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Effectiveness of problem-based learning strategies in improving critical thinking skills of students in biology learning: A literature review

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Abstract. Critical thinking skills are essential 21st-century competencies, yet Biology learning in schools often remains teacher-centered, limiting students' active involvement in analyzing and solving problems. Problem Based Learning (PBL) offers a solution by positioning students at the center of contextual problem-solving activities. This study aims to examine the effectiveness of PBL in enhancing Biology students' critical thinking skills through a systematic literature review (SLR) using content analysis. Data were collected from Google Scholar using the keyword "Critical Thinking Problem Based Learning in Biology Education" and screened from 28,300 articles to 10 relevant ones based on inclusion and exclusion criteria. Findings indicate an increasing research trend over the past decade. PBL effectively improves learning outcomes, critical thinking skills, and student engagement, aligning with 21st-century skills. It is concluded that PBL is an adaptive and applicable strategy to enhance the quality of Biology learning.

Abstrak. Keterampilan berpikir kritis merupakan kompetensi penting abad ke-21, namun pembelajaran Biologi di sekolah masih berpusat pada guru sehingga siswa kurang terlibat aktif dalam menganalisis dan memecahkan masalah. Problem Based Learning (PBL) menjadi solusi dengan menempatkan siswa sebagai pusat pembelajaran berbasis masalah kontekstual. Penelitian ini bertujuan mengkaji efektivitas PBL dalam meningkatkan keterampilan berpikir kritis siswa Biologi melalui systematic literature review (SLR) dengan analisis konten. Data diperoleh dari Google Scholar menggunakan kata kunci "Berpikir Kritis Problem Based Learning pada Pembelajaran Biologi" dan disaring dari 28.300 artikel menjadi 10 artikel relevan sesuai kriteria inklusi dan eksklusi. Hasil kajian menunjukkan tren penelitian meningkat dalam satu dekade terakhir. PBL terbukti efektif meningkatkan hasil belajar, keterampilan berpikir kritis, dan keterlibatan siswa, serta relevan dengan keterampilan abad ke-21. Disimpulkan bahwa PBL merupakan strategi adaptif dan aplikatif untuk meningkatkan kualitas pembelajaran Biologi.

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Introduction

Education plays a crucial role in enhancing the quality of human resources (HR). Education is essential for equipping students with learning and innovation skills (Isnaini & Fanreza, 2024). Following the content of Law Number 20 of 2003 concerning the National Education System, education functions to develop abilities, shape character, and build a dignified national civilization. Education is also expected to produce humans who are faithful, pious, capable, creative, and responsible (Ashidiqi et al., 2024). Education is also one of the keys to national progress, because it can affect the quality of a country's human resources (Nabilah & Syamsurizal, 2024).

Learning is the core of the educational process, which involves interaction between educators and students. Pane and Dasopang (2017) state that the interaction of learning components such as strategy, media, and learning environment determines the success of learning. The teacher is not only a material deliverer, but also a facilitator who creates a pleasant learning atmosphere and is relevant to the needs of students (Marhamah, 2023). Following Permendikbud No. 22 of 2016, learning needs to be student-centered and support the development of 21st-century skills (4C): critical thinking, creativity, communication, and collaboration (Delfiza & Fuadiyah, 2024). However, learning in schools is often still teacher-centered and oriented towards conventional delivery of material without actively involving students in the process of critical thinking and contextual problem-solving. This condition challenges the development of 21st-century skills that demand higher-order thinking, collaboration, communication, and creativity.

Key factors supporting the development of 21st-century skills include the need for a learning model that enhances students' understanding and optimizes the teaching-learning process, ultimately leading to optimal student learning outcomes. One of the effective learning models in improving the teaching-learning process is Problem-Based Learning (PBL). The PBL approach not only focuses on mastering information but also encourages the development of analytical and evaluative skills, as well as the ability to work together among students (Hartati & Billa, 2023).

The PBL learning model enables students to solve the problems they face by encouraging them to be more responsive and creative in addressing existing issues. Critical thinking is one of the essential skills that must be developed through learning. Juliyantika and Batubara (2022), call critical thinking a cognitive process to analyze and reflect on problems. Effective learning requires teachers to design methods that spark student interest, encourage curiosity, and develop critical thinking skills in solving real problems (Asmida et al., 2024; Wulandari et al., 2023). This is particularly important in learning Biology, which requires a contextual and innovative approach.

The application of PBL in Biology learning is considered capable of improving students' critical thinking skills. Students not only memorize concepts, but are also invited to analyze and solve problems related to natural phenomena around them (Ningrum et al., 2023). Various studies have shown that students involved in PBL have better analytical and problem-solving skills than those in conventional learning. PBL also creates a collaborative and interactive learning environment (Sitanggang et al., 2024).

The PBL learning model is consistently proven to improve students' critical thinking skills, but with varying approaches, conditions, and results. Research by Fakhrizal and Hasanah, (2020) showed that through two cycles of direct learning in the classroom, students' critical thinking skills increased from the less critical category (37.81%) to critical (76.90%) after applying PBL in Biology subjects. This result shows the success of PBL in encouraging students' active involvement and significant improvement of analytical skills. Meanwhile, research by Apryani and Suyanto, (2021) applied PBL in online learning during the pandemic, which initially showed less critical results (56.89%) in the first cycle, and increased to moderately critical (78.61%) in the second cycle. This suggests that while PBL remains effective in an online context, its effectiveness is slightly lower than in a face-to-face context, possibly due to the limitations of teacher-to-student interaction and monitoring.

Different from the previous two studies, the study by Sinurat et al. (2025) used a PBL approach assisted by e-LKPD (electronic Learner Worksheet). With a quantitative pretest-posttest method, the results showed an increase in the average critical thinking ability from 40.83 to 85.47, with an N-Gain value of 68.05% (category "effective"). This study highlights that the use of digital media such as e-LKPD can increase the effectiveness of PBL, especially in the context of learning the classification of living things.

The differences in approaches and results in several studies indicate that further analysis is needed to thoroughly understand the effectiveness of PBL in improving students' critical thinking skills. One of them is a literature review in the form of a literature study. Literature study theoretically lies in its ability to compile, analyze, and synthesize various previous research results comprehensively and critically, thus enabling researchers to identify patterns, gaps, and contradictions in empirical findings. Literature studies provide a strong theoretical foundation and are efficient in terms of time and resources, as they utilize secondary data that is already available, yet still yield meaningful and evidence-based conclusions. Based on this background, this study aims to analyze the effectiveness of the PBL learning model in improving students' critical thinking skills in learning Biology. In addition, this study also examines the implementation of PBL in more depth, including implementation strategies, media used, and learning characteristics that affect its

effectiveness. This study is important because the results of previous research show diverse findings, both in terms of approaches, contexts, and outcomes.

This research is structured in the form of a systematic literature study to summarize and synthesize various previous empirical findings comprehensively, so that in this research three main questions are made as follows:

1) What are the research trends regarding the application of PBL models in Biology learning over the past ten years, especially about the development of critical thinking skills?
2) What are the main findings of the literature review regarding the effectiveness of the PBL model in improving students' critical thinking skills?
3) What is the scientific impact of the application of the PBL model on the development of practical, contextualized, and 21st-century skills-oriented Biology learning?

The results of this study are expected to make a theoretical contribution to the development of a more innovative Biology learning model and become a practical reference for educators in designing effective and meaningful learning.

Research Methods

Methods can be divided into several parts, which include:

1) Type

This research method employs the Systematic Literature Review (SLR) type, which involves a systematic examination of several scientific articles that discuss specific topics. This approach utilizes secondary data collected from various current academic literature. The focus of the study was directed at the application of the Problem-Based Learning (PBL) model in biology learning to improve students' critical thinking skills. Data was searched starting in July through the Google Scholar page

2) Data source and time

The data sources in this study were obtained through searching for scientific articles available online using the Google Scholar database as the primary source. The search process was conducted by entering predetermined keywords, resulting in several literature relevant to the focus of the study. The article search was conducted from July 25 to July 27, 2025, considering the currency and relevance of the article content to the topic of Problem-Based Learning in the context of improving students' critical thinking skills in biology learning.

3) Data collection technique

The data collection technique involved searching and downloading scientific articles from the Google Scholar page using the keywords "Critical Thinking Problem-Based Learning in Biology Learning" (see Figure 1). The search process was limited to articles published from 2015 to 2024. The data collection technique was continued by collecting key information from each article based on the research findings. Furthermore, the data analysis technique used was descriptive analysis. The search process was limited to articles published between 2015 and 2024. Selection was made based on several inclusion and exclusion criteria, including publication in original research, Indonesian or English language, open access, relevance to the field of biology education, and direct relevance to the topic of Problem-Based Learning and critical thinking skills, as formulated in Table 1, adapted from Fajeriadi et al. (2024).

Table 1 Inclusion and exclusion criteria (adapted from Fajeriadi et al. 2024).

No	Inclusion criteria	Exclusion criteria
1.	Electronic database search using Google Scholar	Electronic database searches do not use Google Schoolar
2.	Publication within the last 10 years	Articles more than 10 years old
3.	Original article	Review articles
4.	Articles in English and Bahasa Indonesia	Publications not in English or Indonesian
5.	Full access to articles	Open access to all necessary information
6.	Biology Education	Other fields of study
7.	Search based on data in accordance with the theme discussed	Only articles with relevance to the topic

4) Data analysis technique

This data was analyzed using the Content Analysis technique. Content analysis is a method that combines quantitative and qualitative approaches, thus reflecting a blend of positivistic and interpretive paradigms. This analysis process begins with the use of qualitative data in the form of text, which is then examined based on the assumptions or reasoning built by the researcher. Following this, a systematic coding process is conducted to organize the data, and then the interpretation stage is undertaken to generate a meaningful description (Liamputtong, 2005 as cited in Rozali, 2022).

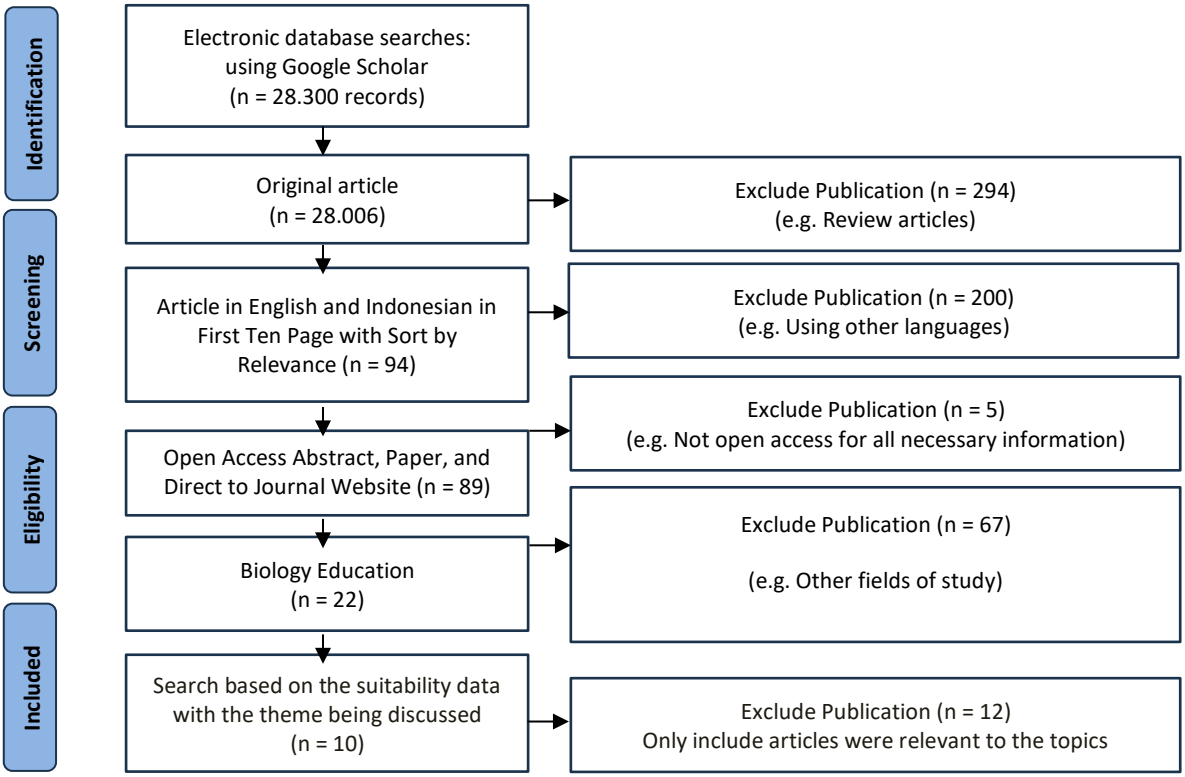

Figure 1 Selection of articles used in SLR using the Prisma model

Results and Discussion

Based on the data collected, the trend of research publications in the field of education from 2015 to 2024 shows a significant increase (Figure 2). In 2015, there were 617 articles, increasing to 888 articles in 2016 and 1,150 articles in 2017. In 2018, the number increased to 1,490 articles, then to 2,010 articles in 2019. A sharper increase occurred in 2020 with 2,630 articles, then jumped to 3,520 in 2021. This figure continued to increase to 4,560 articles in 2022, 6,170 articles in 2023, and a peak in 2024 with 7,070 articles. Cumulatively, over the last ten years, the number of articles published reached 30,105.

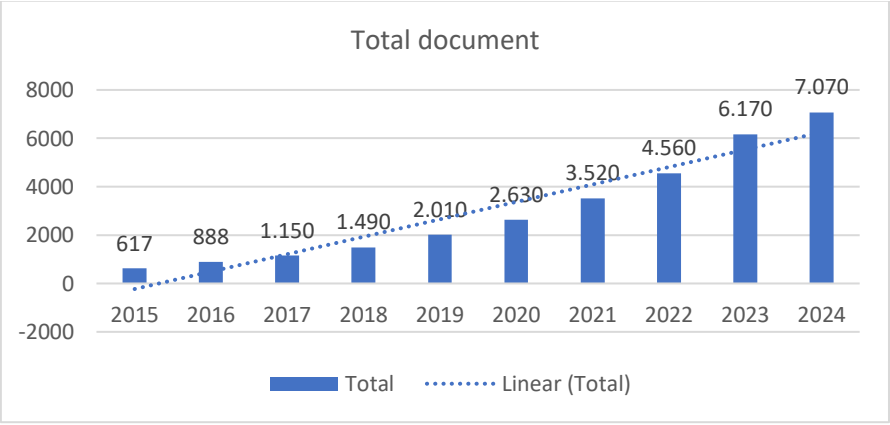

Figure 2 Trend chart 2015-2024

If analyzed more specifically, publications that examine the use of Problem-Based Learning (PBL) in Biology learning show a stable and positive increasing trend over the past ten years (Table 2). In 2015, no relevant articles were found, but from 2016 to 2019, there was a slow increase from one to three articles per year. This trend began to increase significantly in 2020 with 12 articles, then jumped sharply in 2021 with 30 articles, and continued to increase until it

reached 42 articles in 2022, 77 articles in 2023, and a peak in 2024 with 126 articles. This consistent increase reflects a positive and stable trend in researchers' interest and attention to the application of PBL in Biology.

Table 2 Number of PBL Research Publications in Biology Learning from 2015-2024

Year	Number
2015	0
2016	1
2017	1
2018	2
2019	3
2020	12
2021	30
2022	42
2023	77
2024	126
Total	**294**

The increasing trend of publications on Problem-Based Learning (PBL) in Biology learning over the past five years (2020-2025) shows a positive and significant development. This surge in the number of publications reflects the increasing attention of researchers to the effectiveness of the PBL model in supporting 21st-century learning. Several recent scientific studies confirm that PBL is efficacious in improving various aspects of learning, such as ecological awareness, student engagement, and strengthening metacognitive skills and collaborative and authentic problem solving (Al Ayyubi & Wisudawati, 2025). The integration of PBL with digital technology and innovative approaches such as blended learning and the use of game-based educational media also further strengthens its relevance and effectiveness in the context of Biology learning (Fatwa et al., 2025). Empirical research from elementary to secondary school levels shows a significant increase in concept mastery, active participation, and students' critical thinking skills (Tamaela et al., 2020). Although implementation challenges such as limited tutor training and learning facilities are still found, various innovations in the development of digital teaching tools and teacher training have helped overcome them (Diciana et al., 2025). As a concrete example, Wiono & Siregar, (2024) conducted a quasi-experimental study on seventh-grade junior high school students, focusing on the topic of interactions between living organisms and the environment. The results showed that PBL was significantly effective in improving critical thinking skills, with an average N-Gain score of 0.65 (categorized as “moderate”) and a large effect size of 1.18. These findings affirm that PBL can strengthen students’ metacognition, which is an essential ability in critical thinking. Based on the search results on the Google Scholar page with the keyword Critical thinking problem-based learning in biology learning, ten articles published in national journals were selected. The findings of the ten articles are detailed in Table 3.

Table 3 Details of Findings from Ten Articles Relevant to the Topic

Code	Researcher (Year)	Problem	Method	Findings
A1	Emor et al. (2024)	Low learning outcomes, passive students	2 cycles of PTK	Grades increased from 5.7 → 7.3 → 8.4; PBL is effective in improving learning outcomes
A2	Fakhrizal & Hasanah (2020)	Grades below minimum passing grade, low critical thinking	4 cycles of PTK	Critical thinking skills improved each cycle
A3	Apryani & Suyanto (2021)	Low engagement, passive online learning	2 cycles of PTK, online via Google Classroom & Meet	PBL improves critical thinking & learning outcomes during pandemic
A4	Nasrulloh et al. (2023)	Low critical thinking, learning does not match learning style	2 cycles of PTK	PBL improves learning outcomes & critical thinking skills (medium category)
A5	Paramitha et al. (2024)	Passive students, limited critical thinking	3 cycles of PTK	PBL improves student engagement & analytical skills
A6	Hartati & Billa (2023)	Students have difficulty understanding cell material	Quasi: Randomized Pretest-Posttest	PBL significantly improves learning outcomes & critical thinking
A7	Nurhidayati et al. (2024)	Low activeness & critical thinking	Quasi: Non-equivalent Control Group	PBL class had higher results; PBL practiced problem solving
A8	Masrinah et al. (2023)	Students are not active, only memorize	Quasi: Pretest-Posttest two classes	Learning activity increased (83%), positive response (75%)

Code	Researcher (Year)	Problem	Method	Findings
A9	Harnita et al. (2023)	Unattractive learning media	Quasi-experiment with Flash media	PBL + Flash improves biology learning outcomes
A10	Sinurat et al. (2025)	Passive learning, weak critical thinking	Quasi: Pretest-Posttest one experiment vs control	PBL + e-LKPD very effective in improving critical thinking skills

From the analysis of ten articles, it was found that the Problem-Based Learning (PBL) model consistently has a positive impact on Biology learning. Almost all studies reported improvements in student learning outcomes, both in cognitive aspects such as concept mastery and science process skills. In addition, PBL encourages the development of critical thinking skills, analysis skills, and scientific problem-solving effectively. This model is also proven to increase students' motivation and active participation, both in face-to-face and online learning. Through discussion and group work activities, PBL strengthens collaboration skills and encourages more meaningful student engagement. Overall, the PBL model plays an effective role in improving the quality of Biology learning, including the cognitive, affective, and scientific skills dimensions of students.

Based on the review of ten articles examining the application of the Problem-Based Learning (PBL) model in biology learning, this model has a positive influence on various aspects of learning outcomes. PBL is proven effective in improving student learning outcomes, both in terms of cognitive knowledge and science process skills, as shown by the consistent increase in average scores in various studies. In addition, PBL also encourages the development of critical thinking and problem-solving skills, as students are required to analyze situations, seek information, and develop solutions independently or in groups. This model also contributes to increasing students' interest and motivation to learn because its contextual approach makes learning more meaningful and relevant to everyday life. Equally important, PBL helps students develop collaborative skills, such as the ability to work together in groups, discuss, and respect the opinions of others, which are very important in shaping 21st-century competencies.

Some previous research results show strong support for the effectiveness of the Problem-Based Learning (PBL) model in improving the quality of science learning, including Biology. Research by Widiatuti, (2016) states that the PBL model is more effective than the Group Investigation (GI) model in improving students' problem-solving skills in science learning. This shows that the problem-based approach can provide more substantial intellectual challenges for students in solving scientific problems independently. Furthermore, research by Zaidah & Hidayatulloh, (2024) revealed that PBL proved to be superior to conventional models in improving mastery of science concepts of grade VIII junior high school students. Statistical test results show significance with a t-count value of 3.82> t-table 2.000 at a significant level of 0.05. Meanwhile, research conducted by Herlinda et al., (2017) combined the PBL model with a scientific approach and resulted in a significant increase in learning outcomes (t = 5.65), problem-solving skills (t = 2.58), and student interest (t = 1.75). All three values exceeded the t-table (1.68), indicating that the PBL model, with its scientific approach, has a positive impact on various aspects of learning.

When compared to the ten articles previously reviewed, the findings of these three studies show harmony both in terms of methods and results. Methodologically, both the previous and reviewed studies used a quasi-experimental approach to test the effectiveness of the PBL model. Another similarity lies in the focus on measuring learning outcomes, critical thinking skills, and problem-solving. However, some differences enrich the picture of PBL implementation. These differences include the level of education and the subjects studied. Previous research was generally conducted at the junior high school level with a general science context, while the articles reviewed focused more on high school students with specific Biology subjects. In addition, variations in the PBL implementation approach are evident, as seen in the research of Herlinda et al., (2017), which employed a scientific approach. Furthermore, some articles reviewed combined this approach with digital media or e-LKPD. This variation shows the flexibility of the PBL model in being applied to various learning contexts.

Based on the methods used, most of the studies applied quasi-experiments, while the rest used Classroom Action Research (PTK). Quasi-experiments are generally used to test the difference in achievement between experimental classes that apply PBL and control classes that use conventional methods, so that the results have statistical validity and can be generalized. In contrast, PTK is more focused on improving learning in a particular classroom through cycles of reflection and improvement, making it more applicable to teachers. These two approaches complement each other: quasi-experiments provide strong empirical evidence, while PTK provides a practical overview of the continuous implementation of PBL.

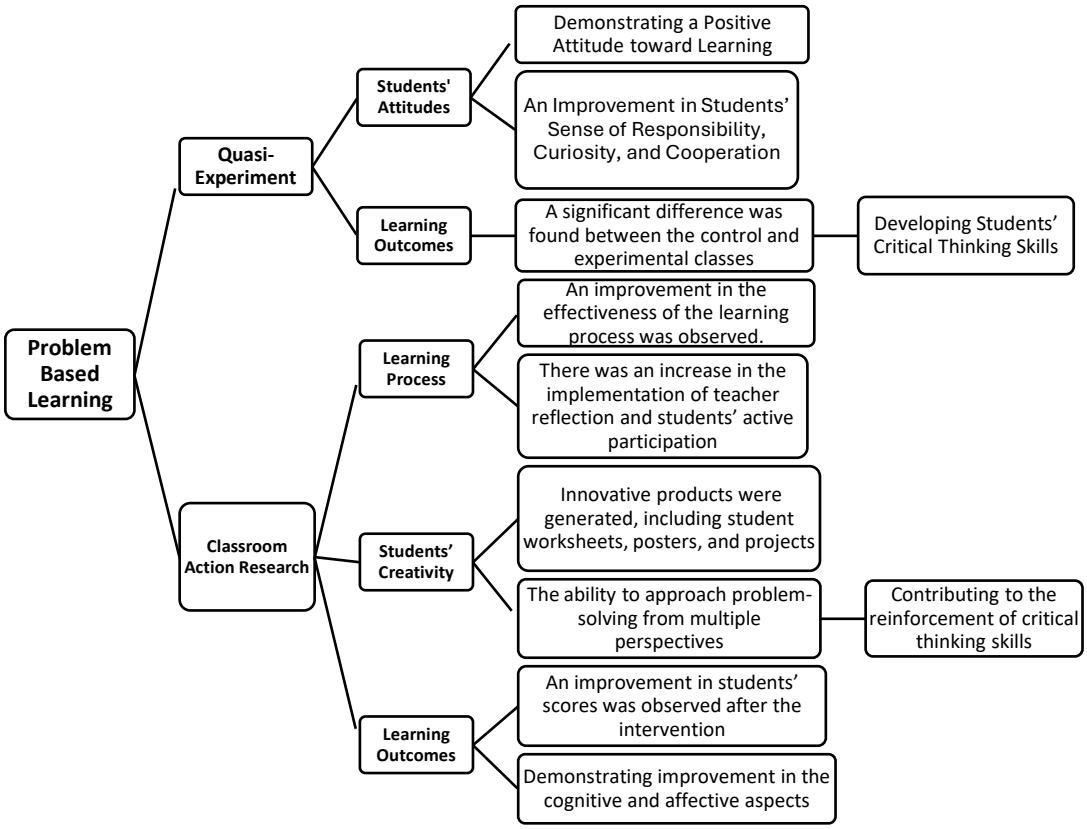

Figure 3 Schematic of PBL-biology research patterns based on analysis of ten articles

Based on the synthesis of the ten articles analyzed and the conceptual mapping regarding the application of Problem-Based Learning (PBL), it was found that this model consistently has a positive impact on various aspects of Biology learning, both from the cognitive, affective, and process skills dimensions. Analysis of the ten articles reviewed, as well as the PBL mind map, shows that Problem-Based Learning consistently has a positive impact on Biology learning, especially in developing students' critical thinking skills (see Figure 3). Findings from the quasi-experimental approach noted significant improvements in learning outcomes and learning processes. The PTK approach also shows PBL can generate student creativity and solve problems scientifically, all of which support the strengthening of critical thinking skills (Iwan et al., 2024; Usman et al., 2024)

In line with the theory of social constructivism (Vygotsky), PBL facilitates students in building knowledge through authentic experiences and social interactions to foster critical thinking skills through the steps of analysis, evaluation, and reflection. In addition, meta-analysis shows PBL has significant positive effects on critical thinking skills in various science disciplines, including Biology (Liu & Pásztor, 2022; Nastiti et al., 2021). According to the motivation, especially in Biology learning, systematic research found that PBL helps students understand scientific concepts and improve critical thinking through data collection activities, synthesis, and group discussions (Usman et al., 2024).

The main problem in this study is the low critical thinking skills of students in learning Biology. Based on literature analysis of quasi-experimental designs and classroom action research (PTK), the implementation of Problem-Based Learning (PBL) has consistently been shown to support students' active engagement in solving authentic problems, thus strengthening the reflective and analytical thinking processes that are at the core of critical thinking. For example, a quasi-experimental study showed that student groups that implemented PBL showed higher critical thinking scores than the control group, indicating that the PBL learning process provided constructive cognitive challenges (Nihlah et al., 2024). On the other hand, a meta-analysis involving many international studies shows that PBL significantly improves students' critical thinking skills, with strong and consistent positive effects across different educational levels as well as science subject contexts (Liu & Pásztor, 2022).

In addition, Biology-based systematic research confirms that PBL strengthens group discussion, data synthesis, and reflection, which are all aspects that directly stimulate critical thinking (Usman et al., 2024). These findings support that through the structure of PBL, including problem identification, investigation, group discussion, and reflection, students become active subjects in learning, which encourages higher-order thinking competencies. Thus, PBL is a very relevant and effective learning strategy to improve students' critical thinking skills in the context of Biology learning. As a practical recommendation, teachers are expected to implement systematically designed PBL scenarios that focus on

real problem solving and collaborative learning, and enrich students' experiences with reflection and analytically oriented discussions.

The results achieved from the application of this pattern are not only an increase in average scores and learning completeness, but also strengthening 21st-century skills, including critical thinking, collaboration, communication, and creativity. Students become better prepared to face real-world challenges as they get used to solving complex problems, working in teams, communicating ideas clearly, and creating innovative solutions. The implication of this finding aligns with the 21st-century learning objectives discussed in the introduction, which aim to equip learners with the relevant competencies needed to address technological developments, social changes, and global challenges. Therefore, the application of PBL integrated with technology, a scientific approach, and local context can be an effective and sustainable learning strategy to improve the quality of Biology education at various levels.

Conclusion

Based on a literature study of ten selected articles, research trends related to the Problem-Based Learning (PBL) model in Biology learning over the past decade indicate a significant increase in interest, with a primary focus on developing students' critical thinking skills. Findings from the reviewed articles indicate that PBL is consistently able to improve critical thinking skills, both through classroom action (PTK) and quasi-experimental approaches, with indicators of improvement covering cognitive aspects, attitudes, and student creativity. In-depth analysis of the articles revealed a pattern that the successful implementation of PBL is strongly influenced by the integration of learning media (such as e-LKPD), the active role of teachers as facilitators, and the active involvement of students in the problem-solving process. These patterns support the development of 21st-century skills, especially critical thinking, collaboration, and creativity in the context of contextual and meaningful Biology learning. However, this study has limitations in the number of articles reviewed and its focus on the Biology education domain only, so generalization to other subjects is still limited. In addition, another limitation lies in the reliance on published secondary data, which cannot directly explore contextual factors in the field. Therefore, future research is recommended to develop a mixed-methods study involving direct observation and teacher or student interviews to obtain a more complete picture. Further research can also expand the study to other subjects and explore the relationship between PBL and other 21st-century skills in more depth.

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