JPPIPA 11(2) (2025)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Enhancing Critical Thinking and Written Communication Skills through Problem-Based Learning Assisted by Virtual Labs

Valina Yolanda[1], Muhammad Nasir[2], Fakhruddin[3]

[1] Magister Pendidikan Fisika, Universitas Riau, Indonesia.

Received: November 13, 2024
Revised: January 06, 2025
Accepted: February 25, 2025
Published: February 28, 2025

Corresponding Author:
Valina Yolanda
valina@gmail.com

DOI: 10.29303/jppipa.v11i2.10287

Abstract: This research investigates the effectiveness of the Problem-Based Learning (PBL) model assisted by virtual laboratories in improving critical thinking and written communication skills among students of MAN 2 Kota Pekanbaru. Utilizing a classroom action research (CAR) design across two cycles, this study focuses on the application of PBL with PhET Simulations. Results reveal significant improvements in both critical thinking and written communication skills. Key findings emphasize the integration of PBL and technology as effective tools for modern physics education. This study concludes with recommendations for broader adoption of virtual labs to address resource limitations and enhance active learning in science classrooms.

Keywords: Critical thinking; Physics education; Problem-based learning; Virtual laboratory; Written communication.

Introduction

The 21st-century learning framework highlights critical thinking and communication skills as essential competencies for students to thrive in a globalized and technologically advanced era (González-Pérez & Ramírez-Montoya, 2022; Hilton & Pellegrino, 2012; Malik, 2018). However, Indonesian students' critical thinking abilities remain low, as reflected in the 2022 PISA survey results (Padilah et al., 2025). The gap is partly attributed to traditional teaching methods that focus on solving equations rather than fostering conceptual understanding and problem-solving skills.

In recent years, there has been a global shift towards integrating innovative pedagogical approaches to address these challenges. Problem-Based Learning (PBL), a student-centered learning model, encourages learners to engage with real-world problems collaboratively, fostering both critical thinking and communication skills (Moustafa & Al-Rashaida, 2024; Ni'mah et al., 2024). This approach is particularly relevant in physics education, where conceptual understanding and application are key to mastery (Al-Kamzari & Alias, 2025; Amanda et al., 2022; Banda & Nzabahimana, 2021).

Despite the clear advantages of PBL, its implementation in Indonesia faces several barriers. Traditional classrooms often lack the resources and training required to support such dynamic teaching methods. Furthermore, limited access to functional science laboratories further compounds the issue, leaving students with minimal opportunities to experiment and explore concepts interactively. Virtual laboratories, such as PhET Simulations, offer a viable solution by providing accessible, interactive platforms that simulate real-world experiments (Rianti et al., 2024).

The integration of PBL and virtual laboratories aligns with Indonesia's Merdeka Curriculum, which emphasizes student-centered learning and competency development (Haetami et al., 2023; Yusuf et al., 2024). By incorporating these tools, educators can create more engaging and effective learning environments, bridging the gap between theoretical knowledge and practical application. This alignment underscores the importance of designing teaching strategies that are both innovative and adaptable to technological advancements (Marliani et al., 2024).

How to Cite:
Yolanda, V., Nasir, M., & Fakhruddin. (2025). Enhancing Critical Thinking and Written Communication Skills through Problem-Based Learning Assisted by Virtual Labs. Jurnal Penelitian Pendidikan IPA, 11(2), 1001–1005. https://doi.org/10.29303/jppipa.v11i2.10287

Moreover, the role of educators is crucial in driving this transformation. Teachers must shift from traditional roles as knowledge dispensers to facilitators who guide students through inquiry-based and collaborative learning processes. This requires targeted professional development programs that equip educators with the necessary skills to implement PBL and virtual labs effectively (Pristianti & Prahani, 2023). With proper training and support, teachers can play a pivotal role in fostering a generation of critical thinkers and effective communicators.

This study aims to explore the implementation of PBL assisted by virtual laboratories to enhance critical thinking and written communication skills. The specific research objectives include: examining the application of PBL to improve critical thinking; assessing its impact on written communication; and evaluating the overall effectiveness of the integrated approach.

Method

The study employed a Classroom Action Research (CAR) design conducted in two cycles (Nainggolan, 2023). Each cycle consisted of four stages: planning, action, observation, and reflection. This cyclical approach ensured continuous improvement in teaching and learning processes.

Participants: Thirty-three students (22 male and 11 female) from Class XI-7 participated in the study. The curriculum adopted was the Merdeka Curriculum with a weekly allocation of four instructional hours. The class was selected due to observed challenges in critical thinking and written communication skills in prior assessments.

Instruments

Critical Thinking Test: Essay-based assessments evaluating interpretation, analysis, evaluation, and inference skills. Written Communication Assessment: Structured tasks requiring students to present data, interpret graphs, and explain scientific phenomena coherently. Observation Sheets: Used by the observer to document student engagement, interaction, and performance during lessons. Lesson Plans and Worksheets: These were specifically designed to align with the PBL model and incorporate virtual lab tools for physics concepts (Gunawan et al., 2018).

Procedure

The procedure began with the planning stage, where the researchers meticulously prepared all necessary teaching materials and instruments. Detailed lesson plans were created to align with the PBL framework. These plans outlined each session's objectives, activities, and assessments. Virtual laboratories were selected as a central tool, and PhET Interactive Simulations were prepared to provide a simulated experimental experience. To ensure the instruments' validity, they were reviewed and validated by subject matter experts. Additionally, pre-tests were administered to assess students' initial critical thinking and written communication abilities, which provided a baseline for measuring progress.

In the action stage, the implementation of PBL began with the introduction of real-world problems related to physics topics (Samadun & Dwikoranto, 2022), such as Newtonian Gravity and Work-Energy principles. Students were divided into collaborative groups and guided through the PBL steps: problem identification, hypothesis formulation, data collection, analysis, and conclusion. Virtual labs were integrated into these activities, allowing students to conduct experiments in a simulated environment. The teacher played a facilitative role, providing scaffolding and ensuring active participation.

During the observation stage, researchers and teachers closely monitored classroom dynamics. Data were collected using observation sheets, focusing on indicators such as student engagement, collaboration, and critical thinking during discussions and activities. Feedback was gathered from students regarding their experiences with PBL and virtual labs (Amelia, 2024; Syam et al., 2024), highlighting both strengths and challenges in the learning process.

The reflection stage involved a thorough analysis of all collected data, including observation notes, test results, and student feedback. Strengths of the implemented strategies were identified, such as increased student engagement and improved problem-solving skills. However, areas requiring improvement, such as clearer guidance in utilizing virtual labs and enhancing group collaboration, were also noted. Based on these insights, lesson plans and activities were refined for the next cycle to address these challenges (Miller et al., 2021; Rizal et al., 2023).

This iterative process was repeated in the second cycle, incorporating the improvements identified during the reflection phase. The refinements included more structured group activities, additional scaffolding for virtual lab usage, and targeted feedback sessions to strengthen written communication skills (Varadarajan & Ladage, 2022). By systematically addressing the challenges of the first cycle, the second cycle achieved significant improvements in student outcomes.

Flowchart of the CAR Process: The following flowchart illustrates the cyclical nature of the CAR methodology employed in this study: Cycle 1 focused on familiarizing students with the PBL approach and virtual labs. Cycle 2 introduced advanced problem-solving tasks and emphasized collaborative analysis. This iterative process ensured gradual improvement in both student outcomes and instructional strategies.

Result and Discussion

The results of this study highlight the effectiveness of the Problem-Based Learning (PBL) model assisted by virtual labs in enhancing critical thinking (Rahmadita et al., 2021) and written communication skills (Sari et al., 2021). Over the two cycles of implementation, students demonstrated consistent improvement in their ability to analyze, infer, and communicate scientific concepts effectively.

In the first cycle, students exhibited moderate progress in critical thinking, particularly in identifying problems and analyzing data. However, their ability to make logical inferences and formulate clear conclusions required further refinement. Similarly, while students improved in presenting data through tables and graphs, they faced challenges in providing coherent explanations of their findings. These initial results indicated the need for enhanced support and clearer guidance in utilizing the virtual lab tools.

The second cycle introduced refined lesson plans and focused on promoting active group collaboration. As a result, significant advancements were observed. Students showcased a deeper understanding of physics concepts, effectively identifying and solving problems with minimal guidance. Their written communication also improved, with clearer organization and precise use of scientific terminology. The increased engagement during discussions and hands-on activities reflected a growing confidence among students in using PBL and virtual labs (Vaez Ghaemi & Potvin, 2021).

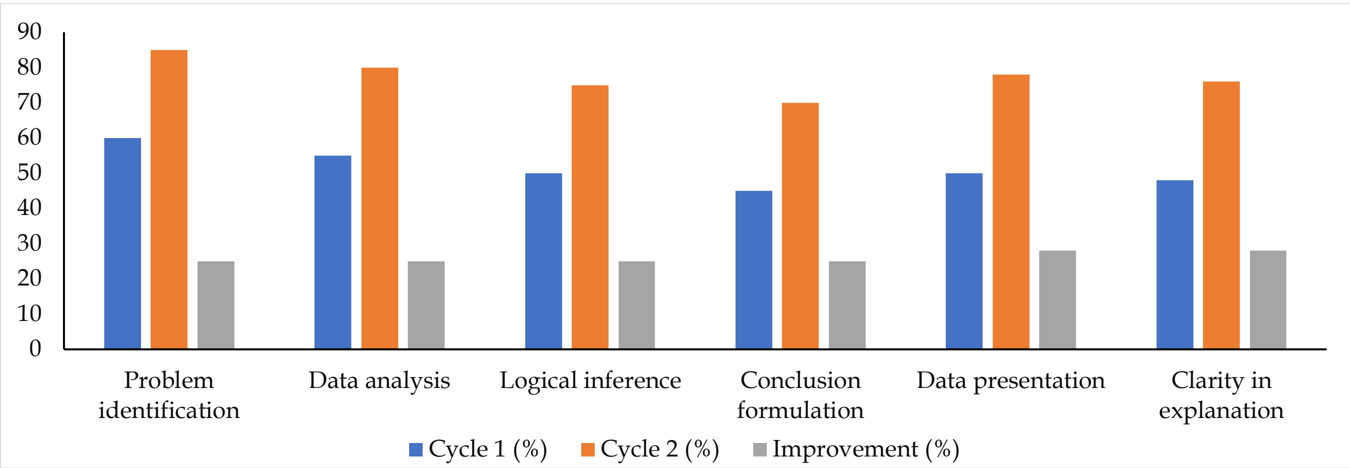

Figure 1. Cycle-wise Results

A comparative analysis of the cycles revealed substantial improvements across all indicators. For instance, the ability to draw logical inferences increased from 50% in Cycle 1 to 75% in Cycle 2, while clarity in written explanations rose from 48% to 76%. These findings underscore the value of iterative refinement in instructional design to address learning challenges effectively.

The results align with prior research, such as Prihatin et al. (2024), which emphasizes the role of PBL in fostering critical thinking and collaborative learning. Moreover, the integration of virtual labs addressed infrastructural limitations, enabling students to explore and interact with scientific phenomena in a simulated environment (Wahyudi et al., 2024). However, the findings also highlight the importance of teacher facilitation and ongoing professional development to maximize the potential of these tools.

In conclusion, the study confirms that PBL, when supported by virtual labs, provides an effective framework for enhancing essential 21st-century skills. Future initiatives should focus on scaling this approach, ensuring that all students have access to the resources and support needed to thrive in a technology-driven educational landscape.

The findings indicate that integrating technology with problem-based learning not only supports conceptual understanding but also fosters higher-order thinking and effective communication among students. By providing opportunities for experimentation and interaction, virtual labs proved to be an invaluable tool in bridging gaps caused by limited physical laboratory access.

However, successful implementation requires ongoing teacher training to maximize the benefits of this approach. Teachers must be equipped with the skills to facilitate group activities, guide inquiry-based discussions, and effectively utilize virtual tools. Additionally, institutional support in terms of infrastructure and resources is essential for sustaining such innovations in education.

Conclusion

This study demonstrates that the PBL model, supported by virtual labs, is an effective strategy to enhance critical thinking and written communication skills in physics education. The iterative nature of the Classroom Action Research process allowed for continuous refinement and improvement, addressing challenges such as initial unfamiliarity with virtual tools and inconsistent group collaboration.

Acknowledgments
The author extends gratitude to MAN 2 Kota Pekanbaru, the principal, and teachers for their support during this research. Special thanks to the students of Class XI-7 for their active participation and valuable feedback.

Author Contributions
The authors listed in this article have contributed to the preparation of the article. The authors have read and approved the publication of the article.

Funding
This research was not funded by external parties.

Conflicts of Interest
The authors have no conflict of interest in writing this article.

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