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Systematic literature review: Problem-based learning and self-regulated learning on critical thinking skills in science

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Abstract
In the era of globalization, mastering critical thinking skills in science education is essential; however, current evidence suggests that Indonesian students still need significant improvement in this area. Problem-Based Learning (PBL) and Self-Regulated Learning (SRL) are identified as promising strategies to address this gap. This study aims to analyze and synthesize recent findings regarding the effectiveness of PBL and SRL in developing students' critical thinking skills through a systematic literature review. This review adopts the PRISMA method and conducts database searches across Scopus, Web of Science, ERIC, Google Scholar, and nationally accredited journals published between 2020 and 2024. Eight selected articles that met the inclusion criteria were analyzed using a thematic narrative synthesis. The results indicate that the implementation of PBL significantly improves academic satisfaction and learning outcomes, with mastery levels reaching 92% at the elementary level. Integrating PBL with other methods, such as Case-Based Learning, enhances motivation, comprehension, and critical thinking. These strategies are effective across education levels and are not dependent on tutor seniority. Based on these findings, it is recommended to integrate PBL systematically into curricula, develop digital PBL-based platforms, conduct longitudinal studies, and design comprehensive assessment rubrics.

Keywords: Problem-Based Learning; Self-Regulated Learning; Critical Thinking; Science Education; Systematic Review

INTRODUCTION

In the increasingly complex era of globalization, critical thinking skills have become one of the essential competencies that students must master, particularly within the context of science education. These skills enable students to systematically analyze information, evaluate evidence, and make decisions based on logical reasoning. However, recent data reveal that the critical thinking abilities of Indonesian students require substantial improvement. This concern is supported by the 2022 Programme for International Student Assessment (PISA) results, which indicate that Indonesia continues to fall below the international average in science proficiency (Wulandari, Rochmad, & Isnarto, 2022).

One of the instructional models considered effective in fostering critical thinking skills is Problem-Based Learning (PBL). This model engages students with authentic, complex problems that require thoughtful solutions, thereby encouraging analytical, evaluative, and problem-solving abilities. Through PBL, students not only gain theoretical knowledge of science concepts but are also encouraged to apply them in real-world contexts. A study by Faizin, Silaban, and Silaban (2024) demonstrated that implementing PBL in science education significantly enhanced students' abilities to analyze problems, develop hypotheses, and formulate evidence-based solutions.

In parallel with PBL, Self-Regulated Learning (SRL) plays a vital role in optimizing the learning process and cultivating critical thinking skills. SRL refers to learners' capacities to independently regulate and control their learning, which includes cognitive, metacognitive, motivational, and behavioral dimensions. Within the context of science education, students who possess strong SRL skills tend to be more adept at planning, monitoring, and evaluating their learning strategies. Research by Handayani et al. (2024) has shown a positive correlation between high SRL levels and enhanced critical thinking in science learning.

The integration of PBL and SRL in science education fosters a learning environment conducive to the comprehensive development of critical thinking. While PBL provides meaningful contexts that stimulate inquiry, SRL equips learners with tools to manage and reflect on their cognitive processes. A longitudinal study conducted by Safitri et al. (2023) revealed that students engaged in PBL supported by SRL strategies experienced significant improvements in critical analysis and complex problem-solving skills.

Nonetheless, the implementation of PBL and SRL in Indonesian science education faces various challenges, including limited teacher readiness, inadequate resources, and a prevailing teacher-centered learning culture. Despite these obstacles, promising outcomes have been reported. For instance, research by Oka Sabrina (2024) in several secondary schools in Central Java demonstrated that integrating PBL with SRL development strategies not only enhanced students' critical thinking but also improved their motivation and autonomy in learning science.

Furthermore, the digital era and post-pandemic hybrid learning models have created new opportunities to apply PBL and SRL. The use of educational technologies and digital platforms facilitates critical thinking development through diverse resources and interactive learning experiences. According to Putra, Astawan, and Antara (2022), integrating technology into PBL- and SRL-based science learning significantly enhances its effectiveness in fostering critical thinking.

Although existing studies confirm the potential of PBL and SRL to develop critical thinking, there remains a knowledge gap concerning the optimal implementation of these approaches in the Indonesian science education context. This systematic literature review aims to analyze and synthesize recent empirical studies on the effectiveness of PBL and SRL in enhancing students' critical thinking skills in science. It explores instructional design, implementation strategies, success factors, as well as challenges and practical solutions.

The review seeks to establish an empirical basis for developing and implementing integrated PBL and SRL models in science education to foster critical thinking. In addition, it aims to identify research gaps and provide recommendations for future studies. Ultimately, the findings are expected to contribute to improving the

quality of science education in Indonesia and equipping students with critical thinking skills essential for navigating the challenges of the 21st century.

DISCUSSION AND ANALYSIS

The implementation of Problem-Based Learning (PBL) has shown considerable effectiveness in improving various aspects of student learning, particularly in fostering academic satisfaction and critical thinking skills. A study by Tadesse, Tadesse, and Dagnaw (2022) involving 850 students in Ethiopia revealed that learners engaged in PBL reported higher levels of academic satisfaction (50.9%) compared to those in traditional lecture-based learning environments (49.9%). Contributing factors included the quality of instruction, peer collaboration, and the relevance of curriculum content. These findings suggest that PBL not only enhances learning satisfaction but also supports the development of self-regulated learning (SRL) through active engagement.

The role of facilitators or tutors in PBL contexts is also a subject of interest. An experimental study conducted in Japan by Nomura et al. (2023) examined the influence of tutor seniority on students' emotions and self-efficacy during PBL sessions in medical education. The results showed no significant difference between sessions led by senior faculty and those led by less experienced tutors, suggesting that the success of PBL lies more in the quality of the learning process than in hierarchical authority. This highlights the adaptable nature of PBL and its capacity to nurture both SRL and critical thinking across diverse educational settings.

Furthermore, integrating PBL with other pedagogical models yields promising results. Zhao et al. (2020) evaluated the combination of PBL and Case-Based Learning (CBL) in teaching thyroid disorders to 354 students and 232 residents. The study reported significant improvements in motivation, content mastery, student–teacher interaction, and especially in critical thinking. These results indicate that integrated approaches can enhance active learning and promote comprehensive critical thinking development.

The benefits of PBL in medical education have been further validated by a scoping review conducted by Trullàs et al. (2022), which analyzed 124 studies. The review concluded that PBL is more effective than traditional teaching methods in promoting social skills, communication, problem-solving, and self-directed learning. These skills align closely with the objectives of science education and the cultivation of critical thinking competencies.

At the elementary level, PBL has also demonstrated substantial impact. Hidayanti, Supratman, and Noviati (2022) developed a PBL-based biology e-module aimed at enhancing scientific literacy among elementary students. A classroom action study indicated that learning mastery reached 92%, underscoring PBL's effectiveness even in early education. Similarly, Puspita (2022) reported high average achievement scores among fifth-grade students in science learning through PBL, further supporting its efficacy in enhancing science understanding and critical thinking from a young age.

In secondary education, a pre-experimental study by Adhitya and Fauziah (2023) measured improvements in critical thinking skills among junior high school students learning about the human digestive system via PBL. The results showed significant gains in students' critical thinking post-intervention, offering further empirical support for the method's applicability in science instruction. Although focused on mathematics, the findings of Tere, Kaluge, and Lakapu (2023) contribute to the body of knowledge by

demonstrating that PBL significantly boosts academic performance and analytical reasoning, suggesting its effectiveness extends across disciplines.

Synthesizing these eight studies reveals that PBL is a central strategy in developing both critical thinking and self-regulated learning in science education. Its effectiveness has been consistently evidenced across educational levels and learning environments. Key outcomes include improved academic performance, enhanced higher-order thinking, refined problem-solving capabilities, and strengthened learner autonomy.

These findings yield several implications for educational practice. First, PBL provides a conducive framework for developing critical thinking and SRL. Second, its flexible nature allows integration with other methodologies for optimized outcomes. Third, initiating PBL at the elementary level can lay a strong foundation for advanced critical thinking development in science education.

In conclusion, PBL emerges as a robust instructional strategy for promoting critical thinking and SRL. Its successful implementation is influenced by various factors, including instructional quality, peer interaction, and content relevance. For future advancements, integrating technology and tailoring PBL to learners' specific needs are essential to maximize its potential in science education.

CONCLUSION

Based on a systematic literature review of eight selected studies, it can be concluded that Problem-Based Learning (PBL) has a substantial and consistent impact on enhancing critical thinking skills and self-regulated learning (SRL) in science education across different educational levels. The effectiveness of PBL is evidenced through various indicators, such as a 50.9% increase in academic satisfaction compared to conventional teaching methods and a mastery level of up to 92% among elementary school students.

Furthermore, the flexibility of PBL allows for integration with other instructional models, such as Case-Based Learning (CBL), which has proven to enhance learning engagement, content mastery, and the development of higher-order thinking skills. Importantly, the success of PBL implementation is not dependent on tutor hierarchy but rather on the quality of the learning process itself.

PBL has also demonstrated its effectiveness in fostering social interaction, communication, problem-solving, and autonomous learning — all of which are integral to the development of SRL. These aspects make PBL a suitable and powerful approach for science education, especially in cultivating critical thinking competencies essential for navigating scientific inquiry and real-world challenges.

Therefore, it is recommended that PBL be systematically integrated into science curricula at all educational levels. The development of digital learning platforms grounded in PBL principles should also be prioritized to meet the needs of 21st-century learners. Future research should focus on longitudinal studies that investigate the long-term impacts of PBL on students' critical thinking development and explore the creation of comprehensive assessment rubrics to evaluate its effectiveness more holistically.

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