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Differentiated Learning and Critical Thinking Skills Development in Biology: A Systematic Literature Review

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ABSTRACT

Learning biology in the 21st century requires students to master critical thinking skills to understand complex scientific concepts. However, traditional teaching methods are often ineffective in facilitating the development of these skills. Differentiated learning offers an approach that can be tailored to students' readiness, interests, and learning profiles, thus potentially improving critical thinking skills. This study examined the effectiveness of differentiated learning in developing biology students' critical thinking skills, as well as identifying effective differentiation strategies and barriers in their implementation. This research used the Systematic Literature Review (SLR) method and followed the PRISMA guidelines. Literature searches were conducted on academic databases such as Scopus and Google Scholar for the period 2018-2024. Differentiated learning proved effective in improving critical thinking skills with strategies such as problem-based learning, collaborative learning, and concept mapping. Barriers found include teachers' time constraints, lack of resources, and inadequate professional training. Differentiated learning can be an effective solution to developing critical thinking skills in biology. Adequate education policy support and teacher professional development are needed to optimize the implementation of differentiated learning.

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1. INTRODUCTION

Learning biology in the 21st century makes it necessary for students to master critical thinking skills in depth to understand complex scientific concepts and their applications in everyday life (Juanda, 2022; Putri *et al*., 2021). Critical thinking is a multifaceted cognitive skill that significantly affects students' academic performance by improving their ability to analyze, evaluate, and synthesize information (Teng & Yue, 2023; Ghanizadeh, 2017; Kim *et al*., 2013). However, various studies have shown that traditional teaching methods fail to effectively facilitate the development of critical thinking skills. Students tend to be passive in receiving information without going through a process of reflection, in-depth analysis, or application in a real context.

In the context of biology, students are faced with the complexity of concepts covering different levels of life organization, from molecular to ecosystem, as well as the interconnectedness of concepts (Labov *et al.,* 2010). To address this challenge, a differentiated learning approach can be an effective solution. It allows teachers to customize learning processes, products, and content based on students' learning profiles, readiness levels, and interests (Joseph *et al*., 2013; Landrum & McDuffie, 2010). With this approach, students gain in-depth conceptual knowledge and practice critical thinking skills through a learning process that is more suited to their needs.

Although differentiated learning has been widely applied in various disciplines, research on its effectiveness in improving learners' critical thinking skills in biology learning is still limited. Most studies focus on the application of differentiated learning in subjects such as mathematics and language, while studies in science, especially biology, have not received adequate attention (Krisnawati, 2024). A study by Hasanah *et al*. (2022) emphasized the essence of effective learning approaches to help students understand biological concepts systematically and critically. However, the study has not explored how differentiation strategies can be effectively applied to develop students' critical thinking skills. Thus, there is an urgent need to examine the relationship between differentiated learning and the development of critical thinking skills in the context of biological learning.

This study offers a novel contribution by examining the effectiveness of differentiated learning in building students' critical thinking skills on complex biology topics, such as ecosystem systems, genetics, and biotechnology. This study will explore how differentiation in content, process, and product can stimulate critical thinking skills through analysis, evaluation, and synthesis of biological concepts. In addition, this study will identify the most effective differentiated learning strategies to increase student engagement and address gaps in understanding in a heterogeneous classroom. With an approach that focuses on critical thinking and differentiation, this research is expected to provide practical guidance for educators in designing responsive and effective biology learning across different levels of education. The results of this study will also contribute to the biology education literature and offer solutions to teaching challenges in the fast-paced information age.

2. METHODS

The study was conducted using the Systematic Literature Review (SLR) approach to explore the effect of differentiated learning on the development of students' critical thinking skills in biology learning. This process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and systematicity in identifying, evaluating, and synthesizing relevant literature (Belle & Zhao, 2023; Cumming *et al*., 2023).

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To establish a clear focus in this study, four research questions have been formulated namely:

(i) How can the implementation of differentiated learning develop students' critical thinking skills in biology learning?
(ii) What differentiation strategies are most effective in developing students' critical thinking skills in the biology classroom?
(iii) What are the barriers and challenges in implementing differentiated learning in biology class?
(iv) What are the existing research gaps related to the implementation of differentiated learning for critical thinking development in biology education?

Literature was searched from various reputable academic databases, including Scopus and Google Scholar. The data search was aided by the use of the publish or perish (PoP) application. The search was conducted with keyword combinations "Differentiated instruction", "critical thinking", "biology education",". Boolean combinations were used, such as: ("differentiated instruction" OR "differentiated learning") AND ("critical thinking") AND ("biology education" OR "science education"). The search was limited to the 2018 to 2024 timeframe to ensure only current research was analyzed. Inclusion and exclusion criteria were shown in **Table 1** and **Figure 1**.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
• A study on the application of differentiated learning in biology learning. • Studies that measure or address the development of critical thinking skills. • Focus on middle school students (junior high school/high school).	• Studies that address differentiated learning in general without a focus on critical thinking skills. • Studies not related to biology or science education. • Review articles, opinion pieces, or publications that are not based on empirical research.

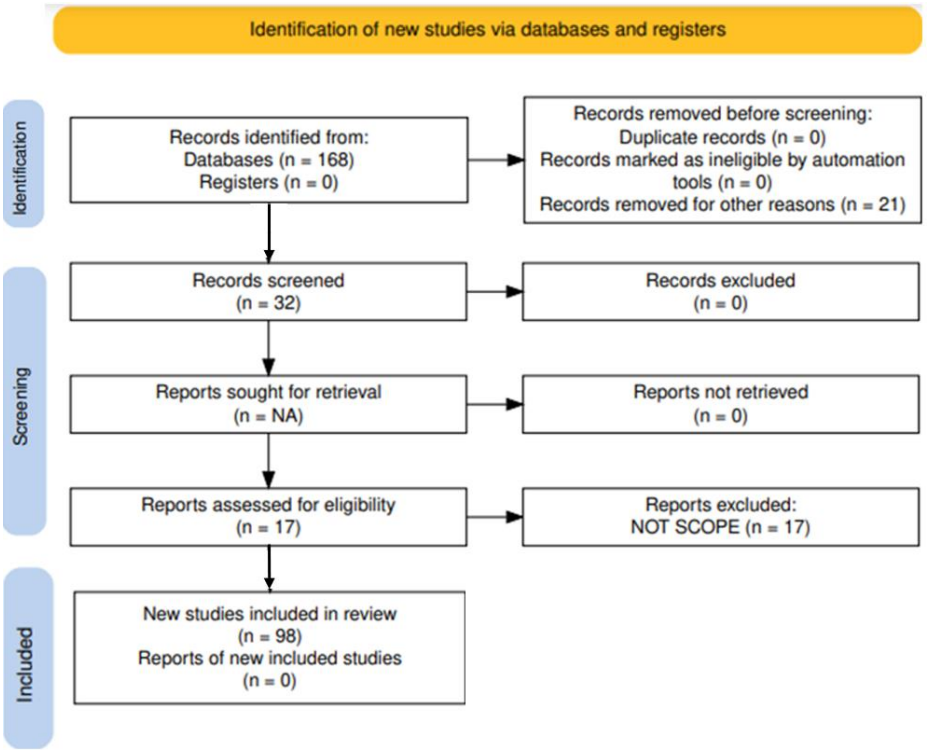

Figure 1. Research algorithm.

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3. RESULTS AND DISCUSSION

3.1. Implementation of differentiated learning that can improve students' critical thinking skills in biology learning

The application of differentiated learning in biology education can significantly improve students' critical thinking skills by customizing instruction to meet diverse learning needs and preferences. Differentiated learning strategies, such as those based on STEM and problem-based approaches, have been shown to have a substantial positive impact on critical thinking. A meta-analysis revealed that STEM-based differentiated learning had a high effect size of 0.892, meaning that there was a significant increase in students' critical thinking skills (Haetami, 2023). Similarly, problem-based differentiated learning has been found to effectively improve critical thinking skills among learners at the primary school level, with significant improvements in pass rates (Maryani & Mawardi, 2024).

In the context of biology education, differentiated learning strategies, including learning stations, task cards, and group work, have been shown to increase students' readiness and confidence, thereby fostering an environment conducive to the development of critical thinking (Meenakshi & Sheeba., 2022). In addition, the implementation of differentiated processes and products in biology classes has positively impacted both students and teachers, suggesting that the approach can optimize learning outcomes by addressing individual learning profiles and readiness levels (Fajrina *et al*., 2024). Furthermore, incorporating multiple intelligence-based differential learning in higher education has been shown to enhance critical thinking skills, providing a viable pedagogical approach that is aligned with the demands of modern education (Alhamuddin *et al*., 2023). Collectively, these findings underscore the potential of differentiated learning to foster critical thinking competencies in biology through accommodating diverse learning styles and promoting active engagement.

3.2. Differentiation strategies that develop students' critical thinking skills in the biology classroom

Effective differentiation strategies in the development of student's critical thinking skills in the biology classroom include a variety of teaching methods that actively engage students and encourage deep cognitive processing. One such strategy is the use of problem-based learning, which has been shown to encourage critical thinking by presenting students with real-world problems that require analytical and evaluative skills to solve (Alsaleh, 2020; El Yazidi, 2023). Collaborative learning is another effective approach, as it promotes critical thinking through peer interaction and discussion, allowing students to explore different perspectives and refine their reasoning skills (Alsaleh, 2020; El Yazidi, 2023). The Reading-Concept Mapping-Numbered Heads Together (Remap-NHT) model is very effective in biology education, as it combines reading comprehension with concept mapping and collaborative discussion, significantly improving students' critical thinking competencies (Safitri, 2023).

In addition, the Empowering Thinking with Questions (TEQ) strategy emphasizes question formulation, which enhances conceptual knowledge and critical thinking by encouraging students to engage deeply with the content and think critically about the information presented (Nur *et al*., 2023). The use of textbooks designed with exercises based on Bloom's taxonomy, specifically targeting higher-order thinking skills, has also been shown to be beneficial in training students' critical thinking skills in biology (Ngenda *et al*., 2024). These strategies, when implemented effectively, can create a dynamic learning environment that supports the development of critical thinking skills essential for academic success in biology.

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3.3. Barriers and challenges in implementing differentiated learning in the biology classroom

The implementation of differentiated learning in biology classrooms faces several barriers and challenges, as highlighted in various studies. One significant challenge is the time constraints faced by teachers, which is a common problem in implementing differentiated learning strategies. Teachers often find it difficult to allocate sufficient time to plan and execute differentiated lessons, as noted in studies from Indonesia and Malaysia, where time constraints were reported by 80% of teachers (Napitupulu *et al*., 2023). In addition, the lack of resources and teaching materials customized for differentiated instruction poses a major barrier. This is particularly evident in Malaysian classrooms, where limited resources and large class sizes hinder the effective implementation of differentiated learning (Lavania & Nor, 2020).

Another challenge is inadequate professional development and training for teachers, which affects their ability to design and implement different learning strategies effectively. This issue is prevalent in various educational contexts, including South Africa and Indonesia, where teachers report a lack of adequate training and support (Napitupulu *et al*., 2023; de Jager, 2013). In addition, teachers often struggle with classroom management and the preparation of different teaching modules, as seen in the case study from Kediri City, where teachers found it difficult to identify individual student needs and provide varied learning materials (Nurfianto *et al*., 2024).

Student resistance to differentiated learning methods also presents challenges, as some students may be reluctant to engage with new learning approaches (Napitupulu *et al*., 2023). Despite these challenges, differentiated learning has shown a positive impact on student engagement and learning outcomes, as demonstrated in studies from India and Kazakhstan, where students showed increased cognitive readiness and interest in biology (Meenakshi & Sheeba., 2022). To overcome these barriers, education policymakers must provide more support in terms of resources, training, and workload management for teachers, enabling them to effectively implement different learning strategies in the biology classroom (Lavania & Nor, 2020).

3.4. Existing research gaps related to the implementation of differentiated learning for critical thinking development in biology education

The implementation of differentiated learning in biology education, specifically to develop critical thinking skills, reveals several research gaps that need to be addressed. While differentiated learning strategies, such as those involving learning stations and task cards, have shown promise in improving students' learning competence and confidence in biology (Meenakshi & Sheeba., 2022), there is a lack of comprehensive understanding of how these strategies specifically impact critical thinking skills. Studies have shown that contextualized teaching and learning (CTL) and guided inquiry-based approaches can significantly improve critical thinking in biology (Bustami *et al*., 2018; Ali *et al*., 2023), yet the integration of differentiated learning with these methods remains unexplored. Furthermore, the role of teachers in effectively implementing differentiated instruction is crucial, as misconceptions and low self-efficacy among educators can hinder its success (Putra, 2023). This highlights the need for professional development to address these misconceptions and improve instructional practices. Furthermore, while multiple intelligence-based differential learning has been shown to improve critical thinking skills in higher education (Alhamuddin *et al*., 2023), its application in secondary biology education is not well documented.

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4. CONCLUSION

Differentiated learning has great potential in improving students' critical thinking skills in biology learning. By customizing learning content, processes, and products according to students' needs and characteristics, differentiated learning allows students to engage actively and deeply. Strategies such as problem-based, collaborative learning, and concept mapping have proven effective in stimulating critical thinking. However, the implementation of differentiated learning faces challenges such as time constraints, lack of resources, and inadequate professional training for teachers. Therefore, comprehensive policy support and training are needed to facilitate the successful implementation of differentiated learning.

This research highlights the need for further exploration of the integration of differentiated learning with other innovative learning methods, such as project-based learning and ethnoscience, to address existing research gaps. Thus, this approach can contribute to improving the effectiveness of biology education and the development of student's critical thinking skills in the fast-paced information age.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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