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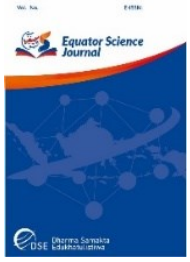

A Literature Review on the Effectiveness of Problem-Based Learning in Enhancing Biology Students' Problem Solving Skills and Learning Outcomes

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ABSTRACT
This study aims to review the effectiveness of the Problem-Based Learning (PBL) learning model in improving students' problem-solving skills and learning outcomes in Biology. This study was conducted using a literature review method of relevant national and international articles. Data sources were obtained through a Google Scholar search with the keywords "Problem-Based Learning" and "Biology", and were selected based on the criteria of the year of publication (2018–2024), relevance to the field of science, and presentation of quantitative data. The analysis techniques used include descriptive analysis, content analysis, and critical analysis. The results of the study show that the PBL model consistently improves students' learning outcomes and critical thinking skills compared to conventional methods. The increase in students' average scores was recorded between 4% and 24%, depending on the combination of approaches, such as audio-visual-based PBL, concept mapping, scaffolding, and role playing. In addition to cognitive aspects, PBL has also been shown to strengthen students' social skills, including cooperation, communication, and self-confidence in group discussions. The success of implementing this model is highly dependent on the role of the teacher as a facilitator, students' readiness for independent learning, and the support of

interactive media. Therefore, PBL is recommended to be applied in Biology learning as an approach that can improve students' academic achievements as well as 21st century competencies.

INTRODUCTION

Education is a major factor in developing human resources to create a competitive generation ready to face future challenges. The quality of a nation's education affects the progress of the nation itself (Utomo et al., 2014). Formal education, which involves the teaching and learning process between teachers and students, is an important means of forming critical, analytical, and creative thinking skills. One of the main challenges in the world of education today is how to create learning that is not only centered on teachers, but is also able to encourage student activity in obtaining and processing information (Mustika & Syamsurizal, 2024).

In the context of the digital age, the urgency of shifting towards student-centered and active learning becomes even more pronounced. The ability to critically analyze media messages (media literacy) and use digital tools effectively (digital literacy) are now essential components of educational competence (Özel, 2025; Furqon, 2023). These literacies enable students to evaluate information credibility, engage in ethical decision-making, and adapt to fast-changing technological environments (Zheng & Kim, 2025). Furthermore, fostering critical thinking is vital to help students assess the validity of the abundant information they encounter daily, particularly in navigating misinformation or AI-generated content (Andrae, 2024). For this reason, educational strategies must evolve to integrate digital tools and learning models that promote inquiry, reflection, and collaboration.

In science learning, especially biology and chemistry, students are expected to be able to think logically, analytically, systematically, critically, and creatively. Effective learning must be able to connect scientific concepts with everyday life phenomena (Apriyani & Alberida, 2023). However, in practice, the learning methods applied in schools are still mostly conventional, where teachers act as the main source of information, while students only receive material passively. As a result, students have less opportunity to explore and develop their understanding in depth (Murtihapsari et al., 2022). Real-life applications such as those related to human health and ecological systems can make biological concepts more meaningful and relevant to students. When inquiry-based learning integrates these contextual elements, it enhances student engagement and deepens conceptual understanding in biology education (Schoeffler, 2024).

Student interest in learning is also a major factor in the success of the learning process. If interest in learning is low, then learning outcomes tend to be low (Pandi et al., 2020). Indonesia's performance in international assessments such as PISA continues to reflect this challenge, where the average score of Indonesian students in scientific literacy remains below the OECD average. This suggests limited ability to interpret data, analyze scientific phenomena, and apply knowledge to real-life contexts. Moreover, the low level of student engagement and critical participation poses a challenge for achieving the goals outlined in the Profil Pelajar Pancasila, which emphasizes critical thinking (Muaziyah et al., 2023), creativity, collaboration, and independence.

One of the main challenges in science learning is the assumption that subjects such as biology and chemistry are difficult to understand because they involve abstract concepts, mathematical calculations, and the relationship between macroscopic, microscopic, and symbolic aspects (Murtihapsari et al., 2022). The way the teacher presents the material also plays an important role in encouraging or inhibiting student interest in learning. A less interactive learning approach can lead to boredom, low student involvement, and lack of critical thinking skills in solving scientific problems (Mustika & Syamsurizal, 2024).

One solution that can be applied to overcome this problem is the use of the Problem-Based Learning (PBL) model. The PBL model focuses on presenting real-world problems that must be solved by students through investigation, discussion, and systematic problem solving (Murtihapsari et al., 2022). With this approach, participants not only learn about scientific concepts but also develop critical thinking, argumentation, and collaboration skills in solving a problem (Apriyani & Alberida, 2023).

As an inquiry-driven and contextualized model, PBL aligns strongly with the development of 21st-century competencies, often referred to as the 4Cs: critical thinking, communication, collaboration, and creativity. These competencies are essential in preparing students to navigate real-world challenges and adapt to the demands of the digital era. Empirical studies in Indonesia have shown that PBL significantly enhances critical thinking by encouraging deeper engagement with content, real-world problem analysis, and meaningful application of knowledge (Ariawan, 2024). Additionally, PBL improves communication skills by requiring students to articulate ideas, present findings, and participate in group discussions (Binnendyk et al., 2023). Its collaborative structure fosters teamwork, as learners actively exchange ideas and solve problems together, often enhanced through the use of video-based media (Nuraydah & Hariani, 2023). Creativity is also nurtured through open-ended tasks, where students are invited to generate novel solutions and apply knowledge in innovative contexts such as differentiated instruction and entrepreneurship-based chemistry projects (Diniyah, 2024).

These findings are in line with the principles of Indonesia's *Kurikulum Merdeka*, which emphasizes student-centered learning to foster autonomy, creativity, and holistic development (Salamah et al., 2024). Teachers are encouraged to adopt innovative pedagogies such as problem-based and project-based learning as part of this curricular framework (Hunaepi & Suharta, 2024). Therefore, integrating PBL into science instruction directly supports national education goals and contributes to the formation of independent, collaborative, and reflective learners.

PBL has been widely studied as a learning model that can improve student learning outcomes, especially in science learning. Several studies have shown that PBL can improve students' critical thinking skills, because this model provides them with the opportunity to actively participate in examining problems and finding solutions based on scientific evidence (Mustika & Syamsurizal, 2024). In addition, this model can also improve students' argumentation skills, which are very important in understanding and evaluating information critically in today's digital era (Apriyani & Alberida, 2023).

In addition to improving critical thinking and argumentation skills, PBL also contributes to improving student learning outcomes. Previous research shows that students who learn using the PBL model tend to have a deeper understanding of biology and chemistry concepts compared to students who learn using conventional methods (Mustika & Syamsurizal, 2024). This is because in PBL, students are given the challenge of solving a problem, which requires them to explore information, think analytically, and develop and convey arguments supported by evidence (Apriyani & Alberida, 2023).

Considering these various benefits, this study aims to analyze the effectiveness of the PBL model in improving students' argumentation skills, learning outcomes, and learning interests in science learning. This study was conducted through a literature review of various previous studies that have examined the influence of PBL in science learning. It is hoped that the results of this study can provide further insight into how PBL can be optimally implemented to improve the quality of learning in schools.

METHOD

This study uses a descriptive qualitative literature review method. Data sources come from national and international scientific articles relevant to the topic of implementing Problem-Based Learning (PBL) in Biology learning. Articles were obtained through a Google Scholar search with keywords such as "Problem-Based Learning in Biology Learning," "critical thinking skills," and "science learning outcomes." The criteria include articles published between 2018 and 2024, discussing the implementation of PBL at the high school or college level, and presenting quantitative and descriptive data related to improving students' cognitive and affective abilities.

The data collected were analyzed through three stages. First, descriptive analysis was used to classify and summarize the objectives, methods, and results of each article. Second, the analysis was carried out to identify trends in findings such as the combination of the PBL model with certain learning media and the role of teachers in the learning process. Third, critical analysis was applied to highlight the validity of the methodology and contribution of each study to the development of the learning model.

Through this approach, researchers gain a comprehensive picture of the effectiveness of the PBL model in improving students' learning outcomes and high-level thinking skills.

RESULTS AND DISCUSSIONS

The implementation of the Problem-Based Learning (PBL) model in Biology learning demonstrates a consistent improvement in students' problem-solving skills. Students actively engage with real-world problems through this model, which fosters critical, analytical, and creative thinking. A learner-centered approach such as PBL transforms the learning experience from passive knowledge reception into active knowledge construction. Studies reviewed in this literature analysis show that students taught using PBL consistently achieve higher average scores than those who follow conventional teaching methods.

A study by Azizi (2019) revealed that role-playing-based PBL yielded an average score of 86.18, compared to 82.80 achieved through standard PBL. Another study by Pitaloka and Slamet (2019) reported a score of 82 when PBL was supported by audiovisual media, significantly higher than the 66 achieved under traditional methods. Similarly, other interventions such as concept mapping (Murdiyah et al., 2020) and scaffolding (Haka & Diana, 2021) showed substantial gains in student achievement. Table 1 presents the summary of these findings.

Table 1. Comparison of Students' Problem Solving Abilities with the PBL Model and Conventional Methods

Researcher	Types of PBL Interventions	Number of Students	Average Value (PBL)	Average Value (Conventional)	Percentage Increase (%)
Azizi (2019)	PBL vs. PBL + Role Playing	30	86.18	82.80	4.1%
The Last Supper (2019)	PBL + Audio Visual	32	82	66	24.2%
Murdiyah et al. (2020)	PBL + Concept Mapping	28	85	70	21.4%
Haka & Diana (2021)	PBL + Scaffolding	35	88	72	22.2%
The Last Supper (2018)	Standard PBL	40	80	65	23.1%

This consistent pattern of improvement aligns with the principles of constructivist learning theory. Learners are encouraged to build their understanding through exploration and inquiry, which are the foundation of PBL. The model emphasizes critical thinking and the development of solutions through guided facilitation. These features reflect Bruner's discovery learning and Vygotsky's theory regarding the Zone of Proximal Development, where the role of the teacher is to support student progress toward higher cognitive abilities. Statistical results further support these conclusions. For example, a One Sample T-Test showed a significance level of 0.000 and a T-count of 41.990, confirming the substantial impact of PBL on critical thinking and problem-solving capabilities. Additional evidence from Cheng et al. (2017) confirmed that students using the PBL model demonstrated a stronger ability to identify and connect biological concepts when compared to their peers in traditional settings.

The benefits of PBL extend beyond academic performance. Ngongo and Efendi (2021) found that students trained under the PBL approach developed greater confidence in expressing opinions and improved their collaboration skills. The model fosters an environment where communication, teamwork, and innovation thrive skills essential for the 21st-century learner. Despite its advantages, the success of PBL implementation relies on several important factors. The teacher's role as a facilitator is critical. Students must be guided to explore solutions independently without being provided with direct answers. The availability of adequate instructional resources, including multimedia and interactive tools, also enhances the effectiveness of the PBL model (Lathifah et al., 2025). Furthermore, student readiness and the capacity for independent learning greatly influence the outcomes.

The reviewed studies also indicate that the effectiveness of PBL varies depending on the types of media and strategies integrated into the learning process. Interventions involving audiovisual materials, role-playing, and concept mapping show greater learning gains than standard PBL alone. This variation highlights the importance of instructional design in maximizing the impact of PBL. Rather than viewing PBL as a fixed model, educators should treat it as a flexible framework that benefits from strategic enhancement with interactive and contextual tools. In the Indonesian educational context, where teacher-centered instruction remains dominant, the adoption of PBL offers a promising alternative. However, its implementation faces practical constraints. Teachers often lack sufficient training in managing inquiry-based activities, and classroom conditions, such as large student numbers and limited infrastructure, pose additional challenges. These barriers must be addressed through professional development, curriculum support, and investment in media resources. Without systemic support, the full potential of PBL to transform science learning into an active, student-centered experience will remain underutilized.

The findings of this review confirm that PBL contributes meaningfully to biology education. Continued research is encouraged to explore long-term retention, examine its application across different student populations, and assess its impact on affective and metacognitive domains.

CONCLUSION AND SUGGESTION

Based on the literature review conducted, it can be concluded that the Problem-Based Learning (PBL) model is effective in enhancing students' problem-solving abilities, particularly in Biology learning. PBL facilitates the development of higher-order thinking skills such as critical thinking, analytical reasoning, and creativity by engaging students with real-world problems that require investigation, discussion, and solution generation. Quantitative data from various studies indicate consistent improvement in students' academic performance, with average score increases ranging from 4% to 24% when PBL is implemented, especially in combination with supportive strategies such as role-playing, audiovisual aids, concept mapping, or scaffolding.

In addition to cognitive gains, PBL positively contributes to the development of students' social and interpersonal skills, including collaboration, communication, and confidence. These skills align with the 21st-century learning framework and the goals of Indonesia's Kurikulum Merdeka, which emphasize student-centered and inquiry-based education. However, the effectiveness of PBL also depends on several critical factors such as the teacher's role as a facilitator, the availability of interactive media, and students' readiness for independent learning. Variations in PBL implementation across different contexts further highlight the need for thoughtful instructional design and adequate professional support for educators.

Therefore, PBL is recommended as a strategic learning model to enhance not only cognitive outcomes but also students' holistic competencies in Biology education. Future research should explore long-term impacts, comparative effectiveness across science domains, and strategies to overcome barriers in practical implementation, particularly in schools with limited resources.

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