Jurnal Pijar MIPA
https://jurnalfkip.unram.ac.id/index.php/JPM
ISSN 1907-1744 (Print)
ISSN 2460-1500 (Online)

Effect of the Problem-Based Learning Model on Critical Thinking Skills and Biology Learning Outcomes

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Received: December 10, 2025. Accepted: January 22, 2026. Published: January 23, 2026

Abstract: Biology learning requires the development of critical thinking skills and learning outcomes through meaningful and contextual processes; however, classroom instruction is often still dominated by conventional approaches. This study aimed to analyze the effect of implementing the Problem-Based Learning (PBL) model on the critical thinking skills and Biology learning outcomes of Grade XI students at SMA Negeri 4 Praya. This research employed a quasi-experimental design with a pre-test–post-test control group. The participants were Grade XI students, divided into an experimental and a control class. The research instruments included a critical thinking skills test based on Ennis' (1996) indicators and a Biology learning outcomes test based on curriculum competencies. The results showed that students in the experimental class achieved significantly higher improvements in both critical thinking skills and learning outcomes compared to the control class. Statistical analysis indicated that implementing the Problem-Based Learning model had a positive, significant effect on student performance. These findings suggest that the PBL model promotes active and meaningful learning, making it an effective approach for enhancing critical thinking skills and Biology learning outcomes among Grade XI students.

Keywords: Biology Learning Outcomes; Critical Thinking Skills; Problem-Based Learning (PBL).

Introduction

In school learning, instructional activities should be designed to help students understand concepts and meanings more easily. Therefore, learning materials should be organized in a clear structure and presented in a simple and systematic manner. In addition, learning should facilitate the development of specific abilities in accordance with the intended learning objectives. The primary goal of learning activities is to help students develop a deep understanding of concepts, rather than merely memorizing isolated facts [1].

Biology is a branch of Natural Sciences taught at various educational levels, including senior high school. At this level, Biology not only introduces fundamental concepts related to living organisms and ecosystems, but also develops students' abilities to observe, analyze, and interpret natural phenomena. Biology learning at senior high school covers a wide range of topics, including genetics, ecology, and cell biology, aiming to equip students with in-depth knowledge and practical skills to understand life processes [2]. Biology instruction emphasizes direct learning experiences for students. Therefore, students require guidance in developing various science process skills. Through these skills, students can acquire deeper scientific knowledge and cultivate a critical, analytical, and systematic scientific attitude in interpreting natural phenomena and applying them in everyday life.

Effective learning occurs when students actively engage in solving real-world problems that are relevant to their lives. Through the Problem-Based Learning (PBL) approach, students are encouraged to analyze situations, formulate questions, develop hypotheses, seek relevant information, and design solutions both independently and collaboratively. This process supports students in constructing understanding, integrating concepts, and continuously developing critical thinking, problem-solving, and teamwork skills [3].

SMA Negeri 4 Praya, one of the public senior high schools in Central Lombok Regency, is committed to improving educational quality by strengthening learning processes that are student-centered. The school is supported by adequate facilities, including laboratories and a library, as well as qualified teaching staff. However, based on preliminary observations conducted in Grade 11 classes in May 2025, classroom instruction was still largely dominated by traditional teaching methods. This condition highlights the need for instructional innovation to promote students' deeper understanding. The implementation of innovative learning models such as Problem-Based Learning (PBL) has not yet been optimized, and its application has not fully reflected the student-centered and constructivist characteristics of the approach.

The learning approach is still largely dominated by traditional teaching methods, resulting in students being less actively involved in scientific thinking, classroom discussions, and independent exploration of Biology-related problems. In addition, the classroom atmosphere tends to become monotonous due to the limited variety of learning activities that encourage interaction or problem-solving. This situation indicates the need to evaluate the implementation of Biology instruction at SMA Negeri 4 Praya. The problems arising from the dominance of conventional teaching methods suggest that current instructional practices have not been optimal. Therefore, an approach is needed to promote students' active engagement and provide opportunities for developing critical thinking and problem-solving skills. One

How to Cite:
R. Yanti, J. Jamaluddin, and I. W. Merta, "Effect of the Problem-Based Learning Model on Critical Thinking Skills and Biology Learning Outcomes", *J. Pijar.MIPA*, vol. 21, no. 1, pp. 13–20, Jan. 2026. https://doi.org/10.29303/jpm.v21i1.11311

learning model that aligns with these characteristics is Problem-Based Learning (PBL).

The implementation of Problem-Based Learning (PBL) is relevant in the context of Biology instruction, as Biology content is often closely related to everyday phenomena that can serve as problem sources. By presenting real-world problems at the beginning of the lesson, teachers can guide students to explore information, analyze facts, and construct concepts through active and meaningful learning experiences. This approach is also aligned with the principles of the Merdeka Curriculum, which emphasizes differentiated learning and instruction based on students' needs.

Problem-Based Learning (PBL) is an instructional approach that places students in real-world problem-solving contexts to encourage collaboration and the development of learning skills. This approach not only focuses on content mastery but also fosters critical thinking, problem-solving, and teamwork skills through students' active involvement in the learning process [4]. In addition, PBL encourages students to actively seek solutions through inquiry activities, group discussions, and reflection, thereby enhancing motivation and conceptual understanding. Research has shown that implementing the PBL model in Biology instruction can significantly improve students' critical thinking skills [5]. This finding is supported by other studies indicating that PBL is effective in improving conceptual understanding and learning outcomes, particularly in the human organ system [6]. However, most previous studies primarily focused on learning outcomes or critical thinking skills separately and paid limited attention to simultaneously examining both variables using a controlled experimental design at the senior high school level. In addition, empirical evidence on the effectiveness of PBL in improving both critical thinking skills and Biology learning outcomes in Indonesian senior high schools remains limited. Therefore, this study is conducted to address these gaps by investigating the effect of PBL on students' critical thinking skills and Biology learning outcomes, thereby providing empirical evidence and strengthening the application of PBL in Biology learning. Consequently, the application of PBL in the learning process at SMA Negeri 4 Praya is expected to address existing instructional challenges and improve the overall quality of students' learning outcomes.

Research Methods

This study employed a quantitative, quasi-experimental design. A quantitative design was selected because the study aimed to measure the effect of implementing the Problem-Based Learning (PBL) model on students' critical thinking skills and Biology learning outcomes using numerical data analyzed statistically. The study applied a Nonequivalent Control Group Design, an experimental design involving two groups: (a) an experimental group, which received instruction using the PBL model, and (b) a control group, which received instruction using conventional teaching methods. Both groups were administered a pre-test prior to the treatment and a post-test after the treatment to examine changes resulting from the implementation of the Problem-Based Learning (PBL) model.

This study was conducted at SMA Negeri 4 Praya, Central Lombok Regency, West Nusa Tenggara, during the first semester of the 2025/2026 academic year, from September 15 to October 3, 2025, with Grade XI students as the research subjects. The study population consisted of all Grade XI students at SMA Negeri 4 Praya in the 2025/2026 academic year, comprising 13 classes, with 36 to 38 students per class.

The sample in this study was selected using purposive sampling, a technique based on specific criteria aligned with the research objectives. In this case, two classes were chosen as samples because they met certain criteria, namely having a relatively equivalent number of students and/or being selected based on recommendations from the supervising teacher who directly taught the classes. The experimental group consisted of Class XI B1, while the control group was Class XI B2. The independent variable in this study was the Problem-Based Learning (PBL) model, whereas the dependent variables were students' critical thinking skills and Biology learning outcomes.

The stages of this study consisted of three phases: preparation, implementation, and analysis. In the preparation phase, the researcher developed research instruments: a critical thinking skills test and a biology learning outcomes test. The instruments were then validated through expert judgment to assess the alignment of the test items with the intended indicators. The critical thinking indicators in this study were based on the framework proposed by Ennis (1996) [7], while the learning outcomes indicators were developed in accordance with the learning objectives (CP) and the requirements of the Merdeka Curriculum. Next, the instruments were empirically tested using item validity analyses based on trial data and Pearson's product-moment correlation to assess each item's validity. In addition, a reliability test was conducted using Cronbach's Alpha coefficient to ensure the internal consistency of the instruments before they were applied in the study. At this stage, the researcher also prepared Problem-Based Learning (PBL)-based instructional materials for the experimental class and conventional instructional materials for the control class.

The implementation phase of the study began with administering a pre-test to both the experimental and control classes to measure students' initial critical thinking skills and Biology learning outcomes. The learning process was then carried out according to the predetermined treatment: the experimental class received instruction using the Problem-Based Learning (PBL) model, while the control class was taught using conventional methods. After the entire instructional sequence was completed, both classes were given a post-test to measure students' critical thinking skills and Biology learning outcomes.

The data obtained from the pre-test and post-test results were analyzed using IBM SPSS Statistics version 26. The data analysis procedures included a normality test using the Shapiro–Wilk test, a homogeneity test using Levene's test, and hypothesis testing using Analysis of Covariance (ANCOVA) to determine the effect of implementing the Problem-Based Learning (PBL) model on the critical thinking skills and Biology learning outcomes of Grade 11 students at SMA Negeri 4 Praya.

Results and Discussion

Critical Thinking Skills

Based on the results of the critical thinking skills pre-test administered to both classes, the students' initial abilities in the experimental and control groups were relatively balanced prior to the implementation of the instructional treatment. In Class B2 (control), the mean pre-test score was 47.1, with a range of 20-70. Of 36 students, most scored below the school's minimum mastery criterion, indicating that there was still considerable room for improvement in their critical thinking skills through a more interactive, context-based learning process. Meanwhile, in Class B1 (experimental), the mean pre-test score was 48.8, with a range of 22-75, from a total of 36 students.

The post-test results of critical thinking skills administered after the instructional process indicated an improvement in both classes. In Class B2 (control), the mean post-test score was 57.39, with a range of 25-82. In Class B1 (experimental), which received instruction using the Problem-Based Learning (PBL) model, the mean post-test score was 72.81, with a range of 45-96. Most students met or exceeded the school's minimum mastery criterion, indicating greater improvement in critical thinking skills.

Table 1. Comparison of Pre-test and Post-test Scores on Critical Thinking Skills

Variabel	Class	N	Mean Pre-test	SD Pre-test	Mean Post-test	SD Post-test
Critical Thinking Skills	Experimental	36	48.8	14.2	72.8	12.4
	Control	36	47.1	12.8	57.3	15.6

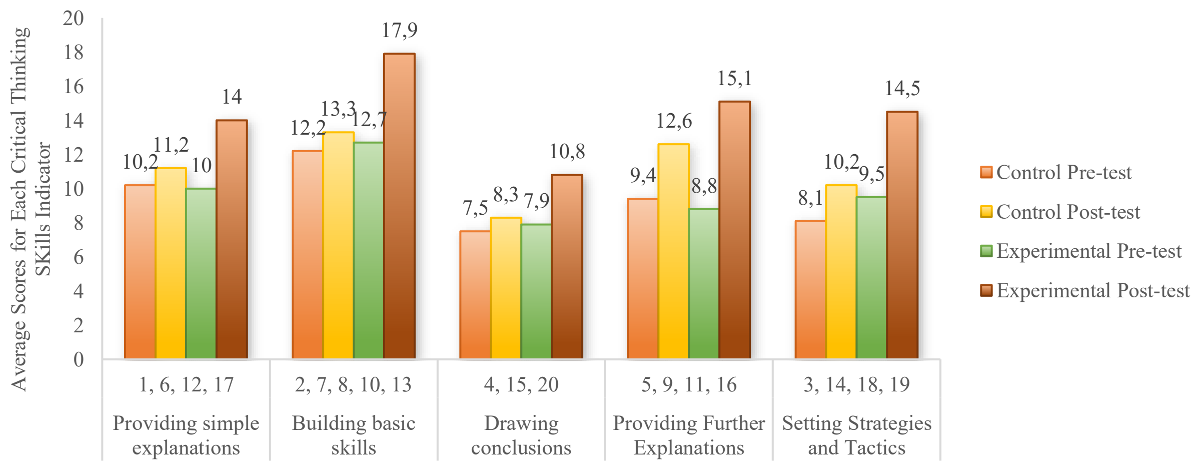

Figure 1. Average Score for Each Critical Thinking Skills Indicator

Based on the results of the critical thinking skills data analysis, an examination was conducted on five indicators by comparing the mean pre-test and post-test scores of the control and experimental classes. The distribution of item numbers for each indicator was as follows: Indicator 1 included items 1, 6, 12, and 17; Indicator 2 consisted of items 2, 7, 8, 10, and 13; Indicator 3 included items 4, 15, and 20; Indicator 4 included items 5, 9, 11, and 16; and Indicator 5 included items 3, 14, 18, and 19.

All indicators showed increases in scores in both groups, with the experimental class consistently achieving higher scores. For Indicator 1 (Providing a simple explanation), the control class mean increased from 10.2 to 11.2, whereas the experimental class showed a greater improvement, rising from 10 to 14. For Indicator 2 (Building basic skills), the control class score increased from 12.2 to 13.3, while the experimental class improved from 12.7 to 17.9. For Indicator 3 (Drawing conclusions), the control class increased from 7.5 to 8.3, and the experimental class improved from 7.9 to 10.8. Furthermore, for Indicator 4 (Providing further explanation), the control class mean increased from 9.4 to 12.6, whereas the experimental class showed a greater improvement, rising from 8.8 to 15.1. Lastly, for Indicator 5 (Setting strategies and tactics), the control class increased from 8.1 to 10.2, whereas the experimental class improved from 9.5 to 14.5.

A normality test was conducted to examine the distributions of pre-test and post-test data on students' critical thinking skills and Biology learning outcomes in both the experimental and control classes. In this study, normality was assessed using the Shapiro–Wilk test in SPSS version 26.

Table 2. Normality Test Results for Critical Thinking Skills

Class		Statistic	df	Sig.
Results Minimum Mastery Criterion (SR)	Pre-test Control	0.960	36	0.219
	Post-tets Control	0.973	36	0.520
	Pre-test Experimental	0.973	36	0.520
	Post-test Experimental	0.965	36	0.297

Based on the normality test results for critical thinking skills, the significance value (Sig.) for the control class was 0.219 (> 0.05) for the pre-test and 0.520 (> 0.05) for the post-test. Meanwhile, in the experimental class, the significance values were 0.520 (> 0.05) for the pre-test and 0.297 (> 0.05) for the post-test. Since all Sig. values in both groups were greater than 0.05, it can be concluded that the pre-test and post-test data on critical thinking skills in both the control and experimental classes were normally distributed. The results of the normality test are presented in the following table.

Data homogeneity in this study was tested using Levene's test with the assistance of SPSS version 26. For the critical thinking skills variable, the homogeneity test results showed a Levene's statistic of 2.478 and a p-value of 0.120 (> 0.05). This indicates that the variance of students' critical thinking skills data between the experimental and control classes was homogeneous.

Table 3. Results of the Homogeneity Test for the Critical Thinking Skills Test

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Scores	Based on Mean	2.478	1	70	0.120

The hypothesis testing in this study aimed to determine whether implementing the Problem-Based Learning (PBL) instructional model had a significant effect on students' critical thinking skills and learning outcomes, after controlling for pre-test scores. The analysis was conducted using Analysis of Covariance (ANCOVA), which examines differences in mean scores between two groups (the experimental and control classes) while accounting for the influence of a covariate (pre-test scores). The analysis was performed using IBM SPSS Statistics version 26, and the results are presented in Table 4 below.

Table 4. Results of the ANCOVA Test for Critical Thinking Skills

Tests of Between-Subjects Effects					
Dependent Variable:			Postest SR		
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Group	4245.094	1	4245.094	20.983	0.000

Based on the analysis presented in Table 7, the F value was 20.983 with a significance level (Sig.) of 0.000 (< 0.05) for the critical thinking skills variable. This indicates that implementing the Problem-Based Learning (PBL) model had a significant effect on students' critical thinking skills, after controlling for pre-test scores. Therefore, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_a) was accepted, indicating that the PBL model significantly improved the critical thinking skills of Grade 11 students at SMA Negeri 4 Praya.

This study demonstrates that implementing the Problem-Based Learning (PBL) model significantly improved Grade 11 students' critical thinking skills at SMA Negeri 4 Praya. Based on the data analysis, a notable increase was observed in the experimental class's pre-test to post-test scores. The mean pre-test score of 48.89 increased to 72.81 after implementing the learning model, with scores ranging from 45 to 96. In contrast, the control class, which was taught using conventional methods, showed a relatively smaller improvement, increasing from 47.14 to 57.39, with scores ranging from 25 to 82.

The ANCOVA results showed an F value of 20.983 with a significance level of 0.000 (< 0.05), indicating a significant effect of the learning model on improvements in critical thinking skills after controlling for students' initial abilities. These findings strengthen the empirical evidence that Problem-Based Learning not only enhances conceptual understanding but also trains students in higher-order thinking processes, which are central to critical thinking skills.

In the control class, the learning process remained oriented toward a conventional, teacher-centered approach. Under this approach, classroom activities tended to focus on content delivery and direct examples provided by the teacher, while students primarily served as recipients of information. Although this pattern can be effective for conveying factual information, it does not fully promote higher-order thinking processes. This may explain why the improvement in critical thinking skills scores in the control class was lower than in the experimental class.

Consistent with these findings, previous research has shown that implementing Problem-Based Learning (PBL) can improve students' critical thinking skills through inquiry activities and group discussions [8]. Similar studies have also reported that problem-based learning is effective in fostering students' analytical abilities by engaging them in collaborative, exploratory learning [9].

Furthermore, implementing the Problem-Based Learning (PBL) model in Biology instruction can help students enhance their analytical, evaluative, and interpretive skills by confronting them with contextual problems that require higher-order thinking. Similar perspectives also suggest that PBL encourages students to develop critical and creative thinking skills through stages of problem identification, data collection, and reflection on learning outcomes [10].

The implementation of the Problem-Based Learning (PBL) model in this study significantly improved students' critical thinking skills in Biology. This can be attributed to the complex nature of Biology content, which is closely related to real-life phenomena and therefore requires an instructional approach that goes beyond mere conceptual mastery. Biology learning in the current era must equip students with critical thinking skills through inquiry-based processes so that they can face global challenges [11]. Through PBL, students are confronted with authentic problems that prompt them to independently analyse and evaluate to identify the most appropriate solutions.

Furthermore, the improvement in critical thinking skills occurs because each stage of the PBL syntax systematically trains specific critical thinking indicators. The investigation phase in PBL requires students to integrate prior knowledge with new information through in-depth inferential processes [12]. This is supported by recent findings indicating that the use of contextual problems in Biology learning significantly enhances students' evaluative abilities compared to conventional instructional models [13]. These results confirm that PBL is effective in transforming students into active and solution-oriented critical thinkers.

The implementation of Problem-Based Learning (PBL) has also been reported to significantly improve the indicators of analysis and evaluation, as students become more active in independently seeking, processing, and interpreting information [14]. Meanwhile, other research has found that applying this model at the elementary school level can foster curiosity, argumentative skills, and group collaboration through challenging, context-based learning activities [15].

Research has also shown that senior high school students who learn Biology through the Problem-Based Learning (PBL) approach experience a significant improvement in critical thinking skills compared to those in conventional classes, particularly in their ability to identify problems and draw conclusions from observations [16]. These findings indicate that problem-based learning not only enhances knowledge acquisition but also trains students to think logically and reflectively.

Overall, these findings are consistent with theories suggesting that problem-based learning is an effective approach for developing students' critical, analytical, and logical thinking abilities [17]. Through Problem-Based Learning (PBL), students are trained to evaluate, compare, and draw conclusions based on evidence gathered during the problem-solving process. Therefore, the results of this study not only confirm previous findings but also strengthen the empirical evidence that the PBL model can be effectively applied in Biology learning at the senior high school level and can yield meaningful improvements in students' critical thinking skills.

Learning Outcomes

Based on the pre-test results administered before the learning process began, an overall description of students' initial abilities in both classes was obtained. In the control class, the mean pre-test score was 36.25, with a range of 15-68 across 36 students. These results indicate that students' initial understanding of the subject matter varied, with some demonstrating strong prior knowledge while others still required reinforcement through subsequent learning activities. Meanwhile, in the experimental class that received treatment using the Problem-Based Learning (PBL) model, the mean pre-test score was 35.83, with a range of 20-55. Similar to the control class, these findings show that students' initial abilities in the experimental class were also diverse, though more evenly distributed.

Based on the processed post-test data, the control class obtained a mean post-test score of 66.81, with a range of 40-95 across 36 students. This score indicates improvement over the pre-test results, suggesting that the learning process positively affected students' understanding. In the experimental class, which received instruction through the Problem-Based Learning (PBL) model, the mean post-test score was 79.28, with a range of 65-100. These results show a more substantial improvement compared to the control class. Most students demonstrated learning outcomes categorized as good to very good.

Table 5. Comparison of Pre-test and Post-test Learning Outcomes

Variable	Class	N	Mean Pre-test	SD Pre-test	Mean Post-test	SD Post-test
Learning Outcomes	Experimental	36	35.8	9.3	79.2	12
	Control	36	36.2	10.3	66.8	12

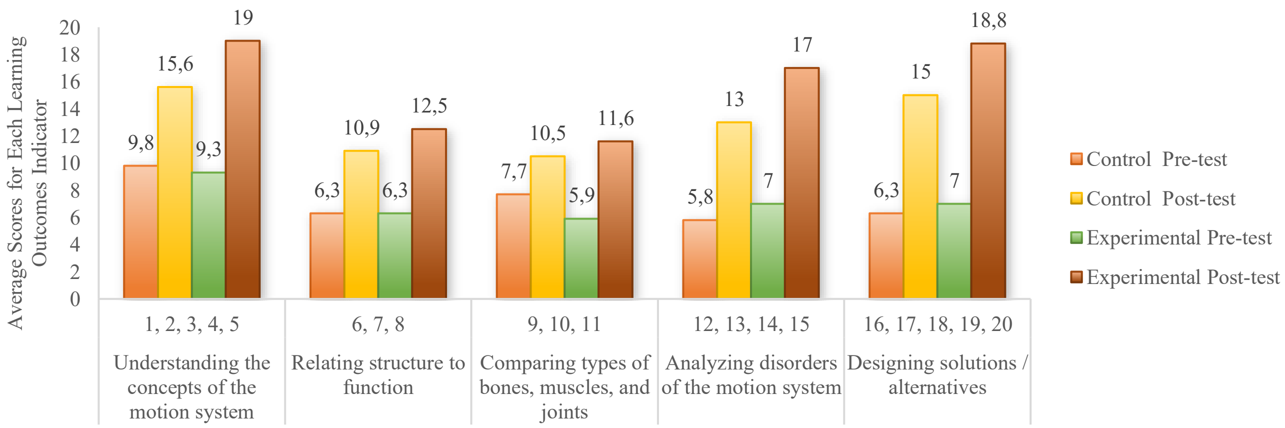

Figure 2. Average Scores for Each Learning Outcomes Indicator

An analysis was conducted on five indicators of students' abilities. The distribution of item numbers for each indicator was as follows: Indicator 1 (Understanding the concept of the musculoskeletal system) consisted of items 1, 2, 3, 4, and 5; Indicator 2 (Relating structure to function) included items 6, 7, and 8; Indicator 3 (Comparing types of bones, muscles, and joints) consisted of items 9, 10, and 11; Indicator 4 (Analyzing disorders of the musculoskeletal system) included items 12, 13, 14, and 15; whereas Indicator 5 (Designing solutions or alternatives) included items 16, 17, 18, 19, and 20.

The analysis results indicated an increase in scores across all indicators in both the control and experimental classes, with the experimental class consistently achieving higher outcomes. For Indicator 1, the control class mean increased from 9.8 to 15.6, while the experimental class improved from 9.3 to 19. For Indicator 2, the control class rose from 6.3 to 10.9, and the experimental class increased from 6.3 to 12.5. For Indicator 3, the control class improved from 7.7 to 10.5, whereas the experimental class increased from 5.9 to 11.6. Furthermore, for Indicator 4, the control class increased from 5.8 to 13, while the experimental class rose from 7.0 to 17. Lastly, for Indicator 5, the control class improved from 6.3 to 15, and the experimental class increased from 7 to 18.8.

This test was conducted to ensure that the pre-test and post-test data from both the experimental and control classes were normally distributed for the learning outcomes variable. Thus, the data met the basic assumptions required for conducting parametric statistical analysis. The results of the normality test for the learning outcomes variable are presented in Table 6 below.

Table 6. Normality Test Results for Learning Outcomes

Class		Statistic	df	Sig.
Result Minimum Mastery Criterion (SR)	Pre-test Control	0.955	36	0.145
	Post-tets Control	0.965	36	0.312
	Pre-test Experimental	0.972	36	0.493
	Post-test Experimental	0.963	36	0.272

Based on the analysis results presented in Table 4.9, the significance (Sig.) value of the pre-test for the control class was 0.145 (> 0.05), while the post-test significance value for the control class was 0.312 (> 0.05). In the experimental class, the significance value for the pre-test was 0.493 (> 0.05), and for the post-test, 0.272 (> 0.05). Therefore, all learning outcomes data in both research groups, namely the control and experimental classes, were normally distributed, as all significance (Sig.) values met the criterion of Sig. > 0.05.

Table 7. Hasil Uji Homogenitas Tes Hasil Belajar

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Scores	Based on Mean	0.047	1	70	0.830

In this study, the homogeneity of variance for the learning outcomes variable was tested using Levene's test in SPSS version 26. The results showed that Levene's statistic was 0.047, with a p-value of 0.830 (> 0.05). This indicates that the variance in students' learning outcomes between the experimental and control classes was homogeneous.

Because the significance value exceeded 0.05, it can be concluded that the learning outcomes data met the assumption of homogeneity of variance. Therefore, the learning outcomes data were suitable for further inferential statistical analysis. The results of the homogeneity test for learning outcomes are presented in the following table.

Table 8. Results of the ANCOVA Test for Learning Outcomes

Tests of Between-Subjects Effects					
Dependent Variable:			Postest SR		
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Group	2804.659	1	2804.659	18.954	0.000

To examine the effectiveness of the Problem-Based Learning (PBL) model on students' learning outcomes, a statistical analysis was conducted, controlling for students' initial abilities. Differences in post-test learning outcomes between the experimental and control classes were analyzed using Analysis of Covariance (ANCOVA), allowing the comparison of adjusted mean scores. All statistical procedures were performed using IBM SPSS Statistics version 26.

The research data indicated a clear improvement in the biology learning outcomes of Grade 11 students after the implementation of the Problem-Based Learning (PBL) model. Prior to the treatment, the experimental class had a mean pre-test score of 36.25, while the control class had a mean score of 35.83. Both classes had relatively comparable initial abilities, suggesting that the subsequent differences in outcomes can be attributed to the different instructional models applied.

After implementing Problem-Based Learning, the experimental class showed significant improvement, with a mean post-test score of 79.28 and a range of 65-100. Meanwhile, in the control class, which used conventional methods, the mean score increased only to 66.81, with a score range of 40 to 95. This improvement indicates that problem-based learning is more effective in optimizing students' learning potential than lecture- and assignment-oriented instruction.

Theoretically, these findings indicate that Problem-Based Learning (PBL) can promote students' active engagement and create meaningful learning experiences. In the process, students are encouraged to understand Biology content on the musculoskeletal system through problem-based situations closely related to real-life contexts. This contextual approach can foster curiosity, motivate students to explore concepts independently, and strengthen conceptual understanding. In line with the view that PBL is oriented toward creating learning experiences that develop independence and responsibility in learning, this model also encourages students to apply the knowledge they acquire [18].

The improvement in learning achievement was also supported by collaborative activities throughout the learning process. Through group discussions, students practised expressing their opinions, responding to their peers' ideas, and jointly formulating conclusions. This phenomenon is consistent with research findings indicating that positive reciprocal interactions in collaborative learning enable students to learn from one another, complement their understanding, and strengthen concepts through active social interaction [19]. Therefore, the improvement in learning outcomes in the experimental class was not solely due to a change in instructional method, but also to the social and cognitive dynamics that developed during the learning process.

The Analysis of Covariance (ANCOVA) results showed an F value of 19.421 with a significance level of 0.000 (< 0.05), indicating a significant effect of implementing the Problem-Based Learning model on students' learning outcomes after controlling for their initial abilities. These findings strengthen the empirical evidence that the differences in learning outcomes between the experimental and control classes were not due to chance but were a direct result of the implementation of different instructional models.

These findings are consistent with previous studies showing that Problem-Based Learning (PBL) not only improves critical thinking skills but also significantly impacts students' learning outcomes, as students gain a deeper understanding through direct learning experiences [14]. This is further supported by other research indicating that the implementation of PBL can enhance both learning outcomes and student motivation, as student-centered learning encourages learners to become more active and responsible for their own learning processes [20]. In addition, other findings suggest that PBL improves Biology learning outcomes by encouraging students to understand concepts through guided observation and focused discussions, making learning more meaningful and strengthening retention of the material studied [16].

These findings further reinforce the view that learning outcomes are influenced not only by students' initial abilities, but also by the quality of the learning process they experience [21]. In problem-based learning, the teacher serves as a facilitator, guiding students' thinking rather than acting as the sole source of information. This condition encourages students to engage more deeply in critical and analytical thinking when understanding Biology concepts, resulting in deeper comprehension and supporting long-term retention of the material.

Similar tendencies have also been reported in studies indicating that implementing Problem-Based Learning (PBL) can improve senior high school students' Biology learning outcomes through active engagement and learner autonomy [22]. Other research further supports these findings, showing that the application of differentiated Problem-Based Learning is effective in enhancing Biology learning outcomes because the learning process is tailored to students' individual needs and abilities [23].

The effectiveness of the Problem-Based Learning (PBL) model in improving students' cognitive learning outcomes stems from transforming students' roles into active agents of learning. Learning patterns that integrate intellectual challenges with independent problem-solving have been shown to strengthen memory retention and promote deeper conceptual understanding [24]. Through this approach, mastery of Biology content is no longer superficial but becomes more meaningful, as students are directly engaged in connecting theoretical knowledge with practical applications in real-world contexts [25]. The findings of this study confirm that collaborative concept internalization throughout the stages of PBL consistently results in superior academic achievement compared to traditional instructional approaches [26].

Based on observations and reflections during the implementation of Problem-Based Learning (PBL), students' learning patterns shifted from initially passive to more enthusiastic and participatory. Students demonstrated greater interest in learning because each session began with a problem situation closely related to their everyday lives. These problems required students to seek information, reason scientifically, and present conclusions in an argumentative manner. This finding is consistent with meaningful learning theory, which emphasizes that learning becomes more effective when students connect new information with their existing cognitive structures [27]. In PBL, this connection is developed through inquiry and discussion activities that help students gradually construct conceptual understanding.

The results of this study confirm that Problem-Based Learning is effective in improving students' Biology learning outcomes at SMA Negeri 4 Praya. This improvement is evident not only in numerical scores but also in the quality of students' engagement and the meaningful learning experiences developed throughout the instructional process.

Conclusion

Based on the results of data analysis and the discussion conducted, it can be concluded that the implementation of the Problem-Based Learning (PBL) model has a significant effect on improving students' critical thinking skills in Biology, as indicated by the significance value ($p < 0.05$), leading to the acceptance of the alternative hypothesis (H_a) and the rejection of the null hypothesis (H_0) for Grade XI students at SMA Negeri 4 Praya. In addition, the implementation of the Problem-Based Learning (PBL) model also has a significant effect on enhancing students' Biology learning outcomes, with a significance value of ($p < 0.05$), resulting in the acceptance of the alternative hypothesis (H_a) and the rejection of the null hypothesis (H_0) for Grade XI students at SMA Negeri 4 Praya. The application of PBL not only improves students' academic performance, as shown by higher post-test scores in Biology, but also enhances higher-order cognitive skills, including analysis, evaluation, and interpretation. Furthermore, PBL positively impacts students' engagement, motivation, and ability to apply knowledge in meaningful, real-life contexts. These findings confirm that PBL provides an effective learning framework that simultaneously develops critical thinking skills and improves learning outcomes in senior high school Biology education.

Author's Contribution

R. Yanti contributed to the development of the research concept and design, data collection, data analysis, and manuscript writing. Jamaluddin and I. W. Merta supervised the overall research process, provided theoretical and academic input, and reviewed and refined the manuscript until the final version.

Acknowledgements

The authors would like to express their sincere gratitude to Allah SWT for His grace and blessings, which enabled this research to be completed successfully. The authors also extend their deepest appreciation to their beloved parents and family for their prayers, moral and financial support, and continuous motivation throughout the preparation and implementation of this study. In addition, the authors would like to thank the Principal of SMA Negeri 4 Praya, the Biology teacher(s), and all Grade XI students who assisted and participated in the research activities. Appreciation is also extended to all parties who provided direct or indirect support in the smooth implementation of this research.

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