Margens
Revista Interdisciplinar

PPGCITE

BIOLOGICAL LITERACY IN THE 21ST CENTURY: A SYSTEMATIC REVIEW OF TEACHING STRATEGIES AND STUDENT OUTCOMES

ALFABETIZAÇÃO BIOLÓGICA NO SÉCULO XXI: UMA REVISÃO SISTEMÁTICA DAS ESTRATÉGIAS DE ENSINO E DOS RESULTADOS DE APRENDIZAGEM DOS ESTUDANTES.

Nofamataro Zebua
Universitas Nias, Indonesia
Yan Piter Basman Ziraluo
Universitas Nias Raya, Indonesia

Resumo: Um obstáculo significativo para a educação no século XXI é o baixo nível de alfabetização biológica entre estudantes do ensino secundário, especialmente no que se refere ao enfrentamento de questões globais como biotecnologia, meio ambiente e saúde. A necessidade de uma avaliação abrangente de métodos de ensino eficazes é reforçada pela urgência em aprimorar essa alfabetização. O objetivo deste estudo é realizar uma análise sistemática das diferentes abordagens pedagógicas utilizadas para promover a alfabetização biológica na educação secundária entre 2020 e 2025. Quinze artigos acadêmicos indexados na Scopus foram submetidos a uma análise temática por meio da metodologia de Revisão Sistemática da Literatura, baseada no protocolo PRISMA. Os resultados demonstram que métodos como letramento disciplinar, aprendizagem centrada no estudante, métodos científicos e integração de tecnologias digitais melhoram significativamente os resultados cognitivos, afetivos e as habilidades científicas dos estudantes. Contudo, ainda persistem desafios, como equívocos conceituais dos estudantes, limitações pedagógicas dos professores e a ausência de contextualização prática nos recursos didáticos. Este estudo recomenda a criação de modelos de aprendizagem mais inclusivos, contextualizados e holísticos. Os resultados possuem implicações relevantes para educadores, elaboradores de currículo e formuladores de políticas públicas na construção de práticas inovadoras e eficazes de ensino de ciências em uma era marcada pela complexidade global.

Palavras-chave: Literatura Biológica; Estratégias de Ensino; Ensino Secundário; Resultados de Aprendizagem dos Alunos; Revisão Sistemática da Literatura.

Abstract: *A significant obstacle to education in the twenty-first century is the low level of biological literacy among secondary school pupils, especially when it comes to tackling global concerns like biotechnology, the environment, and health. The need for a thorough evaluation of successful teaching methods is underscored by the urgency of improving this literacy. The purpose of this study is to conduct a systematic analysis of the different teaching approaches that have been used to raise biological literacy in secondary education between 2020 and 2025. Fifteen academic articles that were indexed by Scopus were subjected to a thematic analysis using a Systematic Literature Review methodology that was based on the PRISMA protocol. The results show that methods like disciplinary literacy, student-centered learning, scientific methods, and digital technology integration greatly enhance students' cognitive, affective, and scientific skill outcomes. But there are still issues, such as students' misunderstandings, teachers' pedagogical shortcomings, and the absence of real-world context in teaching resources. The creation of more inclusive, contextual, and holistic learning models is advised by this study. The results have significant ramifications for educators, curriculum designers, and legislators in creating innovative and impactful science teaching methods in the age of global complexity.*

Keywords*: Biological Literacy; Teaching Strategies; Secondary Education; Student Learning Outcomes; Systematic Literature Review.*

CAPES 1.54 ELSEVIER Scopus

1 INTRODUÇÃO

As the study of life, biology serves as both a basis for comprehending the cosmos and a major factor in daily decisions pertaining to biotechnology, the environment, and health (OECD, 2019; Suwono, Permana, et al., 2023). Biological literacy has emerged as a critical skill for students in the twenty-first century, particularly in light of the Fourth Industrial Revolution and developments in the life sciences (Momsen et al., 2022; Ramaila & Molwele, 2022). In addition to conceptual knowledge, scientific thinking, problem-solving, and reflective attitudes toward current biology-based issues are all components of biological literacy (Hewitt et al., 2019; Hornejas & Guntalidad, 2024; Ridlo et al., 2022). Thus, a crucial query emerges: Have the methods of instruction used in secondary schools been successful in promoting biological literacy?

Research indicates that biological literacy has distinct qualities that call for particular attention, even though science literacy has been a primary focus of international curricula (Adam et al., 2025). Biology differs from general science literacy in terms of terminology, conceptual approaches, and ethical considerations (Ke et al., 2021; Luft et al., 2022). Inequalities in resources, teacher quality, and the prevalence of rote learning methods exacerbate biological literacy issues in Indonesia (Sidauruk et al., 2025). As a result, investigating contextual and evidence-based learning strategies has become a pressing issue that requires methodical attention.

Numerous studies show that methods like inquiry-based learning (IBL), problem-based learning (PBL), socioscientific issues (SSI), and the use of digital technology have improved students' biological literacy (Georgiou & Kyza, 2023; Suwono, Rofi'Ah, et al., 2023). These results are still dispersed and inadequately consolidated, though. In many instances, it is also unclear which metrics—cognitive, affective, or psychomotor—are employed to evaluate the development of biological literacy. This emphasizes the necessity of synthesizing knowledge through a Systematic Literature Review (SLR) in order to pinpoint implementation gaps, trends, and the efficacy of strategies.

The literature that is currently available also shows that different nations and educational levels have different areas of emphasis. While studies in developing nations are more concerned with mastering content and fundamental conceptual understanding, research in developed nations tends to place more emphasis on the development of scientific argumentation and critical thinking skills (Chimbunde et al., 2023; Prayogi et al., 2024; Suwono, Rofi'Ah, et al.,

2023). This discrepancy illustrates an epistemological void in biology education's focus, which needs to be taken into account within a framework for global education. It is crucial to consider whether biological literacy teaching methods have been modified to fit regional social, cultural, and academic contexts in this regard.

Furthermore, assessing the effectiveness of biological literacy instruction is still a major concern. According to Toma & Lederman (2022) and Almulla & Al-Rahmi (2023), some studies employ instruments that are not valid or only concentrate on cognitive outcomes, ignoring shifts in students' attitudes and scientific abilities. These discrepancies undermine empirical data on the efficacy of instructional strategies and impede cross-study generalization. Therefore, to determine the most representative and reliable assessment techniques for biological literacy, a systematic review is required.

Despite the use of a variety of strategies, few studies have specifically looked at the connection between particular teaching methods and learning outcomes like scientific engagement, science-based decision-making, and the development of 21st-century competencies. The majority of current research is descriptive rather than analytical or evaluative, which means it doesn't offer specific recommendations for educational policy (Lane, 2020; Ortagus et al., 2020). A thorough systematic review is necessary to fill this extremely pertinent research gap.

This background informs the study's objective, which is to conduct a systematic review of scholarly literature on teaching methods for improving biological literacy and how they affect students' learning outcomes. The primary focus is on research trends, the most common tactics used, biological literacy measurement techniques, and the learning outcomes attained. By taking this approach, the study should offer a thorough conceptual and methodological mapping for creating biology teaching strategies that are more successful and pertinent to the 21st century.

A number of research questions were developed in order to direct this systematic review and offer a distinct analytical focus. The purpose of these questions is to investigate the variety of teaching methods used in secondary biology education, look at how they relate to different aspects of learning objectives, and pinpoint enduring problems and gaps in the field. The research questions are as follows:

> RQ1: What teaching strategies have been employed in academic studies to enhance secondary students’ biological literacy?
>
> RQ2: How are these teaching strategies related to different dimensions of learning outcomes (cognitive, affective, and scientific skills)?

RQ3: What are the main gaps and challenges in biological literacy research based on studies published in the past decade?

2 METHOD

Study Design

According to the most recent Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, this study uses a Systematic Literature Review (SLR) methodology. This approach's goal is to identify teaching strategies and student outcomes in the context of developing biological literacy in secondary education by conducting a systematic, transparent, and organized review of pertinent academic literature.

Data Sources and Search Strategy

Scopus AI (Elsevier), which offers comprehensive coverage of top-notch scientific publications worldwide, is the main database utilized. Between January 2020 and May 2025, systematic literature searches were carried out, focusing only on peer-reviewed, English-language journal articles from secondary education contexts. The following Boolean combinations were used to create the search terms:

> teaching" OR "instruction" OR "pedagogy" OR "education") AND ("strategies" OR "methods" OR "approaches" OR "techniques") AND ("biology" OR "life science" OR "biological science" OR "bio") AND ("literacy" OR "understanding" OR "knowledge" OR "comprehension") AND ("secondary education" OR "high school" OR "adolescent education" OR "teen education

Inclusion and Exclusion Criteria

To ensure consistency and relevance, the inclusion and exclusion criteria were defined as follows (see **Table 1** for details):

Table 1. Article Inclusion and Exclusion Criteria

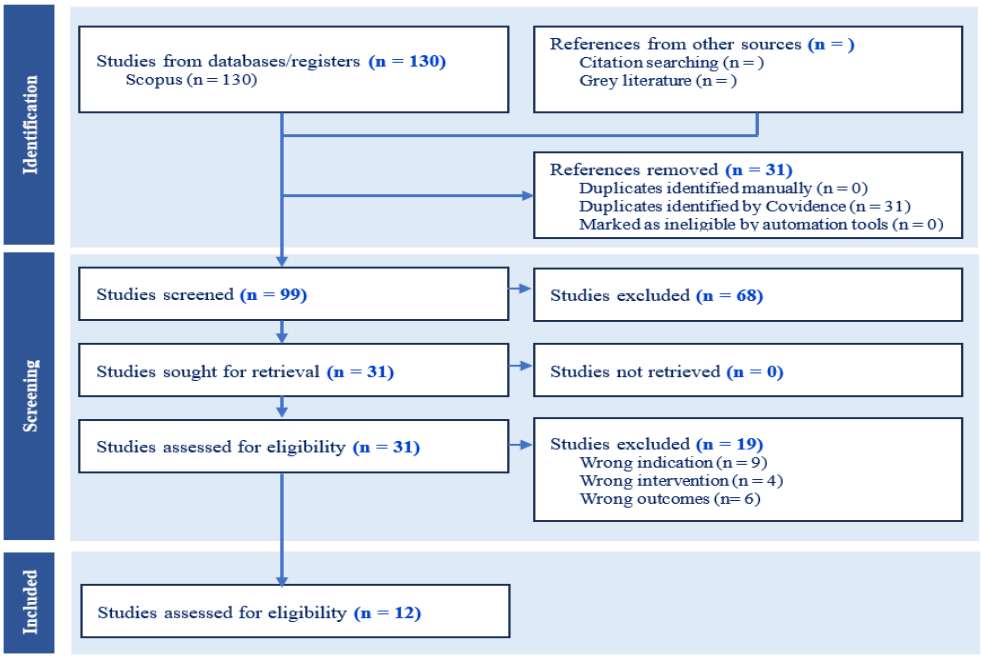
Criteria	**Inclusion**	**Exclusion**
Study Type	Peer-reviewed journal articles only	Conference paper, books, book chapter, reviews
Language	Articles in English	Articles in languages other than English
Year Range	Published between 2020 - 2025	Published before 2020
Education Level	Focused on biological literacy in the context of secondary education	Did not explicitly address biological literacy

Research Focus	Analyzed teaching strategies and/or student learning outcomes	Theoretical articles without empirical data
Indexing	Peer-reviewed journal articles indexed in Scopus	Conference papers, editorials, dissertations, books, and grey literature
Scientific Topic (Subject Area)	Discussed future directions or trends in biological literacy research	Did not include any discussion on future research directions
Academic discipline	Limited to the fields of: Social Sciences, Environmental Sciences, Agricultural Sciences and Biology, Arts and Humanities, Biochemistry, Genetics and Molecular Biology, and Multidisciplinary Studies.	Articles from the fields of engineering, economics, or other fields that are not relevant to the context of education or biology.
Keywords in the article	Only articles containing the keywords students, education, learning, science education, teaching, knowledge, or curricula in the title, abstract, or keywords were selected.	Articles will be rejected if they do not contain the keywords students, education, learning, science education, teaching, knowledge, or curricula in the title, abstract, or keywords

Screening and Selection Process

The identification and selection process followed the PRISMA flow diagram, consisting of four stages: identification, screening, eligibility, and inclusion. The initial search yielded 130 articles. After removing duplicates and screening titles and abstracts based on the inclusion-exclusion criteria, 99 articles were selected for full-text review. Of these, 12 articles met all criteria and were included for in-depth analysis in this study (see **Figure 1** for the PRISMA flow diagram).

Figure 1. PRISMA diagram



Source: Prepared by the authors.

The selection process outlined in the PRISMA flow diagram demonstrates a rigorous and systematic approach to identifying and refining relevant studies. This transparent documentation of inclusion and exclusion decisions reinforces the validity of the review and supports the credibility of the findings discussed in subsequent sections. In the end, 12 studies were included in the final review shown in **Table 2**.

Table 2. List of studies analyzed in the systematic review based on publication year and article title.

Authors and Years of Publication	Titles
Saad-Alraddadi A. (2025)	The Impact of Lee strategy on the Achievement of Secondary School Students in Biology and the Development of their Cognitive Representation
Gajic, M. M., Miljanovic, T. B., Babic-Kekez, S. S., Županec, V. D., & Jovanovic, T. T. (2021).	Correlations between teaching strategies in biology, learning styles, and student school achievement: Implications for inquiry-based teaching
Shazhanbayeva S. (2024)	Integrative education as the basis for students' worldview knowledge in the process of teaching biology in high school
Haberbosch, M., Vick, P., Schaal, S., & Schaal, S. (2025)	Enhancing Molecular Biology Content Knowledge and Teaching Self-Efficacy in Pre-Service Teachers Through Virtual and Hands-On Labs and Reflective Teaching
Molz, A., Kuhn, J., & Müller, A. (2022)	Effectiveness of science outreach labs with and without connection to classroom learning: Affective and cognitive outcomes
Nalle, C., Ilma, A. Z., Saryanto, S., & Rejokirono, R. (2025)	The role of numerical and scientific literacy in preparing students for the challenges of the 21st century: A systematic review and bibliometrics analysis
Fidiastuti, H. R., Lestari, S. R., Suhadi, S., Prabaningtyas, S., & Setiawan, M. (2025)	Microbiology literacy mapping: a comprehensive analysis using RStudio
Santoso, H., Harjati, P., Sujarwanta, A., Achyani, A., & Sutanto, A. (2025)	Unveiling Research Gaps in Biology Teaching Materials for Secondary Science Education: A Bibliometric Review of Scopus (2000–2024)
Hartono, A., Djulia, E., Hasruddin, H., & Jayanti, U. N. A. D. (2023)	Biology Students' Science Literacy Level on Genetic Concepts
Muna, N., Paxton, M., Frith, V., & van der Merwe, M. (2020)	Unpacking the multimodal discourse demands of microscopy in a bioscience laboratory
Rahmadhani, F., Lestari, S. R., & Sari, M. S. (2021)	Analysis of preliminary science literacy ability and student cognitive learning outcomes on the concept of digestive system topic
Sartika, D., Nurlina, Mutmainna, Aris, N. A., & Musliana. (2023)	The scientific literacy profile of senior high school student based on science competence dimension

Source: Prepared by the authors.

Data extraction and analysis

An analysis matrix comprising the following elements was used to extract data: (1) study identification; (2) year of publication; (3) country of origin; (4) methodological design; (5) teaching strategies used; (6) measured learning outcomes; (7) biological literacy indicators; and (8) future research directions. To find patterns and new trends in the literature, data were manually extracted and coded using a thematic approach. In order to categorize student learning

outcomes across cognitive, affective, and scientific skill dimensions and to show thematic distributions, data analysis was done using a descriptive-qualitative approach backed by tabulation and visualization. Additionally, the relationship between teaching strategies and learning outcomes was emphasized, as was the way in which earlier researchers developed future research directions pertaining to biological literacy.

3 RESULT

Effective Teaching Strategies for Improving Biological Literacy in Secondary Education

Through a thorough review of the literature, several teaching strategies have been identified to improve the biological literacy of secondary students. Student-centered learning, like the Lee Teaching Strategy, which prioritizes critical thinking, active engagement, and group learning, is the first method that has been extensively studied. When compared to conventional lecture-based methods, this approach has been demonstrated to greatly enhance students' comprehension and retention of biological concepts (Alraddadi, 2025). Teachers noticed a more lively classroom environment, and students reported feeling more motivated and involved.

Furthermore, there has been an increase in interest in disciplinary literacy-based interventions, like the Engagement Model of Academic Literacy for Learning (EngageALL). In the context of biology, this model uses resources such as the Generative Vocabulary Matrix to improve students' academic vocabulary and conceptual understanding. According to studies, students who took part in this intervention showed improved learning motivation and academic achievement (Larson, 2014). Additionally, although they tend to slow down content coverage, comprehensive reading strategies like the SQ3R method have been found to improve deep comprehension of biology texts. In the meantime, students' science literacy and performance on biology and English tests have improved thanks to the Reading Apprenticeship approach, which incorporates metacognitive practices into biology instruction (Greenleaf et al., 2011).

Using the ADDIE model to create student worksheets, Problem-Based Learning (PBL) techniques have also shown promise, especially in fostering quantitative literacy in subjects like the respiratory system. Students gave these worksheets positive feedback, and experts validated them (Apriyani, 2019). Despite implementation challenges, the Science-Technology-Society (STS) approach is equally important because it promotes active student engagement with scientific and social issues. According to studies, teachers keep refining this strategy because it improves students' motivation and involvement in the learning process.

With research demonstrating that biology instruction tailored to students' preferred learning styles can enhance academic performance, learning style adaptation has also become a critical tactic. This demonstrates the value of inquiry-based learning that is adaptive (Gajić et al., 2021). The use of tactile representations in conjunction with traditional vocabulary instruction greatly enhanced the biological vocabulary mastery of students with special needs, such as blind English language learners. This strengthens the case for the value of inclusive teaching methods.

The use of integrative teaching methods in biology classes has also grown in popularity, especially those that focus on helping students form their own worldviews. Such methods have been demonstrated through pedagogical experiments to assist students in comprehending the relationship between biological knowledge and social realities, thereby equipping them to deal with societal changes. Beyond the viewpoint of the student, teacher professional development is also essential to improving biological literacy. Preservice teachers' mastery of molecular biology material and their teaching self-efficacy have been successfully increased through blended learning training that combines online and in-person laboratory sessions (Haberbosch et al., 2025). Furthermore, the Secondary School Vocabulary Lists (SVL) and other discipline-specific vocabulary resources help to improve academic literacy in biology and other subjects.

In order to improve secondary students' biological literacy, these strategies, taken together, highlight the significance of active learning, disciplinary literacy integration, personalized teaching approaches, and teacher capacity building. To investigate long-term efficacy and the relationships between increasingly intricate learning components, more research is still required.

THE RELATIONSHIP BETWEEN TEACHING STRATEGIES AND LEARNING OUTCOME DIMENSIONS: COGNITIVE, AFFECTIVE, AND SCIENTIFIC SKILLS IN THE CONTEXT OF SCIENCE EDUCATION

The effects of different teaching methods on the three primary learning outcomes—cognitive, affective, and scientific skills—have been empirically studied. The results show that choosing the right teaching strategies is essential to improving students' overall learning outcomes.

Both direct and indirect instruction have complementary functions in the cognitive dimension. While indirect instruction is better suited for abstract concepts, patterns, and

generalizations, direct instruction works well for imparting facts, regulations, and procedures. It has been demonstrated that combining the two methods improves students' capacity for critical thought and problem-solving (Rüütmann & Kipper, 2011). Additionally, preservice teachers' cognitive performance in grasping science content has been greatly enhanced by escape room-based approaches, which frame learning as fun challenges. Students' cognitive achievement has also benefited from the use of scientific methods in lesson planning, especially when it comes to subjects like growth. It has been demonstrated that incorporating extracurricular activities like Science Outreach Labs (SOLs) improves students' conceptual understanding, particularly when it is directly related to classroom instruction (Molz et al., 2022). Nevertheless, there is a need for more research because experiential learning techniques, like case studies or simulations in nursing education, have not shown any discernible cognitive differences (Adamson, 2012).

In the affective domain, techniques like escape rooms improve students' attitudes toward science, positive emotions, and self-confidence in addition to improving comprehension. Although these effects tend to diminish over time, SOL programs also have a significant affective impact, such as raising students' interest in learning and their perception of themselves in science (Molz et al., 2022). According to other studies, reflective exercises in science classes support students' development of character and socioemotional skills by assisting them in making the connection between cognitive concepts and life values. On the other hand, LESLLA teachers in the Netherlands underutilized affective strategies in the context of adult literacy and second language learning, suggesting that learners' affective domains could be better supported. Although early research has found no discernible differences, experiential learning strategies are also meant to increase student affect (Adamson, 2012).

In the psychomotor or scientific skill dimension, scientific methods improve students' practical abilities in lab and experimental settings in addition to having an impact on cognition and affect (Machin, 2014). According to Demirbaş & Yağbasan (2009), redesigned science curricula that include elements of skills, attitudes, and values emphasize the significance of incorporating psychomotor dimensions alongside cognitive and affective goals. However, early research has not found any appreciable differences in the psychomotor skills that are intended to be improved by human patient simulation in nursing education.

All things considered, all three aspects must be incorporated into teaching methods that enhance student learning outcomes. Comprehensive science literacy is less effectively fostered by learning that only concentrates on cognitive achievement, ignoring affective components and scientific skills. The most promising path for revolutionary science education in the twenty-

first century seems to be incorporating techniques that blend scientific methods, reflective exercises, and practical experiences.

GAPS AND CHALLENGES IN BIOLOGICAL LITERACY RESEARCH: A REFLECTION

Over the past ten years, research on biological literacy has identified a number of conceptual gaps and implementation issues that require educators and researchers to give them careful consideration. The absence of interdisciplinary approaches in biology education is one significant gap. With little integration of biology with other disciplines like psychology, sociology, and health sciences, the majority of studies continue to be scientifically fragmented (Fidiastuti et al., 2025; Nalle & Ilma, 2025). Furthermore, there is little correlation between biology content and real-world situations because a large portion of the teaching content is abstract and unrelated to social, health, or environmental issues that are pertinent to the lives of the students (Akuma & Callaghan, 2019; Hartono et al., 2023; Santoso et al., 2025). This reduces the everyday relevance of biological knowledge and results in low knowledge transfer.

Approaches to literacy that oversimplify fundamental abilities, especially in the early phases of learning, represent another gap. Without offering enough opportunities for more expansive and unrestricted literacy skills like conceptual understanding, scientific reasoning, and critical communication, many curricula continue to place a strong emphasis on phonics and text decoding (Hoffman et al., 2021). However, despite improvements in explicit reading and writing instruction, biology instruction still rarely incorporates multimodal literacy practices, such as the use of diagrams, animations, microscopic visualizations, and simulations. Due to this disparity, students are less able to comprehend and incorporate various types of scientific representation (Muna et al., 2020).

The implementation of inquiry-based biology instruction (IBPW) is fraught with difficulties. Creating authentic inquiry activities, controlling classroom dynamics, and conducting thorough assessments of student progress are all challenges that teachers frequently face (Akuma & Callaghan, 2019; Castro & Morales, 2017). One important factor is teacher competency, especially when it comes to a lack of knowledge about educational technology, a shallow understanding of pedagogy, and a limited mastery of biology content (Akuma & Callaghan, 2019). The standard of science instruction that promotes scientific literacy is adversely impacted by these constraints.

Misconceptions about biology also pose a serious problem. Due to a lack of independent reading of scientific materials, many students have long-standing misconceptions about genetics and bodily systems (Hartono et al., 2023; Rahmadhani et al., 2021). This emphasizes the necessity of context-based literacy strategies that can inspire students to actively investigate biology. Designing reliable and thorough tools that can measure science literacy—which includes conceptual understanding, application, and the affective and ethical aspects of scientific knowledge—remains a significant assessment challenge (Sartika & Aris, 2023).

Lastly, studies reveal that biology education frequently takes a limited and content-centered approach to socio-scientific issues (SSI). Without incorporating ethical, social, or public policy considerations, educators frequently portray contentious subjects like genetic engineering or climate change as factual knowledge (Tidemand & Nielsen, 2017). However, this wider viewpoint is crucial for helping students develop a critical understanding of biology's place in society.

Future directions for biological literacy, like incorporating health education and enhancing students' self-efficacy in comprehending and effectively applying biological knowledge, are reflected in emerging themes (Santoso et al., 2025). This is in line with the demand for cutting-edge teaching strategies that foster social consciousness, individual values, and 21st-century biology learning abilities in addition to imparting knowledge (Nalle & Ilma, 2025; Santoso et al., 2025). In order to create engaging and revolutionary teaching methods and guarantee that biological literacy genuinely prepares students to handle the complexity of the contemporary world, it will be essential to address these gaps and difficulties.

4 DISCUSSION

The study's main focus and goals—identifying efficient teaching methods for raising biological literacy among secondary students and analyzing the ways in which these methods impact learning outcomes across cognitive, affective, and scientific skill dimensions—are directly addressed by the study's findings. The most popular tactics, according to the systematic analysis, are inquiry- and reflection-based methods, disciplinary literacy integration, and student-centered learning (Almulla & Al-Rahmi, 2023; Hornejas & Guntalidad, 2024; Suwono, Permana, et al., 2023). These results are consistent with the frameworks of contemporary science pedagogy and social constructivism, which place an emphasis on students' active participation and relevance to real-world situations. The usefulness of escape rooms in enhancing students' cognitive and affective performance, however, was discovered in an

unexpected way. This method is still relatively new and has not received enough attention in formal science education. The effectiveness of this strategy emphasizes how crucial it is for science education in the twenty-first century to stay open to unconventional approaches.

All things considered, the study's findings lend credence to the idea that inclusive, reflective, and active methods are very successful in fostering biological literacy. Conceptual understanding, critical thinking abilities, and student motivation for learning are all positively impacted by strategies like the Lee Teaching Strategy (Alraddadi, 2025), EngageALL (Larson, 2014), and Problem-Based Learning (Apriyani, 2019). On the other hand, methods that combine technology and multimodality, like scientific methods and outside labs (Science Outreach Labs), have been shown to improve learning outcomes in a comprehensive way (Molz et al., 2022). These findings emphasize the value of integrated teaching approaches that support students' practical skills and scientific attitudes in addition to cognitive aspects.

There are a number of significant parallels and divergences between this study and earlier research. For example, it supports Adamson's (2012) conclusion that simulations and other experiential learning techniques don't always result in appreciable gains in cognitive and psychomotor skills. However, according to (Gajić et al., 2021), reflective and learning-style-adaptive approaches seem to have a bigger impact on learning outcomes. The knowledge that not all active strategies ensure success if they are not balanced with contextual awareness and sensitivity to students' needs is thus expanded by this study. Additionally, this study provides fresh proof of the value of disciplinary literacy and the application of resources for field-specific vocabulary as crucial pillars for enhancing biological literacy.

The majority of the findings have significant generalizable ramifications for biology teaching methods in nations with similar secondary education features. Generalizing the findings to developing country contexts should be done with caution, though, as most of the examined studies came from nations with comparatively high levels of educational resources. The success of these tactics may be impacted by variations in learning cultures, teacher preparation, and access to technology. In order to make sure that the strategies found can be modified and contextualized to local realities, it is imperative that this study be repeated in the Indonesian context.

This study suggests that future research concentrate more on longitudinal studies to evaluate the long-term effects of teaching strategies on students' biological literacy in light of the limitations noted. Furthermore, comprehensive research on the integration of digital technologies is required, especially in the development of critical literacy and scientific skills

appropriate for the twenty-first century. Even though teachers play a crucial role in guaranteeing the effectiveness of classroom implementation, there is still a research gap regarding their involvement in the design and evaluation of instructional strategies.

This study's primary contribution is its methodical mapping of biological literacy teaching strategies that have been empirically tested between 2020 and 2025. This study provides trustworthy advice for researchers, educators, and policymakers to create more pertinent and context-specific pedagogical interventions by using a PRISMA-based methodology and selecting articles that are indexed by Scopus. Additionally, as the cornerstone of significant and long-lasting biological literacy, this paper advances the conversation about the significance of striking a balance between cognitive, affective, and scientific skill outcomes.

5 CONCLUSION

This study offers a methodical synthesis of the different teaching approaches used during the previous five years (2020–2025) to improve the biological literacy of secondary students. This article uses a PRISMA approach to identify the dominant approaches that have been empirically proven to improve students' cognitive, affective, and scientific skill dimensions. These approaches include inquiry-based methods, disciplinary literacy approaches, student-centered strategies, and technology integration. The study also shows that contextual, integrative, and reflective approaches have a lot of promise for developing thorough and useful biological knowledge.

However, a number of enduring issues have prevented biological literacy from realizing its full potential, such as a lack of comprehensive assessment procedures, low teacher pedagogical competency, a lack of real-world context integration in instructional materials, and enduring student misconceptions. This study also emphasizes how underutilized interdisciplinary learning, multimodal diversity, and socioemotional approaches are in biology education today. These results highlight how urgently biology teaching paradigms need to shift from merely imparting knowledge to developing the scientific attitudes, empathy, and sophisticated literacy skills necessary for the twenty-first century.

REFERÊNCIAS

Adam, U. A., Ayanwale, M. A., Lameed, S. N., Owolabi, T., Onowugbeda, F. U., Oladejo, A. I., Okebukola, P. A., Ogolo, K. G., & Adebowale, M. A. (2025). Bridging culture and science: Culturo-Techno-Contextual Approach in culturally relevant biology pedagogy. The Journal of Educational Research, 118(2), 100–115.

Adamson, K. A. (2012). Piloting a Method for Comparing Two Experiential Teaching Strategies. Clinical Simulation in Nursing, 8(8), e375–e382. https://doi.org/10.1016/j.ecns.2011.03.005

Akuma, F. V, & Callaghan, R. (2019). A systematic review characterizing and clarifying intrinsic teaching challenges linked to inquiry-based practical work. Journal of Research in Science Teaching, 56(5), 619–648. https://doi.org/10.1002/tea.21516

Almulla, M. A., & Al-Rahmi, W. M. (2023). Integrated Social Cognitive Theory with Learning Input Factors: The Effects of Problem-Solving Skills and Critical Thinking Skills on Learning Performance Sustainability. Sustainability, 15(5), 3978. https://doi.org/10.3390/su15053978

Alraddadi, A. S. (2025). The Impact of Lee strategy on the Achievement of Secondary School Students in Biology and the Development of their Cognitive Representation. New Perspectives in Science Education - International Conference, 2025(14).

Apriyani, W. (2019). The Effectiveness of Student Worksheet Development Based on Problem-Based Learning in Respiratory System Material to Improve High School Students' Quantitative Literacy. Journal of Physics: Conference Series, 1397(1). https://doi.org/10.1088/1742-6596/1397/1/012058

Castro, J. A. F., & Morales, M. P. E. (2017). "Yin" in a guided inquiry biology classroom - Exploring student challenges and difficulties. Journal of Turkish Science Education, 14(4), 48–65. https://doi.org/10.12973/tused.10212a

Chimbunde, P., Moreeng, B. B., & Chawira, M. (2023). A Model for Developing Critical Thinking Skills in Teaching History: Lessons from Zimbabwe. Journal of Culture and Values in Education, 6(3), 194–212. https://doi.org/10.46303/jcve.2023.28

Demirbaş, M., & Yağbasan, R. (2009). An analysis of the realization rate of affective objectives of science and technology curriculum. 2009 International Conference on Application of Information and Communication Technologies, AICT 2009. https://doi.org/10.1109/ICAICT.2009.5372537

Fidiastuti, H. R., Lestari, S. R., Suhadi, S., Prabaningtyas, S., & Setiawan, M. E. (2025). Microbiology literacy mapping: a comprehensive analysis using RStudio. Asian Education and Development Studies, 14(3), 383–403. https://doi.org/10.1108/AEDS-07-2024-0140

Gajić, M. M., Miljanović, T. B., Babić-Kekez, S. S., Županec, V. D., & Jovanović, T. T. (2021). Correlations between teaching strategies in biology, learning styles, and student school achievement: Implications for inquiry based teaching. Journal of Baltic Science Education, 20(2), 184–203. https://doi.org/10.33225/jbse/21.20.184

Georgiou, Y., & Kyza, E. A. (2023). Fostering Chemistry Students' Scientific Literacy for Responsible Citizenship through Socio-Scientific Inquiry-Based Learning (SSIBL). Sustainability, 15(8), 6442. https://doi.org/10.3390/su15086442

Greenleaf, C. L., Litman, C., Hanson, T. L., Rosen, R., Boscardin, C. K., Herman, J., Schneider, S. A., Madden, S., & Jones, B. (2011). Integrating literacy and science in biology Teaching and learning impacts of reading apprenticeship professional development. American Educational Research Journal, 48(3), 647–717. https://doi.org/10.3102/0002831210384839

Haberbosch, M., Vick, P., Schaal, S., & Schaal, S. (2025). Enhancing Molecular Biology Content Knowledge and Teaching Self-Efficacy in Pre-Service Teachers Through Virtual and Hands-On Labs and Reflective Teaching. Education Sciences, 15(5). https://doi.org/10.3390/educsci15050632

Hartono, A., Djulia, E., & Jayanti, U. N. A. D. (2023). BIOLOGY STUDENTS' SCIENCE LITERACY LEVEL ON GENETIC CONCEPTS. Jurnal Pendidikan IPA Indonesia, 12(1), 146–152. https://doi.org/10.15294/jpii.v12i1.39941

Hewitt, K. M., Bouwma-Gearhart, J., Kitada, H., Mason, R., & Kayes, L. J. (2019). Introductory Biology in Social Context: The Effects of an Issues-Based Laboratory Course on Biology Student Motivation. CBE—Life Sciences Education, 18(3), ar30. https://doi.org/10.1187/cbe.18-07-0110

Hoffman, E. B., Paciga, K. A., & Whittingham, C. E. (2021). The problem with pigeons in research and practice: communicating early literacy essentials and foundations in curriculum and instruction. Literacy, 55(3), 159–171. https://doi.org/10.1111/lit.12257

Hornejas, J. S., & Guntalidad, J. A. A. (2024). Project-based learning approach on content mastery and cognitive skills: a pedagogical model for senior high school biology students. Sapienza: International Journal of Interdisciplinary Studies, 5(2), e24034. https://doi.org/10.51798/sijis.v5i2.763

https://doi.org/10.1080/00220671.2024.2446898

Ke, L., Sadler, T. D., Zangori, L., & Friedrichsen, P. J. (2021). Developing and Using Multiple Models to Promote Scientific Literacy in the Context of Socio-Scientific Issues. Science & Education, 30(3), 589–607. https://doi.org/10.1007/s11191-021-00206-1

Lane, J. L. (2020). Maintaining the Frame: Using Frame Analysis to Explain Teacher Evaluation Policy Implementation. American Educational Research Journal, 57(1), 5–42. https://doi.org/10.3102/0002831219848689

Larson, S. C. (2014). Exploring the roles of the generative vocabulary matrix and academic literacy engagement of ninth grade biology students. Literacy Research and Instruction, 53(4), 287–325. https://doi.org/10.1080/19388071.2014.880974

Luft, J. A., Jeong, S., Idsardi, R., & Gardner, G. (2022). Literature Reviews, Theoretical Frameworks, and Conceptual Frameworks: An Introduction for New Biology Education Researchers. CBE—Life Sciences Education, 21(3). https://doi.org/10.1187/cbe.21-05-0134

Molz, A., Kuhn, J., & Müller, A. (2022). Effectiveness of science outreach labs with and without connection to classroom learning: Affective and cognitive outcomes. Physical

Review Physics Education Research, 18(2). https://doi.org/10.1103/PhysRevPhysEducRes.18.020144

Momsen, J., Speth, E. B., Wyse, S., & Long, T. (2022). Using Systems and Systems Thinking to Unify Biology Education. CBE—Life Sciences Education, 21(2). https://doi.org/10.1187/cbe.21-05-0118

Muna, N., Paxton, M., Frith, V., & van der Merwe, M. (2020). Unpacking the multimodal discourse demands of microscopy in a bioscience laboratory. International Journal of Science Education, 42(16), 2742–2764. https://doi.org/10.1080/09500693.2020.1836429

Nalle, C., & Ilma, A. Z. (2025). The role of numerical and scientific literacy in preparing students for the challenges of the 21st century: A systematic review and bibliometrics analysis. Edelweiss Applied Science and Technology, 9(3), 2199–2210. https://doi.org/10.55214/25768484.v9i3.5769

OECD, I. (2019). Health at a glance 2019: OECD indicators. Paris: OECD Publishing. https://doi.org/10.1787/health_glance-2015-en

Ortagus, J. C., Kelchen, R., Rosinger, K., & Voorhees, N. (2020). Performance-Based Funding in American Higher Education: A Systematic Synthesis of the Intended and Unintended Consequences. Educational Evaluation and Policy Analysis, 42(4), 520–550. https://doi.org/10.3102/0162373720953128

Prayogi, S., Bilad, M. R., Verawati, N. N. S. P., & Asy'ari, M. (2024). Inquiry vs. Inquiry-Creative: Emphasizing Critical Thinking Skills of Prospective STEM Teachers in the Context of STEM Learning in Indonesia. Education Sciences, 14(6), 593. https://doi.org/10.3390/educsci14060593

Rahmadhani, F., Lestari, S. R., & Sari, M. S. (2021). Analysis of preliminary science literacy ability and student cognitive learning outcomes on the concept of digestive system topic. AIP Conference Proceedings, 2330. https://doi.org/10.1063/5.0043317

Ramaila, S., & Molwele, A. J. (2022). The Role of Technology Integration in the Development of 21st Century Skills and Competencies in Life Sciences Teaching and Learning. International Journal of Higher Education, 11(5), 9. https://doi.org/10.5430/ijhe.v11n5p9

Ridlo, S., Marina, H., Sapitri, D., Hadiyanti, L. N., & Listyono, L. (2022). Scientific Literacy-Based Flipped Classroom Virtual Strategy for Biology Learning in the New Normal Era. Jurnal Pendidikan IPA Indonesia, 11(4), 672–683. https://doi.org/10.15294/jpii.v11i4.38247

Rüütmann, T., & Kipper, H. (2011). Teaching strategies for direct and indirect instruction in teaching engineering. 2011 14th International Conference on Interactive Collaborative Learning, ICL 2011 - 11th International Conference Virtual University, VU'11, 107–114. https://doi.org/10.1109/ICL.2011.6059556

Santoso, H., Harjati, P., Sujarwanta, A., & Sutanto, A. (2025). Unveiling Research Gaps in Biology Teaching Materials for Secondary Science Education: A Bibliometric Review of Scopus (2000–2024). International Journal of Learning, Teaching and Educational Research, 24(6), 689–709. https://doi.org/10.26803/ijlter.24.6.32

Sartika, D., & Aris, N. A. (2023). The scientific literacy profile of senior high school student based on science competence dimension. AIP Conference Proceedings, 2619. https://doi.org/10.1063/5.0122563

Sidauruk, J. M., Susilowati, M., & Akbar, K. K. (2025). Indonesia's Struggle with Education Inequality: Is Reform the Answer? Indonesia Discourse, 2(1).

Suwono, H., Permana, T., Saefi, M., & Fachrunnisa, R. (2023). The problem-based learning (PBL) of biology for promoting health literacy in secondary school students. Journal of Biological Education, 57(1), 230–244. https://doi.org/10.1080/00219266.2021.1884586

Suwono, H., Rofi'Ah, N. L., Saefi, M., & Fachrunnisa, R. (2023). Interactive socio-scientific inquiry for promoting scientific literacy, enhancing biological knowledge, and developing critical thinking. Journal of Biological Education, 57(5), 944–959. https://doi.org/10.1080/00219266.2021.2006270

Tidemand, S., & Nielsen, J. A. (2017). The role of socioscientific issues in biology teaching: from the perspective of teachers. International Journal of Science Education, 39(1), 44–61. https://doi.org/10.1080/09500693.2016.1264644

Toma, R. B., & Lederman, N. G. (2022). A Comprehensive Review of Instruments Measuring Attitudes Toward Science. Research in Science Education, 52(2), 567–582. https://doi.org/10.1007/s11165-020-09967-1. Acesso em: 30 ago. 2025.

Submissão em: 26/09/2025
Aprovação em: 05/04/2026