RESEARCH ARTICLE

The effect of PBL integrated RMS on biological literacy and critical thinking ability of high school students

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Abstract: This study aimed to determine the effect of Problem-Based Learning (PBL) integrated Reading, Mind Mapping, and Sharing (RMS) on biological literacy and critical thinking skills in biotechnology material. This type of research is Quasi-Experimental with pre-test-post-test experiments and a control group design. The researcher conducted the research because most of the students who became respondents considered biotechnology material less attractive, so students' understanding and activeness could have been more optimal in the learning process. The research samples were 72 students of class X MIPA at SMA Negeri 2 Kota Serang, Banten. The research sample was divided into two groups: the experimental group that applied the PBL integrated RMS model and the control group that applied the PBL model. The research instruments used were biological literacy ability tests and critical thinking ability tests. Biological literacy skills were measured using biological literacy-based multiple-choice test instruments, while critical thinking skills were measured using essay test instruments. The hypothesis test used was MANOVA statistical analysis. The results of statistical tests showed a significant effect of PBL integrated with RMS on biological literacy and critical thinking skills on biotechnology material with a significance value of 0.000 < α. Students with an integrated RMS learning model are more effective than those with a PBL learning model, which is indicated by the post-test value being higher than the pre-test value. This research contributes to the field of biology education by showing that the PBL learning model integrated with RMS can be an effective alternative learning model to improve students' biological literacy and critical thinking skills. The findings of this study are expected to be useful for biology teachers in choosing a suitable learning model to improve the quality of biology learning in schools.

Keywords: biotechnology; biological literacy; critical thinking; PBL; student

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Introduction

Scientific literacy has long emerged as a common goal of school science curricula. Science literacy includes understanding how science works in practice, how scientists do research and collect data, and the processes scientists use to ensure valid and reliable findings (Struminger et al., 2021). Researchers in education describe the importance of scientific literacy in developing responsible decision-makers in the future and promoting sustainable development (Mansfield & Reiss, 2020). Wang et al. (2022) define science literacy as an understanding of science and its application in society. Science literacy divided into three levels: practical or functional literacy, civic literacy (or literacy as power), and cultural or ideal literacy (Wang et al., 2024). Scientific literacy has been recognized as one of the main goals of science education since its inception, even more than its essential meaning (Bórquez-Sánchez, 2024).
Science literacy, especially biological literacy, is an important provision for students in 21st-century

education, which requires literate individuals to have a variety of abilities, competencies, and mastery of various literacies. Critical thinking skills can be trained in science literacy-based learning (Zahroh & Yuliani, 2021). In practice, learning not based on scientific literacy is a problem caused by several elements, such as using models, strategies, and learning methods that could be more optimal. Biology learning based on science literacy will help students develop critical thinking skills, understand biological concepts in depth, and apply them in everyday life (Fitriani et al., 2020). One branch of science literacy is biological literacy, which refers to science literacy in biology subjects that can help students understand content, especially biology, and prioritize biological contexts (Djamahar et al., 2021). A biologically literate individual includes an understanding of the principles of biology, critical concepts in biology, human impact on the biosphere, the history of the development of biological concepts, personal values related to biological inquiry, biodiversity and culture, the impact of biology and biotechnology on society, and the importance of biology for individuals (Semilarski & Laius, 2021).

The problem in education today is the need for more science literacy and critical thinking ability. One of the challenges in the development of science teaching is the development of students' critical thinking. Critical thinking is understood as a way to help students compare sources, question information, and distinguish reliable information from misinformation, which is part of developing 21st-century skills (Cabello et al., 2024). Students' science literacy skills were found to be very concerning, which was recorded as very low, as revealed by Anisa et al (2021) and Ermawati et al (2023). Furthermore, the 2018 PISA survey data ranked Indonesia 74th out of 79 countries, showing a low position (Faradilla et al., 2024). Indonesia also ranks bottomless in reading ability in several countries worldwide (Djamahar et al., 2021). In addition, students need more interest in reading literacy-type questions (Ristanto et al., 2023). The low interest in reading or literacy in Indonesia is influenced by several factors, including the lack of reading habits from an early age, limited educational facilities, and the lack of book production in Indonesia (Anisa et al., 2021).

The low critical thinking ability of students is closely related to the choice of learning methods, learning that tends to be teacher-centered, mastery of material, students tend to be required to hone the memory aspect, without being invited to think and less train students to develop their reasoning power in applying material concepts (Mulyanti et al., 2023; Peppen et al., 2021). In addition, the low level of critical thinking is because, during the process of carrying out a lesson in everyday life, it is considered ineffective in developing an interest, talent, and potential within students (Anisa et al., 2021). Adequate school facilities and infrastructure are critical to improve students' critical thinking skills. A curriculum based on distinguishing arguments, writing pedagogy, and online group discussions improved students' critical thinking skills (Saldıray & Doğanay, 2024). Findings from Paula et al. (2024) emphasize the importance of promoting service-learning experiences in education to promote and develop students' disposition toward critical thinking (Alvarez-huerta et al., 2024).

The concept of Biology material, especially Biotechnology, is still challenging to understand for grade X students because it is considered complex to be explained in detail by the teacher, especially in the subchapter of modern biotechnology, which includes genetic engineering such as nuclear cloning and gene cloning (Khalisah et al., 2024; Sari et al., 2024). Based on the pre-research results of the needs analysis at SMAN 2 Serang City involving 75 participants, it shows that biotechnology material is considered less attractive for students, with only 22 (29.3%) choosing it as exciting material. In contrast, 11 other students (14.7%) think it interesting. In addition, students critical thinking skills still need to improve because their understanding and activeness are still not optimal; many students are still not active when the learning process takes place. Thus, serious efforts are needed to improve science literacy skills, especially biological literacy and critical thinking, including understanding complex material such as Biotechnology.

Seeing this situation, steps or solutions that can be taken, such as innovating in the learning process, are needed. One way to overcome this problem is to improve the subject matter in the learning process through a more effective learning model, namely problem-based learning (PBL) integrated with reading, mind mapping, and sharing (RMS). The general purpose of the PBL learning model is to invite students to be more courageous and creative in their imagination. With their imagination, students are guided by teachers to create discoveries by improving existing ones and creating new ideas or ideas. Several studies on the implementation of the RMS learning model that involves critical steps such as reading, making mind maps, and sharing in learning science concepts have been shown to improve critical thinking, metacognitive skills, and concept understanding (Muhlisin et al., 2020).

The findings from Muhlisin et al.'s (2020) research provide strong support for the effectiveness of the RMS learning model in improving learning quality. There is research that supports the integration of PBL with the RMS learning model. The study showed that the class that applied the integration of PBL with RMS achieved an average post-test score of 68.46, while the class that applied the traditional learning model only achieved a score of 48.92. This finding shows that the integration between PBL and RMS can be an effective approach to improving learning quality and student achievement (Muhlisin et al., 2020). Research with another RMS learning model is from Widyaningsih and Yusuf (2024) that the RMS learning model in school laboratory courses is effectively used to develop student learning outcomes, and students give a good response to RMS learning.

Research using PBL models, among others, from Nursaidah et al. (2022) tried to find out the effect of online-based problem-based learning on self-confidence and social interaction of X MIPA class students at SMA Negeri 6 Tasikmalaya, West Java-Indonesia. The results of data analysis and hypothesis testing from Nursaidah's research found that problem-based learning affected self-confidence and social interaction with a high category. A lesson using online-based problem-based learning must be supported by the readiness of students and teachers so that learning becomes effective.

Another research reviews several topics related to teacher perceptions of the application of problem-based learning, the advantages and disadvantages of problem-based learning as a basis for modifying learning models, and the importance of collaboration skills for elementary school students. The result of this research is the design of a problem-based learning model-collaboration (PBL-C) with six steps, namely orienting students to the problem, organizing students to learn and division of tasks, guiding the investigation, proving the results of the investigation, developing and presenting the work, and analyzing and evaluating the problem-solving process (Sajidan et al., 2022).

In contrast to some previous studies, this research seeks the Effect of the Problem-Based Learning Model Integrated Reading, Mind Mapping, and Sharing (RMS) on Biological Literacy and Critical Thinking Ability of SMA Negeri 2 Serang Students on Biotechnology Material provided by the teacher. This research is expected to determine the effectiveness of problem-based learning and integrated RMS models. Hypothesis testing of this research is MANOVA (Multivariate Analysis of Variance) statistical analysis. This study seeks to obtain an overview of the use of a PBL learning model integrated with RMS in improving biological literacy among high school students in Serang City. Researchers also examined and analysed whether the RMS-integrated PBL model could improve students' critical thinking skills, including in understanding complex material such as Biotechnology. The results of this research from one school are expected to be a reference for Biology teachers in implementing science literacy-based learning so that they can better educate students.

Method

This research is a type of Quasi-Experimental research with pretest-postest Experiment and control group design. The research sample was divided into two groups: the experimental group that applied the PBL-integrated RMS model and the control group that used the PBL model. This research variable consists of 1 independent variable and two dependent variables. The independent variable is the Problem-Based Learning (PBL) model integrated with Reading, Mind Mapping, and Sharing (RMS), while the dependent variable is students' biological literacy and critical thinking skills.

The population that became the focus of this study were all X MIPA class students at SMAN 2 Serang City in the even semester of the 2023/2024 academic year, totaling 264 students. The researcher's sample was determined through the simple random sampling method, and as many as 72 students were randomly selected to be sampled. After that, an instrument test was conducted to assess the validity and reliability of the test of students' biological literacy and critical thinking skills. The next step is to analyze the score data obtained using statistical analysis methods. Pre-test and post-test scores from the experimental and control groups will be analyzed to calculate N-Gain. Kolmogorov-Smirnov testing was conducted to ensure normality, while homogeneity of variance data was tested using Levene's method and homogeneity of covariance data using Box's M test. Hypothesis testing will use MANOVA (Multivariate Analysis of Variance) statistical analysis, because this research analyses two dependent variables simultaneously so that researchers can see the effect of learning models on students' abilities in aspects of biological literacy and critical thinking.

Results and Discussion

Validity Test

The validity test used on the instrument of students' biological literacy skills uses the point biserial correlation technique—the results of the validity test calculation on biological literacy skills are in Table 1.

Table 1. Results of the Biological Literacy Ability Validity Test

Question Number	Criteria
1,2,3,4,5,6,7,8,9,10.12,13,14,15,16,19, and 20	Valid
11, 17, and 18	Not Valid

The next validity test on the student's critical thinking ability instrument uses the PPM (Pearson Product Moment) test formula because the scoring used is polytomous. The results of the validity test calculation on critical thinking skills can be seen in Table 2.

Table 2. Critical Thinking Ability Validity Test Results

Question Number	Criteria
1,2,3,4,5,6,7,8,9,10.11, and 12	Valid
-	Not Valid

Reliability Test

The reliability test aims to test the accuracy of the tool in measuring what is to be measured. Reliability testing on biological literacy instruments uses the Kuder-Richardon formula. In this case, there are three items, namely question numbers 11, 17, and 18, which are invalid, so they are not used in reliability testing. The results of the reliability test of the research instrument on 40 students of class XI MIPA outside the research sample with a significant level of 5% and degrees of freedom dk = n-2 then obtained r table of 0.32 while r count is 0.887. Because r count (0.887) is greater than r table (0.32), the research instrument in the form of this test is declared reliable.

Reliability testing on critical thinking ability instruments uses Cronbach's Alpha because the scoring is polytomous (5-4-3-2-1). The calculation of the reliability test on the critical thinking ability instrument with a significant level of 5% obtained r count = 0.78 while r table = 0.32. Because the r count is more important than the r table, the research instrument in this test is declared reliable or suitable to use in research.

Descriptive Results

This section describes the mean score, maximum score, minimum score, standard deviation, and variance of the experimental and control classes. The results of the descriptive analysis are as seen in Table 3.

Table 3. Descriptive Statistics of Biological Literacy Skills

Statistics Indicator	Indicator Descriptive			
	Experimental Class		Control Class	
	Pre-test	*Post-test*	*Pre-test*	*Post-test*
Average Value	28.06	83.17	26.83	68.67
Minimum Value	12.00	76.00	18.00	53.00
Maximum Value	41.00	100.00	41.00	82.00
Standard Deviation	7.71	6.54	6.37	8.00
Variance	59.48	42.83	40.60	64.00

Table 3 shows that the pre-test and post-test scores of each indicator have increased. The average pre-test and post-test scores of students' biological literacy skills conclude that PBL alone is an effective learning method, but the results of integrating PBL with RMS have much more potential because they can increase understanding, develop important skills, and motivate students.

This section describes the mean score, maximum score, minimum score, standard deviation, and variance of the experimental and control classes. The results of the descriptive analysis are in Table 4.

Table 4. Descriptive Statistics of Students' Critical Thinking

Statistics Indicator	Descriptive Indicator			
	Experimental Class		Control Class	
	Pre-test	*Post-test*	*Pre-test*	*Post-test*
Average Value	36.08	81.44	27.36	71.81
Minimum Value	21.00	75.00	10.00	58.00
Maximum Value	50.00	90.00	40.00	81.00
Standard Deviation	7.10	4.00	8.58	6.47
Variance	50.36	16.03	73.61	41.82

Based on Table 4, the pre-test and post-test values of each indicator have increased. The post-test value of each indicator of the experimental class is much higher than that of the control class post-test. This means that the experimental class, which is PBL learning integrated with RMS, has the potential to be more effective than the control class, which is a PBL learning model only.

Prerequisite Test

Normality Test

The results of the normality test of students' literacy and critical thinking skills are in Table 5.

Table 5. Normality Test Results of Students' Literacy and Critical Thinking Skills

Variable	Group	Statistics	Sig
Literacy of Biology	Experiment	0.14	0.082
	Control	0.12	0.200*
Critical Thinking	Experiment	0.11	0.200*
	Control	0.14	0.096

After the normality test using the Kolmogorov-Smirnov test, the data for critical thinking variables and biological literacy in both the experimental and control groups showed a significance value greater than 0.05. This confirms that the data is normally distributed, reinforcing the validity of our findings.

Assumption of Homogeneity of Variance

The results of the homogeneity of variance test of students' biological literacy and critical thinking skills are in Table 6.

Table 6. Homogeneity Test of Variance of Biological Literacy and Critical Thinking Ability of Students with Levene's Test

Variable	Statistic	Sig
Literacy of Biology	0.829	0.366*
Critical Thinking	0.830	0.365*

The researcher chose Levene's Test method to test homogeneity. If the significance value (sig) < 0.05, then the data is considered homogeneous, and H0 is accepted, but if the significance value (sig) > 0.05, then H0 is rejected, and the data is considered inhomogeneous. Based on the results of homogeneity testing, the variance of critical thinking and biological literacy variables is homogeneous, with each significance value more significant than α (0.05).

Homogeneity Test of Covariance Matrix

Testing the homogeneity of the covariance matrix in hypothesis testing utilizes Box's M test and is facilitated by the powerful SPSS 24 software. This test is used to assess the MANOVA hypothesis which requires the uniformity of the covariance matrix of the dependent variable between groups. The results of the covariance matrix similarity test analysis can be seen in Table 7.

Table 7. Analysis Results of Box's M Test to See the Homogeneity of the Covariance Matrix

Box's M	F	Sig.
4.154	1.342	0.259

Box's M test is used to test the MANOVA assumption that the covariance matrix of the dependent variable is the same. The Box's M number is 4.154, with an F value of 1.342 and a significance value of 0.259. A significance value greater than 0.05 indicates the assumption is met.

Hypothesis Test

Simultaneous Hypothesis Test

If the significance value (sig) > 0.05, then H0 is accepted, meaning that the PBL model does not affect biological literacy and critical thinking skills. The results of the simultaneous hypothesis testing are shown in Table 8.

Table 8. ANOVA Multivariate Testing Results (Simultaneous)

Effect		F	*p-value*
Group	*Pillai's Trace*	45.612	0.000
	Wilks' Lambda	45.612	0.000
	Hotelling's Trace	45.612	0.000
	Roy's Largest Root	45.612	0.000

Table 8 is a multivariate test comparing experimental and control groups on the variables studied simultaneously. From the table, the p-value obtained, which is smaller than α = 5% (0.000 <0.050), states that simultaneously, there is a significant difference between the two experimental and control groups on the average N-Gain of critical thinking and biological literacy.

Partial Hypothesis Test

The Table 9 are the results of multivariate ANOVA (partial) testing.

Table 9. Multivariate ANOVA (Partial) Testing Results

Variable	F	p-*value*
Literacy of Biology	66.521	0.000
Critical Thinking	27.048	0.000

Table 9 shows that the average N-Gain of biological literacy is more dominant than critical thinking.

N-Gain Analysis

The Table10 are the results of N-Gain descriptive analysis

Table 10. N-Gain Descriptive Analysis Results

Variable	Group	Mean	St. Dev.	Minimum	Maximum
Literacy of Biology	Experiment	0.77	0.09	0.64	1,00
	Control	0.57	0.11	0.27	0.79
Critical Thinking	Experiment	0.71	0.07	0.56	0.86
	Control	0.61	0.09	0.35	0.74

Descriptive analysis showed that the experimental group's average N-Gain of biological literacy was 0.77 ± 0.09 higher than the average N-Gain of biological literacy in the control group of 0.57 ± 0.11. Then, the experimental group's average N-Gain of critical thinking was 0.71 ± 0.07 higher than the average N-Gain of critical thinking in the control group of 0.61 ± 0.09.

The results of the statistical testing of hypothesis 1 concluded that PBL (Problem-Based Learning) integrated with RMS (Reading, Mind-Mapping, and Sharing) affects students' biological literacy skills in biotechnology material. The essence of biological literacy is to understand biological principles in depth and apply them appropriately by engaging in discussions, searching for valid biological information, interpreting published tables and figures, and making personal and community decisions. In other words, biological literacy focuses on using fundamental concepts in biology to make decisions in solving problems through scientific inquiry (Vonny et al., 2021). Based on the analysis that has been done previously, it is known that PBL integrated with RMS has a significant effect on biological literacy skills. This finding is in line with Aradia and Fitri (2023), who state that the PBL model substantially impacts students' biological literacy skills. The importance of biological literacy skills emphasizes the need to improve the quality of synergistic learning to achieve relevant skills in the 21st century. PBL helps students develop problem-solving skills and a scientific understanding of natural phenomena.

Through PBL, students not only master the subject matter but also develop critical thinking skills, work together in teams, and increase students' awareness of issues in the biotechnology environment. PBL provides a challenging learning experience, allowing students to find creative and sustainable solutions to real-world problems (Nafiah & Suyanto, 2017; Syamsudin, 2020). In conclusion, PBL is a practical learning approach that prepares students to face future challenges by becoming creative, collaborative, and environmentally conscious individuals (Hindun et al., 2024).

The results showed that PBL learning integrated with RMS was able to improve students' literacy and critical thinking skills, indicating that the integration of PBL (Problem-Based Learning) learning with the RMS (Reading, Mind Mapping, and Sharing) learning model is a practical approach that combines two different learning models to improve students' concept understanding and problem-solving skills. The test and analysis of biological literacy skills (Table 3) showed a very significant increase from the pre-test average of 28.06 to 83.17 in the post-test. This increase indicates that the results of integrating PBL with RMS have more significant potential because they can improve understanding, develop essential skills, and motivate students. PBL guides students in identifying, analyzing, and finding solutions to complex problems, while RMS emphasizes student engagement through reading, mind mapping, and sharing understanding. This results from the theory of Muhlisin (2018), which emphasizes that the use of the RMS learning model has an impact on improving student learning outcomes and understanding and accepting scientific concepts more deeply, such as in the philosophy of science. Likewise, the research results from Widyaningsih and Yusuf (2019) said that students' positive responses to RMS learning positively impacted their learning outcomes. Thus, using the RMS learning model can significantly improve student learning outcomes.

The integration of PBL and RMS can be done with a combination of both sources Arends (2012) and Muhlisin et al. (2016), including (1) start with the problem: The teacher presents a real-world problem that is complex and relevant to the subject matter in the study, namely biotechnology material, (2) Reading: the teacher provides students with text or learning resources relevant to the problem. Then, please direct them to identify important information. (3) Mind Mapping: The teacher asks students to create mind maps to organize information from the reading, connect concepts, and build understanding (Arends, 2012). (4) Sharing: The teacher facilitates a discussion session where students share their mind maps, explain their understanding, and give each other feedback. (5) Further investigation: Based on the discussion, the teacher identifies knowledge gaps and directs students to investigate further. (6) Solution presentation: The teacher asks students to formulate a solution to the problem based on the understanding that has been built. (7) Reflection: The teacher ends with a reflection session to evaluate the learning process, identify lessons learned, and plan the next steps.

This integration can improve students' concept understanding, where PBL helps students understand the relevance of the subject matter to the real-world context. In contrast, RMS helps them organize and process information effectively. Then combining these two models can train students to think critically, analyze data, solve problems, and make decisions. Finally, it can increase student motivation and engagement; stated by Diani et al. (2018) that in the RMS model (Reading, Mind Mapping, and Sharing), the implementation of learning is adjusted to the concept of constructivism, that learning is not only a process of absorbing information, ideas, and abilities for materials that will be newly built by the brain and knowledge is not only conveyed by the teacher but built and improved by himself (Diani et al., 2018). Learners must have experience in making hypotheses, testing hypotheses, manipulating objects, solving problems, looking for answers, describing, researching, dialoguing, expressing questions, and others to create new constructions.

According to Uno and Bybee (1994), biological literacy has four dimensions: nominal, functional, structural, and multidimensional. Furthermore, from the average post-test scores in the experimental class, it can be concluded that the nominal dimension, which is the ability of students to understand biological terms and concepts (Uno & Bybee, 1994), is the most dominant dimension in biological literacy skills, followed by structural, multidimensional, and functional dimensions.

The results of the statistical testing of hypothesis 2 concluded that PBL (Problem-Based Learning) integrated with RMS (Reading, Mind Mapping, and Sharing) affects students' critical thinking skills in biotechnology material. Based on the analysis that has been done before, it is known that PBL integrated with RMS has a significant influence on critical thinking skills. This finding aligns with Muhlisin et al. (2016), who said that applying the RMS learning model can effectively improve students' critical thinking skills and integrate these critical thinking skills into various aspects of different academic abilities. Evidence of this is the 55.6% increase in critical thinking skills achieved by the RMS learning model compared to the conventional model. Then, Muhlisin et al. (2020) also conducted a study that said that the implementation of learning with the integration of PBL and the RMS learning model was better than conventional learning, as shown by the average score of the post-test of the class with the integration of PBL and the RMS learning model was higher when compared to the average score of the post-test in the traditional class. The learning process in the PBL integration class with the RMS learning model shows that learning goes well, as indicated by students' average evaluation score of the lecturer's learning process. Teachers and lecturers can use the integration of PBL and RMS models in learning biology to improve thinking skills and everyday problems.

This finding also aligns with other research conducted by Suhirman and Khotimah (2020), saying that the PBL model significantly impacts students' critical thinking skills and science literacy in class XI MAN 1 Mataram, which shows the importance of applying effective learning models in improving these schools' education quality. Then this is also in line with Ilyas et al. (2022), that there are differences in higher-order thinking skills between students who are treated using the RMS model and students who are not treated or use conventional models. The RMS model significantly improved students' higher-order thinking skills and positively impacted learning outcomes, interpreted that the RMS model has a reasonably high effect on students' higher-order thinking ability in class XI of the MIA program at SMA Negeri 1 Sigli in physics subjects.

Critical thinking skills have six indicators, according to Facione (2023), namely 1) interpretation, 2) analysis, 3) inference, 4) evaluation, 5) explanation, and 6) self-regulation. Furthermore, from the average results of the post-test scores in the experimental class, it can be concluded that the self-regulation indicator has the highest value compared to other indicators. This indicator means that students can monitor their learning process, such as evaluating material understanding, identifying learning difficulties, and finding solutions to these difficulties; students can manage negative emotions that arise during the learning process, such as anxiety, frustration, and boredom; and also, students are responsible for their learning process and do not blame external factors for learning failures.

Overall, this study's results indicate that the PBL model integrated with RMS can improve students' critical thinking skills, as shown in Table 4, where there is a significant increase from 36.08 to 81.44. This data means that the experimental class, which is PBL learning integrated with RMS, has the potential to be more effective, especially self-regulation, because students play an active role in reading activities, mapping information, and sharing understanding with classmates as part of the RMS learning process (Nainggolan et al., 2023). The RMS model significantly improves students' higher-order thinking skills and positively impacts learning outcomes. Learning with the RMS model is efficacious in improving student learning achievement. During the implementation of learning, the approach focuses more on discussing the material, which provides opportunities for students to understand the concept thoroughly (Widyaningsih et al., 2019).

The indicators of students' critical thinking skills are interrelated and do not stand alone. Effective self-regulation involves the synergy of all these aspects. The six indicators of critical thinking skills are interrelated with each other. With the interpretation indicator, students can understand and explain the information provided, identify the main idea, and clarify meaning. The analysis indicator helps students break down information into smaller parts, identify relationships between parts, and understand the overall structure. The inference indicator allows students to draw logical conclusions based on available information, make predictions, and identify assumptions. With the evaluation indicator, students can assess the credibility of information, recognize bias, and make judgments based on clear criteria. With the explanation indicator, students can convey the results of thinking logically and structure and support arguments with relevant evidence; then, with the self-regulation indicator, students can monitor their thinking processes, identify biases and errors, and reflect to improve the quality of thinking. These six interrelated indicators work together to form comprehensive critical thinking skills. Affandy et al. (2019) suggested that critical thinking skills are self-regulation in deciding something that consists of interpretation, analysis, evaluation, inference, and exposure using evidence, concepts, methodologies, criteria, or contextual considerations that are the basis for drawing conclusions/statements. Critical thinking skills are intellectual potential that can be developed through learning processes like the PBL learning model integrated with RMS.

Conclusion

The test results show the integrated PBL on the biological literacy skills of SMA Negeri 2 Serang students using biotechnology material. The impact of PBL-integrated RMS on students' critical thinking skills in biotechnology material is significant. In connection with these results, the authors propose suggestions: (1) Teachers are advised to allocate sufficient time in the learning schedule so that students have enough time to think, plan, and draw mind mapping in depth. Adequate time allocation is expected to help students optimize learning and improve their biological literacy and critical thinking skills. (2) Future researchers are advised to develop this study with other subject matter variations and at different educational levels to determine the effectiveness of this model more broadly.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

K. Nihlah: conducting the research, collecting data, writing the original article. **R. H. Ristanto:** supervising the research. **T. H. Kurniati:** supervising the research.

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