



## Implementation of the Merdeka Curriculum in Biology Learning: Its Relationship with Senior High School Students' Critical Thinking Skills and Scientific Literacy in Parepare City

Yuliarti Ramli <sup>1</sup>, Nur Zakiyah R <sup>2</sup>, Fitrih Mustari <sup>3</sup>

<sup>1,2,3</sup> Universitas Muhammadiyah Parepare, Indonesian

Korespondensi : ✉ [yuliartiramli.yr@gmail.com](mailto:yuliartiramli.yr@gmail.com)

### Article Info

Article History

Received : 15-01-2026

Revised : 20-03-2026

Accepted : 10-04-2026

### Keywords:

Merdeka curriculum;  
Critical thinking skills;  
Scientific literacy;  
Biology learning

### ABSTRACT

*This study aims to analyze the implementation of the Merdeka Curriculum in biology learning and its relationship with senior high school students' critical thinking skills and scientific literacy. The study is grounded in the persistently low levels of scientific literacy and higher-order thinking skills among Indonesian students, while empirical studies examining the relationship between the implementation of the Merdeka Curriculum and these competencies, particularly in biology learning contexts, remain limited. A mixed-methods approach with an explanatory sequential design was employed to obtain a more comprehensive understanding by integrating quantitative and qualitative data. The research sample involved 100 eleventh-grade students and biology teachers at the senior high school level selected through purposive sampling. The research instruments included a Merdeka Curriculum implementation questionnaire, a Higher Order Thinking Skills (HOTS)-based critical thinking test, a scientific literacy test developed based on the Program for International Student Assessment (PISA) framework, and interview guidelines. The findings revealed that the implementation of the Merdeka Curriculum was categorized as fairly good ( $M = 63.64$ ), while students' critical thinking skills ( $M = 54.06$ ) and scientific literacy ( $M = 51.26$ ) remained at a moderate level. Pearson correlation analysis demonstrated a strong relationship between the implementation of the Merdeka Curriculum and critical thinking skills ( $r = 0.785$ ;  $p < 0.001$ ), as well as a very strong relationship with scientific literacy ( $r = 0.880$ ;  $p < 0.001$ ). In addition, critical thinking skills were strongly associated with scientific literacy ( $r = 0.785$ ;  $p < 0.001$ ). These findings indicate that implementing the Merdeka Curriculum in biology learning has substantial potential to support the development of 21st-century competencies, particularly critical thinking skills and scientific literacy, although further optimization of instructional strategies and greater implementation readiness in schools remain necessary to achieve more effective outcomes.*

### INTRODUCTION

Critical thinking skills and scientific literacy are fundamental competencies students need to address the challenges of the 21st century. These competencies not only enhance students' academic capacity but also serve as a foundation for evidence-based decision-making, complex problem-solving, and rational understanding of social and scientific phenomena. In the context of science education, critical thinking skills are essential for enabling students to analyze information, evaluate arguments, and formulate logical conclusions, whereas scientific literacy involves understanding scientific concepts, interpreting data, and applying scientific knowledge in everyday life (Ni'mah, 2019; OECD, 2023). However, the current state of education in

Indonesia indicates that achieving these competencies remains a serious challenge. The results of the Program for International Student Assessment (PISA) in 2022 revealed that Indonesian students' scientific literacy scores were still below the OECD average, with an average score of 383, and only a small proportion of students achieved the minimum competency level. This condition highlights the need for an educational transformation that is more focused on strengthening higher-order thinking skills and students' scientific literacy (OECD, 2023).

Biology learning holds a strategic position in fostering critical thinking skills and scientific literacy because its subject matter is directly related to life phenomena, environmental issues, health, and technological developments. Contextual, inquiry-based, and problem-oriented biology learning enables students to develop analytical abilities, data interpretation skills, and scientific reasoning more comprehensively (Usman et al., 2024). Within the context of educational reform in Indonesia, the implementation of the Merdeka Curriculum represents one of the government's strategic efforts to strengthen 21st-century competencies through more flexible, differentiated, and student-centered learning. This curriculum emphasizes project-based learning, authentic assessment, and the strengthening of the *Pancasila Student Profile*, which are expected to promote the development of students' critical thinking skills and scientific literacy (Fatmawati et al., 2024). Theoretically, the flexibility of the Merdeka Curriculum provides students with opportunities to independently construct conceptual understanding, while project-based learning and scientific approaches can enhance reflective thinking, argumentation, and evidence-based decision-making skills.

Previous studies have demonstrated that Problem-Based Learning (PBL), Project-Based Learning (PjBL), and Socio-Scientific Issues (SSI)-based approaches positively contribute to the development of students' critical thinking skills and scientific literacy. A study by Zakiyah et al. (2023) found that STEM-integrated PBL significantly improved students' critical thinking skills. Similarly, Herlita et al. (2023) reported that the PjBL-STEM model enhanced critical thinking abilities in science learning. Meanwhile, Rohali and Hamimi (2024) found that integrating a scientific approach based on Socio-Scientific Issues within the Merdeka Curriculum strengthened students' critical thinking skills. Regarding scientific literacy, Irwandi et al. (2025) reported that biology instruction grounded in critical analysis and contextual discussion significantly improved students' scientific literacy. Nevertheless, most previous studies have primarily focused on the effectiveness of specific instructional models or the development of learning media, thereby providing limited empirical evidence of the direct relationship between the implementation of the Merdeka Curriculum and students' critical thinking skills and scientific literacy in actual classroom practice.

On the other hand, studies concerning the implementation of the Merdeka Curriculum have largely focused on teachers' and students' perceptions, the evaluation of learning tools, or the partial effectiveness of educational programs, without integrating an analysis of the relationship between curriculum implementation and the simultaneous development of critical thinking skills and scientific literacy, particularly within the context of biology learning at the senior high school level. In fact, understanding the relationships among these variables is crucial for providing empirical evidence regarding the extent to which curriculum policy implementation supports the achievement of 21st-century competencies. Furthermore, empirical studies in local contexts, particularly in Parepare City, South Sulawesi, remain relatively limited, resulting in a

lack of contextual understanding regarding the implementation of the Merdeka Curriculum in secondary biology education.

Based on these research gaps, this study offers a novel analysis of the relationship between the implementation of the Merdeka Curriculum and students' critical thinking skills and scientific literacy simultaneously within the context of senior high school biology learning. This study not only examines curriculum implementation descriptively but also integrates measurement of critical thinking skills based on HOTS and scientific literacy based on the PISA framework, and in-depth qualitative data collection through interviews, using an explanatory sequential mixed-methods approach. This approach enables a more comprehensive understanding of the relationships among variables and the factors influencing the implementation of the Merdeka Curriculum in educational practice.

Therefore, this study aims to analyze the implementation of the Merdeka Curriculum in biology learning and its relationship with senior high school students' critical thinking skills and scientific literacy in Parepare City. The findings are expected to advance theoretical understanding of competency-based curriculum implementation in the context of 21st-century education, while also providing practical implications for teachers, schools, and policymakers for optimizing the Merdeka Curriculum's implementation to improve the quality of biology learning and strengthen students' competencies.

## **METHOD**

This study employed a mixed-method approach using an explanatory sequential design, in which quantitative data collection and analysis were conducted in the initial phase, followed by qualitative data collection to further elaborate, explain, and interpret the quantitative findings. The selection of this design was based on the consideration that the relationship between the implementation of the Merdeka Curriculum, critical thinking skills, and scientific literacy requires not only statistical evidence but also a contextual understanding of the factors influencing instructional implementation in actual classroom settings. Therefore, integrating quantitative and qualitative data was expected to provide a more comprehensive understanding of the phenomenon under investigation (Creswell & Creswell, 2018).

The study was conducted at two senior high schools in Parepare City, South Sulawesi, Indonesia, which had implemented the Merdeka Curriculum in their instructional processes. The research population comprised all eleventh-grade students enrolled in the selected schools. The selection of eleventh-grade students was based on the consideration that they had experienced the implementation of the Merdeka Curriculum more extensively than students at lower grade levels, thus possessing more adequate learning experiences to represent curriculum implementation in biology learning. The research sample was determined using a purposive sampling technique, in which participants were selected based on specific criteria relevant to the study objectives. The quantitative sample consisted of 100 eleventh-grade students, with 50 students selected from each school. Meanwhile, qualitative data were collected through in-depth interviews with four biology teachers directly involved in implementing the Merdeka Curriculum in both schools.

The research instruments consisted of four types: (1) a Merdeka Curriculum implementation questionnaire, (2) a critical thinking skills test, (3) a scientific literacy test, and (4)

an interview guideline. The Merdeka Curriculum implementation questionnaire was developed to assess students' perceptions of the implementation of Merdeka Curriculum-based learning, covering aspects such as instructional flexibility, differentiated learning, project-based learning, and authentic assessment. The critical thinking skills test was developed based on HOTS indicators, including the ability to analyze, evaluate, provide logical reasoning, and draw conclusions regarding a particular issue. Meanwhile, the scientific literacy test was developed based on the PISA framework, which includes the ability to explain scientific phenomena, evaluate and design scientific investigations, and interpret scientific data and evidence (OECD, 2023). The interview guideline was used to explore in depth teachers' experiences in implementing the Merdeka Curriculum, including the supporting factors and challenges encountered during biology instruction.

Prior to implementation, all research instruments underwent validation by three experts in education and science learning to ensure appropriateness of content, construct, and linguistic aspects. In addition to expert validation, the instruments underwent empirical validity testing to assess the feasibility of the items before being administered to the research participants. The validation results indicated that the research instruments met the required feasibility criteria and were deemed valid for data collection.

Data collection was conducted in several stages. In the first stage, quantitative data were collected through the administration of the Merdeka Curriculum implementation questionnaire, as well as critical thinking skills and scientific literacy tests administered to students. The results of the quantitative analysis were subsequently used to determine the focus of exploration in the qualitative phase. In the second stage, in-depth interviews were conducted with biology teachers to deepen understanding of the factors influencing the implementation of the Merdeka Curriculum while simultaneously providing explanations for the quantitative findings. The integration of both types of data was conducted during the interpretation stage to produce a more comprehensive understanding of the relationship between the implementation of the Merdeka Curriculum and students' critical thinking skills and scientific literacy.

Quantitative data were analyzed using descriptive and inferential statistics in JASP. Descriptive analysis was used to describe data tendencies through mean scores, standard deviations, minimum scores, and maximum scores. Prior to conducting correlational analysis, the data were tested for normality using the Shapiro–Wilk test to ensure that the assumptions of parametric statistics were fulfilled. Subsequently, the relationships among the implementation of the Merdeka Curriculum, critical thinking skills, and scientific literacy were analyzed using the Pearson correlation test. Meanwhile, qualitative data were analyzed through the stages of data reduction, data display, and conclusion drawing to strengthen the interpretation of the quantitative findings.

This study was designed to provide empirical evidence regarding the implementation of the Merdeka Curriculum in biology learning and its relationship with 21st-century competencies, particularly critical thinking skills and scientific literacy. Through systematic research procedures and the integration of quantitative and qualitative approaches, this study is expected to demonstrate adequate levels of traceability and replicability for similar research contexts.

## RESULT AND DISCUSSION

The results of this study were obtained through descriptive and inferential statistical analysis of three main variables: the implementation of the Independent Curriculum, critical thinking skills, and student scientific literacy.

Table 1. **Descriptive Statistics of Research Variables**

Variables	Mean	Std. Deviation	Minimum	Maximum	P-value of Shapiro Wilk
Merdeka curriculum implementation questionnaire	63,64	18,09	26,7	96,7	0,057
Critical thinking skills test	54,06	20,25	11,7	11,9	0,209
Scientific literacy test	51,26	20,81	93,3	95,2	0,112

### Implementation of the Merdeka Curriculum in Biology Learning

The findings revealed that the implementation of the Merdeka Curriculum in biology learning at the two senior high schools in Parepare City was categorized as moderately good, with a mean score of 63.64. This finding indicates that the educational transformation promoted by the Merdeka Curriculum is beginning to be implemented in classroom practices, although it has not yet been fully optimized across all aspects. This condition suggests that teachers have made efforts to implement more flexible, student-centered learning principles and provide greater opportunities for the development of contextual learning experiences.

Conceptually, the Merdeka Curriculum was designed to provide flexibility in learning through content simplification, differentiated instruction, and strengthened project-based learning to develop students' 21st-century competencies. According to the Ministry of Education, Culture, Research, and Technology, the Merdeka Curriculum emphasizes deeper learning that is relevant to students' needs, allowing teachers greater autonomy to adjust instructional strategies to classroom contexts. In biology learning, such flexibility is particularly important because the subject matter is directly related to life phenomena, environmental issues, health, and technological developments, thus requiring learning approaches that go beyond conceptual memorization toward scientific exploration and reasoning.

Interview findings indicated that teachers perceived the Merdeka Curriculum as offering greater flexibility in instructional practices than the previous curriculum. Teachers had begun implementing PjBL, although its implementation remained relatively simple and had not yet been systematically integrated. This condition suggests that the implementation of the Merdeka Curriculum has progressed toward a more constructivist learning approach, although it is still in the adaptation phase.

These findings are consistent with the study by Fatmawati et al. (2024), which found that implementing the Merdeka Curriculum in biology learning can enhance student engagement through project-based learning and problem-solving, though its success is strongly influenced by teacher readiness and the availability of instructional facilities. Similarly, Rohali and Hamimi (2024) found that implementing a science-based approach to learning within the Merdeka Curriculum could encourage students' active engagement in the learning process and strengthen higher-order thinking skills.

Nevertheless, the findings also indicate that the implementation of the Merdeka Curriculum has not yet been fully optimized. Interview results revealed limitations in facilities, particularly in biology laboratories, that hindered the full implementation of scientific investigation activities. Furthermore, teachers reported that authentic assessment, as emphasized in the Merdeka Curriculum, had not yet been implemented, and learning evaluation remained dominated by conventional testing methods. In fact, authentic assessment plays an important role in comprehensively assessing higher-order thinking skills, problem-solving abilities, and students' scientific competencies (Panadero et al., 2019).

Therefore, the implementation of the Merdeka Curriculum in biology learning has progressed in a positive direction; however, further improvements are still required in instructional facilities, the implementation of authentic assessment, and the development of more in-depth project-based learning to ensure optimal achievement of 21st-century competencies.

### **Student's Critical Thinking Skills**

The findings revealed that students' critical thinking skills were categorized as moderate, with a mean score of 54.06. This finding indicates that students have developed the ability to analyze information, provide logical reasoning, and draw conclusions; however, these abilities have not yet been optimally developed across various scientific problem-solving situations.

Critical thinking skills are among the essential competencies in 21st-century learning because they are associated with individuals' ability to evaluate information rationally, construct evidence-based arguments, and make logical decisions. According to Ennis (2019), critical thinking involves a reflective, rational process for determining what to believe or what actions to take based on available evidence. In the context of biology learning, critical thinking skills are required to understand biological phenomena, analyze cause-and-effect relationships, and evaluate scientific information objectively.

The moderate category identified in this study may be attributed to the fact that instructional practices supporting the development of critical thinking skills have not yet been fully optimized. Interview findings revealed that although teachers had implemented project-based learning, the assigned projects remained relatively simple due to limited instructional time, while students tended to require longer time to complete the activities. As a result, students' opportunities to engage in exploration, investigation, scientific argumentation, and reflection on the learning process remained limited.

These findings are in line with the study conducted by Usman et al. (2024), which stated that problem-based and project-based learning in biology has substantial potential to improve critical thinking skills; however, its effectiveness is influenced by the quality of instructional implementation, the duration of learning activities, and students' level of engagement. Furthermore, Herlita et al. (2023) demonstrated that integrating STEM and PjBL approaches can enhance critical thinking skills when students are given sufficient opportunities to conduct investigations and reflect on real-world problems.

Another factor that may have influenced students' critical thinking achievement is the absence of authentic assessment in the instructional process. Learning evaluation, which remains predominantly based on conventional tests, tends to focus more on conceptual mastery rather

than students' analytical, evaluative, and argumentative abilities. In contrast, according to Panadero et al. (2019), authentic assessment can encourage students to develop reflective and critical thinking skills through context-based tasks grounded in real-life situations.

Therefore, the moderate level of critical thinking skills should not be interpreted as a failure in implementing the Merdeka Curriculum. Rather, it reflects that the educational transformation is still in a transitional phase. Consequently, strengthening HOTS-based instructional strategies, optimizing project-based learning, and developing authentic assessment practices are necessary to foster students' critical thinking skills more effectively.

#### Student's Scientific Literacy

The findings revealed that students' scientific literacy was categorized as moderate, with a mean score of 51.26. This finding indicates that students have acquired basic abilities in understanding scientific concepts, interpreting information, and explaining biological phenomena; however, these abilities have not yet developed optimally for more complex scientific analysis and evidence-based decision-making.

Scientific literacy is an important competency in 21st-century education because it is not only about mastery of scientific concepts but also about individuals' ability to apply scientific knowledge to understand phenomena, evaluate information, and make decisions based on empirical evidence. According to OECD (2023), scientific literacy encompasses the ability to explain phenomena scientifically, evaluate and design scientific investigations, and critically interpret data and evidence. In the context of biology learning, scientific literacy is particularly important because most biology content is directly related to daily life, health, environmental issues, climate change, and developments in biotechnology.

The moderate category of scientific literacy found in this study suggests that biology instruction has not yet fully provided students with meaningful scientific experiences. Interview findings with teachers indicated that although project-based learning had been implemented, the projects conducted remained relatively simple and did not consistently involve in-depth scientific investigations. Moreover, limited laboratory facilities reduced students' opportunities to conduct experiments, make observations, and collect scientific data. This condition consequently limited students' experiences in developing investigative skills and interpreting scientific data.

These findings are reasonable considering that scientific literacy develops optimally when students are directly involved in scientific inquiry, evidence-based discussions, and contextual problem-solving. Ni'mah (2019) emphasized that scientific literacy cannot be effectively developed merely through information-transfer-based instruction but requires learning experiences that enable students to explore real-world phenomena and construct scientific arguments. Similarly, Irwandi et al. (2025) found that biology learning grounded in critical analysis and contextual discussion significantly improved scientific literacy, as students became more actively engaged in evaluating evidence and connecting concepts to real-life situations.

In addition to facility limitations, the absence of authentic assessment in learning practices may also have contributed to the less-than-optimal achievement of scientific literacy. Learning evaluation that remains dominated by conventional tests tends to emphasize conceptual mastery rather than students' abilities to interpret data, construct scientific arguments, or solve context-based problems. In contrast, authentic assessment through projects, portfolios, experiments, and

case studies can provide broader opportunities for students to demonstrate scientific literacy in meaningful ways (Panadero et al., 2019).

Nevertheless, the moderate achievement in scientific literacy should not be viewed entirely negatively. These findings indicate that students already possess a reasonably strong foundation of scientific literacy. Therefore, strengthening inquiry-based instructional strategies, optimizing laboratory facilities, and implementing authentic assessment practices have the potential to further improve students' scientific literacy in the future.

Tabel 2. Results of Correlation Test of Research Variables

Hubungan Variabel	Nilai r	Kategori
Merdeka Curriculum Implementation – Critical Thinking Skills	0,785	Kuat
Merdeka Curriculum Implementation – Scientific Literacy	0,880	Sangat Kuat
Critical Thinking Skills – Scientific Literacy	0,785	Kuat

### The Relationship between Merdeka Curriculum Implementation and Students' Critical Thinking Skills

The findings revealed a strong and significant relationship between the implementation of the Merdeka Curriculum and students' critical thinking skills, with a correlation coefficient of  $r = 0.785$  ( $p < 0.001$ ). This finding indicates that the better the implementation of the Merdeka Curriculum in biology learning, the greater the tendency for students' critical thinking skills to develop. However, this strong relationship should not be interpreted as a direct causal relationship; rather, it indicates a close association between the quality of instructional implementation and the development of students' critical thinking abilities.

Theoretically, this relationship can be understood because the Merdeka Curriculum positions students as active participants in the learning process through more flexible approaches, differentiated instruction, independent exploration, and project-based learning. These characteristics provide students with greater opportunities to construct knowledge through inquiry, problem analysis, reflection, and scientific argumentation. In biology learning, this approach is particularly relevant because much of the subject matter requires analytical thinking to understand life phenomena, biological cause-and-effect relationships, and the interpretation of scientific data.

Interview findings indicated that teachers had begun implementing PjBL in instructional practices, although its implementation remained relatively simple and had not yet been fully optimized. Nevertheless, the implementation of simple projects still provided students with opportunities to engage in problem-solving and basic decision-making processes. This condition suggests that the implementation of the Merdeka Curriculum has begun to create a more active learning environment compared to approaches primarily oriented toward information transfer.

These findings are consistent with those of Usman et al. (2024), who found that problem-based and project-based learning in biology education can enhance critical thinking skills by training students to evaluate information, construct arguments, and solve problems logically. Similarly, Rohali and Hamimi (2024) demonstrated that implementing Socio-Scientific Issues (SSI)-based scientific learning within the Merdeka Curriculum improved students' critical thinking skills through evidence-based discussions and strengthened scientific reasoning.

However, the findings also reveal an interesting paradox worth discussing. Although the correlation between implementing the Merdeka Curriculum and critical thinking skills was relatively strong, students' critical thinking achievement remained in the moderate range. This finding suggests that the quality of Merdeka Curriculum implementation in schools has not yet been fully optimized across all components. Interview findings revealed that limited instructional time, students' slower pace in completing projects, and the absence of authentic assessment limited students' opportunities to develop analytical and reflective thinking skills.

This condition can be understood because critical thinking skills do not develop instantly but require consistent learning experiences, complex tasks, reflective feedback, and assessment practices that support the development of higher-order thinking. According to Ennis (2019), critical thinking develops optimally when students are repeatedly given opportunities to analyze, evaluate, and construct decisions based on logical reasoning. Therefore, strengthening the implementation of the Merdeka Curriculum by optimizing PjBL, developing authentic assessments, and enhancing HOTS-based instruction is essential to improve students' critical thinking skills.

### **The Relationship between Merdeka Curriculum Implementation and Students' Scientific Literacy**

The findings revealed a very strong and significant relationship between the implementation of the Merdeka Curriculum and students' scientific literacy, with a correlation coefficient of  $r = 0.880$  ( $p < 0.001$ ). This finding indicates that the quality of Merdeka Curriculum implementation is closely associated with students' ability to understand scientific phenomena, interpret data, and apply scientific concepts in everyday life contexts.

Conceptually, this relationship can be explained by the fact that the Merdeka Curriculum emphasizes more contextual, flexible, and experience-based learning. In biology instruction, this approach enables students to understand concepts not only at a theoretical level but also through the exploration of biological phenomena relevant to daily life. Project-based learning and scientific activities, integral components of the Merdeka Curriculum implementation, have the potential to strengthen scientific literacy by engaging students in observation, investigation, data interpretation, and evidence-based problem-solving.

These findings are supported by Ni'mah's (2019) study, which emphasized that scientific literacy develops optimally when students are provided with inquiry-based learning experiences and opportunities for scientific argumentation. Likewise, Irwandi et al. (2025) demonstrated that biology learning grounded in critical analysis and contextual discussion significantly improved scientific literacy, as students were trained to understand the relationships between scientific concepts and real-world situations.

Although the identified relationship was categorized as very strong, students' scientific literacy achievement remained in the moderate category. This finding indicates that the implementation of the Merdeka Curriculum has not yet fully provided optimal scientific learning experiences. Interview findings revealed that limited laboratory facilities represented one of the major barriers in biology instruction. Experimental and scientific investigation activities, which should serve as important means of strengthening scientific literacy, could not be conducted

optimally. In addition, the relatively simple nature of project-based activities limited students' opportunities to engage in more complex scientific investigations.

These findings suggest that the strong relationship between the implementation of the Merdeka Curriculum and scientific literacy demonstrates the curriculum's considerable potential to support students' competency development. However, its effectiveness is highly influenced by the quality of implementation at the school level, including teacher readiness, instructional facilities, and evaluation strategies employed. Therefore, improving laboratory facilities, optimizing project-based learning, and implementing authentic assessment are crucial factors in enhancing students' scientific literacy more effectively.

### **The Relationship between Critical Thinking Skills and Students' Scientific Literacy**

The findings also revealed a strong and significant relationship between students' critical thinking skills and scientific literacy, with a correlation coefficient of  $r = 0.785$  ( $p < 0.001$ ). This finding indicates that students with stronger critical thinking skills tend to demonstrate higher levels of scientific literacy. This relationship suggests that critical thinking skills are among the essential foundations of scientific literacy.

Theoretically, this relationship can be understood because scientific literacy requires not only conceptual understanding but also the ability to analyze information, evaluate evidence, and draw logical conclusions. Students with stronger critical thinking skills tend to be better able to understand scientific information in depth, connect multiple concepts, and evaluate the validity of information before making decisions. In the context of biology learning, these abilities are particularly important because many biological phenomena require evidence-based interpretation and logical reasoning.

These findings are consistent with Ni'mah's (2019) study, which found that scientific literacy requires reflective and evaluative thinking as a foundation for understanding scientific phenomena. Similarly, Irwandi et al. (2025) found that students with stronger critical thinking skills tended to demonstrate better understanding of scientific issues, greater ability to evaluate data, and stronger evidence-based argumentation skills.

Nevertheless, the findings also revealed that the strong relationship between critical thinking skills and scientific literacy has not yet resulted in high achievement levels for both variables. This condition suggests that strengthening one competency should be accompanied by integrated and sustainable instructional strategies. The development of critical thinking through HOTS-based tasks, scientific discussions, and investigative projects will be more effective when accompanied by authentic scientific experiences and assessment practices that support students' reflective abilities.

Therefore, the findings reinforce the argument that improving students' scientific literacy cannot be separated from strengthening critical thinking skills. Consequently, biology learning within the Merdeka Curriculum should be directed not only toward conceptual mastery but also toward the development of analytical, evaluative, and argumentative skills to enable students to face the challenges of the 21st century in a more adaptive and evidence-based manner.

## CONCLUSION

This study concludes that implementing the Merdeka Curriculum in senior high school biology learning demonstrates considerable potential to support the development of students' critical thinking skills and scientific literacy through more flexible, student-centered, and project-based learning approaches. Although the relationships between curriculum implementation and both competencies are strong, students' achievement levels remain moderate, indicating that instructional effectiveness is still influenced by challenges such as limited facilities, suboptimal project implementation, time constraints, and inconsistent authentic assessment practices. These findings reinforce the theoretical perspective that active, context-based learning environments contribute to the development of 21st-century competencies. Therefore, optimizing project-based learning, strengthening authentic assessment, enhancing teacher capacity, and improving instructional resources are essential to maximize curriculum effectiveness. Despite providing empirical evidence on the implementation of the Merdeka Curriculum in biology education, this study is limited by its correlational design and restricted context; thus, broader, longitudinal studies are recommended to provide a deeper understanding of the factors influencing the development of critical thinking skills and scientific literacy.

## REFERENCES

- Ahmad, D. N., Sanjayanti, A., & Setyowati, L. (2024). Implementasi Kurikulum Merdeka Belajar pada Pembelajaran Sains. *Edusaintek: Jurnal Pendidikan, Sains dan Teknologi*, 11(4), 1677–1693. <https://doi.org/10.47668/edusaintek.v11i4.1322>
- Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). Sage Publications.
- Direktorat Sekolah Menengah Atas. (2021). *Pengembangan instrumen penilaian berbasis literasi sains*. Jakarta: Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi.
- Ennis, R. H. (2019). Critical thinking: A streamlined conception. In *The Palgrave Handbook of Critical Thinking in Higher Education* (pp. 23- 43). Palgrave Macmillan.
- Fatmawati, B., Muhammad, M., & Fenny, R. 2024. *Fostering Students' Problem-Solving Skills through Biology Learning Model Integrated with Kurikulum Merdeka*. *Jurnal Pendidikan Biologi Indonesia*, 10(2). DOI: 10.22219/jpbi.v10i2.32857
- Herlita, F., Yamtinah, S., & Wati, I. K. (2023). The Effect of the PjBL-STEM Model on Students' Critical Thinking Ability in Science Learning. *Jurnal Inovasi Pendidikan IPA*, 9(2), 192–202. <https://doi.org/10.21831/jipi.v9i2.57963>
- Irwandi, Mariana, A. C., & Jayanti, S. (2025). Enhancing Biology Students' Scientific Literacy through the Critical Analysis and Discussion-Comparison with the Extended Learning Community Model. *Jurnal Pendidikan IPA Indonesia*, 14(4), 629.642. <https://doi.org/10.15294/jpii.v14i4.31909>
- Madlazim, M., & Indana, S. (2023). Profile of Student's Critical Thinking Skills and The Effectiveness of Problem-Based Learning Models Assisted by Digital Worksheet in Science Learning on Motion and Force Materials. *IJORER: International Journal of Recent Educational Research*, 4(4), 481–496.
- Mulyati, D., Leni, S. M., & Rifaatul, M. (2024). Persepsi Siswa dan Guru terhadap Implementasi Kurikulum Merdeka dalam Mata Pelajaran Biologi. *Jurnal Life Science: Jurnal Pendidikan Dan Ilmu Pengetahuan Alam*, 6(2), 36–44. 10.31980/lsciences.v6i2.354
- Ni'mah, F. 2019. Research trends of scientific literacy in Indonesia: Where are we?. *Jurnal Inovasi Pendidikan IPA*, 5(1), 2019, 23-30. <https://doi.org/10.21831/jipi.v5i1.20862>
- Nurfauziah, Y., Nugraha, A., & Putri, A. R. (2024). Pengembangan Modul Pembelajaran Literasi Sains Berbasis Kurikulum Merdeka pada Materi Fotosintesis di Sekolah Dasar. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, 9(3), 2158–2170.
- OECD. (2023). *PISA 2022 Results: The State of School Education in Indonesia*. OECD Publishing.

- Panadero, E., Broadbent, J., Boud, D., & Lodge, J. M. (2019). *Using Formative Assessment to Influence Self- and Co-Regulated Learning: The Role of Authentic Assessment*. *Assessment & Evaluation in Higher Education*, 47(6), 1–16. DOI: 10.1080/02602938.2021.1984869
- Pusat Penilaian Pendidikan. (2019). *Panduan penulisan soal HOTS (Higher Order Thinking Skills)*. Jakarta: Kementerian Pendidikan dan Kebudayaan.
- Rohali, A., & Hamimi, E. (2024). *Innovation in Merdeka Curriculum E-Module: Integrating Scientific Approach with Socio-Scientific Issues to Improve Students' Critical Thinking*. *Indonesian Journal of Educational Research and Review*, 7(3). DOI: 10.23887/ijerr.v7i3.82919
- Usman, A., Kukuh, M., & Agus, P. U. 2024. *How Can Problem-Based Learning Promote Critical Thinking Skills in Biology Material? A Systematic Literature Review*. *Research and Development in Education (RaDEn)*, 4(1). DOI: 10.22219/raden.v4i1.32401
- Zakiah, N., Yulianti, R., & Ferry, I. (2023). Pengaruh Pembelajaran PBL Terintegrasi STEM terhadap Keterampilan Berpikir Kritis Peserta Didik. *Jurnal Jeumpa: Jurnal Pendidikan Sains dan Biologi*, 10(2), 269–277. <https://doi.org/10.33059/jj.v10i2.8479>
- Zahirah, D. F., & Oktavia, S. (2023). Efektivitas STEM–Project Based Learning untuk Peningkatan Kemampuan Literasi Sains dan Berpikir Kreatif Peserta Didik pada Materi Kesetimbangan Kimia. *Journal of Chemical Education*, 11(2), 112–120. <https://doi.org/10.26740/ujced.v12n2.p121-131>