tools are urgently needed to measure critical thinking, scientific process, and problem-solving skills in virtual laboratory-based learning. Research could also focus on developing adaptive and inclusive digital instructional tools to support sustainable, contextualized learning.

CONCLUSION

The purpose of this study is to analyze current research trends, identify the methods used, and evaluate the main findings related to the combined application of problem-based learning and virtual laboratories in physics education in Indonesia. A systematic literature review of 28 articles published between 2016 and 2024 revealed that research trends indicate growing interest in integrating PBL and virtual laboratories to improve the quality of physics education. The most commonly used methods were experiments (50%) and development (39%). Dependent variables were primarily critical thinking skills, problem-solving, concept mastery, and scientific process skills. The main findings from the reviewed studies indicate that combining PBL and virtual laboratories consistently improves student learning outcomes and the effectiveness of the learning process. Therefore, integrating these two approaches is highly relevant for developing physics curricula and instructional strategies in the 21st-century learning era. This study recommends exploring other technology-based PBL approaches and developing authentic assessment tools for further research to support more innovative, applied, and sustainable physics learning.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

All authors have contributed to the conceptualization, methodology, formal analysis, investigation, and writing this article.

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AUTHOR PROFILES



Muizzatul Islamiyah
amimuizzatul@gmail.com
 affiliation: Physics Education Study Program, Faculty of Mathematic
 and Natural Science
[Google Scholar](#)



Sujito

sujito.fmipa@um.ac.id

affiliation: Physics Education Study Program, Faculty of Mathematic and Natural Science

[Google Scholar](#), [Sinta](#), [Scopus](#)



Nasikhudin

Nasikhudin.fmipa@um.ac.id

affiliation: Physics Education Study Program, Faculty of Mathematic and Natural Science

[Google Scholar](#), [Sinta](#), [Scopus](#)