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STEM IN BIOLOGY CLASSROOM: EXPLORING IMPLEMENTATION CHALLENGES IN INDONESIAN SCHOOLS

Annesha Rahmadayanti[1*], Rita Rahmayanti[2], Pani Aswin[3]
[1, 2, 3] *Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Bengkulu*

*Corresponding Author: Annesharhmdynti@gmail.ac.id

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ABSTRACT

STEM-based learning (Science, Technology, Engineering, and Mathematics) has the potential to enhance the relevance of biology education to 21st-century life through interdisciplinary and project-based approaches. However, its implementation in Indonesia still faces various challenges. This review article aims to identify the key barriers to implementing STEM in biology education, particularly concerning teacher readiness, facilities and infrastructure, and educational policy support. This study employed a narrative literature review method based on 15 national and international journal articles published between 2015 and 2025. Sources were collected through Google Scholar, DOAJ, ScienceDirect, and SpringerLink using the keywords "STEM education," "biology learning," and "Indonesia." The review found four major challenges: (1) limited teacher competence in designing interdisciplinary learning; (2) lack of laboratory and technological facilities; (3) misalignment between the curriculum and assessment systems with STEM principles; and (4) low student motivation and literacy in STEM. Several initiatives, such as teacher training, project-based learning practices, and the integration of local contexts, have shown promising results. This study highlights the need for comprehensive strategies to strengthen teacher capacity, provide adequate infrastructure, and align educational policies to ensure that STEM implementation in biology education can be more effective and sustainable in the Indonesian context.

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INTRODUCTION

In the 21st century, education faces new demands that not only focus on content mastery but also on developing skills such as critical thinking, creativity, collaboration, and communication. STEM-based learning (Science, Technology, Engineering, and Mathematics) has emerged as a promising strategy to address these challenges. As an interdisciplinary approach, STEM allows students to connect scientific concepts, including biology, with technology and engineering in real-life contexts, which is expected to enhance both learning relevance and student motivation (Saragih et al., 2025; Sari et al., 2021). For example, research in Indonesia has shown that STEM implementation can improve students' critical thinking skills (Rahmawati, 2025) specifically in biology education, STEM integration holds great potential because biology, as a life science, enables students to explore real-world contexts—such as ecosystems, genetics, and the environment, which are highly suitable for project-based approaches and the development of 21st-century skills.

However, the implementation of STEM in biology education in Indonesia still faces several significant challenges (Diana et al., 2021; Prasetyo et al., 2021). For instance, studies indicate that pre-service biology teachers have insufficient understanding of learning models that support 21st-century skills (Jayanti et al., 2024). Furthermore, national literature reviews show that when STEM implementation is examined comprehensively in Indonesia, several major obstacles emerge, including teacher readiness, limited laboratory facilities, and regional disparities(Cahyanti et al., 2022; Farwati et al., 2021; Reyza et al., 2020).

In the Indonesian context, literature studies reveal that although interest in STEM research has increased, school conditions in the field do not yet uniformly support the implementation of this learning model. For example, a scoping review noted that out of 597 articles on STEM implementation in Indonesia between 2015–2020, only 154 met the inclusion criteria, and most of the studies were conducted in specific provinces, indicating that understanding and implementation of STEM are not yet widespread nationally(Farwati et al., 2021). Moreover, in biology education, a systematic study highlighted that challenges such as outdated curricula, limited resources, and insufficient teacher training contribute to decreased student motivation in STEM-based biology learning (Pujiati TM et al., 2025).

Considering these conditions, several aspects warrant special attention as part of the challenges in implementing STEM in Indonesian biology education: (1) teacher readiness, teachers need competencies not only in biology but also in designing interdisciplinary learning and utilizing technology and engineering; studies show that many teachers still lack direct experience in implementing STEM-based learning (Diana et al., 2021; Sulaeman et al., 2022). (2) facilities and infrastructure, including laboratories, technological devices, and school infrastructure supporting project-based learning; the lack of these facilities remains a significant barrier (Farwati et al., 2021; Reyza et al., 2020). (3) Curriculum and learning context, dense and fragmented disciplinary curricula often hinder effective STEM integration in biology education; additionally, local context and adaptation to Indonesian school conditions must be considered (Cahyanti et al., 2022; Herliani et al., 2021). (4) student motivation and readiness, despite students' potential, low science literacy, limited practical experience, and traditional learning models can impede the effectiveness of STEM in biology learning (Karunia & Ridlo, 2022).

Considering these factors, it is essential to conduct a comprehensive literature review to systematically identify the main challenges in implementing STEM in Indonesian biology education and to formulate strategic recommendations to ensure that this approach can be implemented more effectively and sustainably. Thus, this article aims to bridge the gap between the high potential of STEM-based biology learning and the realities of its implementation in Indonesian schools.

METHODS

This study employs a narrative literature review approach to examine the implementation of STEM-based learning in

biology education in Indonesia. This method was selected because it allows for the exploration, synthesis, and analysis of findings from various relevant empirical studies and reviews, with a focus on identifying challenges, implementation strategies, and research gaps. Literature was collected from open-access and academic databases, including Google Scholar, DOAJ, ScienceDirect, SpringerLink, and Garuda, using keywords such as "STEM education AND biology AND Indonesia," "implementation of STEM AND biology learning," and "teacher readiness AND STEM AND Indonesia," covering publications from 2015 to 2025.

Relevant articles were chosen based on inclusion criteria: scholarly works (empirical or review) addressing STEM implementation in biology or science education in Indonesia, available in full-text open-access, and written in either Indonesian or English. Opinion pieces or studies focused on disciplines other than biology were excluded. Selected articles were then analyzed thematically, concentrating on teacher readiness, infrastructure and facilities, curriculum and educational policy, as well as student motivation and preparedness. The findings were synthesized to identify the main challenges, the strategies that have been applied, and recommendations for improving STEM implementation in biology education in Indonesia.

RESULTS AND DISCUSSION

The review reveals that the implementation of STEM-based learning in biology education across Indonesian schools presents both significant potential and persistent challenges. In principle, STEM learning has proven effective in improving critical thinking, problem-solving, and creativity among students, especially when integrated into project-based contexts (English, 2016; Rahmawati, 2025). However, within the Indonesian context, its adoption in biology education remains limited due to multiple systemic and practical barriers. These include inadequate teacher preparedness, limited facilities, fragmented curricula, and low student motivation and literacy in STEM fields (Farwati et al., 2021; Reyza et al., 2020).

Teacher readiness emerges as one of the most critical factors influencing the successful implementation of STEM. Studies indicate that many biology teachers, both pre-service and in-service, lack sufficient training and conceptual understanding of interdisciplinary approaches that connect science, technology, and engineering in classroom practice (Jayanti et al., 2024; Sulaeman et al., 2022). Research by Diana et al., (2021) also emphasizes that STEM integration requires not only pedagogical competence but also technological literacy and creativity in designing learning scenarios. Consequently, professional development programs that focus on inquiry-based and engineering design processes are urgently needed to build teacher confidence and classroom capability (Margot & Kettler, 2019; Saavedra et al., 2012).

Infrastructure and resources are another major concern. Many schools in Indonesia still face shortages in laboratory facilities, digital tools, and experimental materials essential for project-based STEM learning (Farwati et al., 2021; Hanif et al., 2019). This condition creates disparities between urban and rural schools, where unequal access to technology limits students' opportunities to engage in authentic STEM experiences. Improving school infrastructure and integrating low-cost, locally relevant experiments have been proposed as sustainable alternatives to support biology learning (Bardoe et al., 2023; Wan et al., 2021).

Curriculum structure and national education policy also contribute to the challenge. The existing Indonesian curriculum remains largely content-heavy and discipline-specific, making interdisciplinary implementation difficult (Cahyati & Herliani, 2021). As noted by Pujiati TM et al (2025), curriculum rigidity and assessment systems that prioritize factual knowledge over skills hinder teachers from adopting STEM-based innovation. Curriculum reform that embeds STEM principles explicitly, particularly in biology, could help bridge this gap and enhance contextual learning through problem-based and design-based tasks (Becker & Park, 2011; Bybee, 2013).

Student-related factors, such as motivation, engagement, and literacy in science

and mathematics, also influence the effectiveness of STEM in biology classrooms. Studies indicate that students often find STEM learning challenging due to a lack of prior exposure to inquiry-based learning and limited opportunities for experimentation (Karunia & Ridlo, 2022; Sari et al., 2021). Nevertheless, integrating local environmental issues or community-based projects into biology lessons has shown promise in boosting student interest and scientific reasoning (Rahayu & Wulandari, 2025). When STEM activities are contextualized in everyday problems, such as biodiversity, waste management, or health issues, students are more likely to perceive biology as relevant and meaningful.

Overall, the review highlights that the implementation of STEM in Indonesian biology education requires systemic collaboration between teachers, institutions, and policymakers. Strengthening teacher competence through continuous professional development, providing adequate infrastructure, and aligning curriculum and assessment with STEM principles are critical strategies for sustainable integration. In addition, school-based innovations that adapt global STEM frameworks to local contexts can play a vital role in fostering both student engagement and scientific literacy. Hence, while challenges remain, the potential of STEM-based biology education to equip Indonesian students with 21st-century skills remains highly promising provided that implementation barriers are addressed comprehensively.

CONCLUSION

The implementation of STEM-based learning in biology education in Indonesia holds significant potential for enhancing both the relevance of learning and students' 21st-century skills. Nevertheless, several substantial challenges remain, including teacher readiness, limited facilities and infrastructure, curriculum misalignment, and low levels of student motivation and STEM literacy. This literature review indicates that although certain initiatives, such as teacher training, project-based learning, and the integration of local contexts, have yielded positive outcomes, more comprehensive strategies are still required. Strengthening teacher competencies, providing adequate infrastructure, and fostering alignment between national policies and school-level innovations are essential to ensure the effective and sustainable implementation of STEM in Indonesian biology education.

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