Indonesian Technology and Education Journal
E-ISSN: 2985-8216; P-ISSN: 2985-8208
https://journal.diginus.id/index.php/ITEJ

The Effectiveness of the Problem-Based Learning Model in Enhancing Critical Thinking Skills: A Gender-Differentiated Analysis in Biology Learning

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ARTICLE INFO

Keywords:

Biology learning;
Critical thinking skills;
Gender differences;
Problem-based learning;
Quasi-experimental study.

Article History

Received: April 26, 2026
Revised: May 08, 2026
Accepted : May 14, 2026

ABSTRACT

This study examined the effectiveness of the Problem-Based Learning (PBL) model in improving students' critical thinking skills in Biology and investigated whether gender influenced critical thinking performance on the Human Circulatory System topic. A quasi-experimental pretest–posttest control group design was employed. The participants were 72 eleventh-grade students from a Madrasah Aliyah Negeri in Cianjur, West Java, Indonesia. They were divided into an experimental group taught through PBL (n = 36) and a control group receiving conventional instruction (n = 36). Data were collected using a ten-item essay test covering five indicators of critical thinking and analyzed using Two-Way Analysis of Variance. The results showed that the learning model significantly affected students' critical thinking skills ($F = 33.845$, $p < 0.001$), with the PBL group achieving higher scores than the conventional group. Gender also had a significant effect ($F = 11.049$, $p = 0.001$), as female students obtained higher mean scores than male students. However, the interaction between learning model and gender was not significant ($F = 1.143$, $p = 0.288$), indicating that the effectiveness of PBL was relatively consistent across gender groups. The study was limited to one school, one Biology topic, and existing classroom groupings, which restricted random assignment and may have introduced selection bias. Nevertheless, the findings support PBL as an effective instructional approach for strengthening critical thinking in Biology education. This study extends previous research by jointly examining instructional model and gender, while showing that gender differences in performance do not significantly moderate the effectiveness of PBL.

To cite this article : Nurhayati, N., Agustina, T. W., Julita, U. (2026). The Effectiveness of the Problem-Based Learning Model in Enhancing Critical Thinking Skills: A Gender-Differentiated Analysis in Biology Learning. Indonesian Technology and Education Journal, 4(1), 223 - 237. Doi. 10.61255/itej.v4i1. 1239

INTRODUCTION

The implementation of the Problem-Based Learning (PBL) model requires teachers to be creative in all aspects of the instructional process to accommodate students' learning needs and provide meaningful learning experiences. This includes preparing and developing teaching materials and student worksheets, which should be distributed prior to classroom instruction to encourage students to engage in independent learning before face-to-face interaction with the teacher. This is because the stages of the PBL model facilitate students' ability to analyze problems, develop critical thinking skills, and generate innovative alternative solutions based on information obtained from various sources (Taufik et al., 2022). In this learning approach, students are encouraged to explore, analyze, and evaluate information in order to identify solutions to contextual problems that are relevant to the subject matter. The primary objective is

to enhance students' critical thinking, collaboration, and communication skills while enabling them to construct knowledge through practical problem-solving activities. As a result, the learning process becomes more meaningful, student-centered, and interdisciplinary (Safirah et al., 2024), (Sinurat et al., 2025). The demand for critical thinking skills has significantly influenced human life, shaping various aspects of civilization and cultural development. Many problems encountered in everyday life require critical analysis and should be addressed through the application of scientific methods (Aminah et al., 2025). By developing critical thinking abilities, students can strengthen their readiness to manage and resolve learning-related challenges more effectively.

Previous studies have indicated that many students still lack adequate critical thinking skills, particularly in solving problems and responding to questions related to learning materials. These findings suggest that the overall level of critical thinking skills in Biology education remains relatively low (Syamsi & Fitrihidajati, 2021). Most students are accustomed to learning activities that emphasize memorizing concepts, principles, and procedures without simultaneously developing critical thinking skills to address the problems they encounter in real-life situations (Paramitha et al., 2024). This condition may be attributed to several factors, including limited a lack of learning experiences that encourage critical thinking and inadequate support from teachers and the school environment, These circumstances may lead to the underdevelopment of students' critical thinking abilities. Furthermore, the persistence of teaching practices that focus heavily on the retention of theoretical knowledge, rather than promoting the active development and application of critical thinking skills, may also contribute to this issue (Ika Putra Viratama et al., 2025). Therefore, it is essential for educators to establish learning environments that actively support and strengthen students' critical thinking development.

Students' critical thinking skills can be improved through the selection of appropriate instructional models. The choice of a learning model is essential to ensure that learning objectives are achieved optimally. An instructional model is considered effective when students actively participate in the learning process, the learning atmosphere is engaging and enjoyable, teachers employ innovative teaching strategies, and the focus remains on achieving the intended learning outcomes. Furthermore, learning should be meaningful, allowing students to be directly involved in the learning process rather than merely acting as passive recipients of information from the teacher. One instructional model that is closely aligned with students' everyday experiences and real-life situations is Problem-Based Learning (PBL) (Sari & Airlanda, 2022). The Problem-Based Learning (PBL) model directs and engages students in addressing specific problems, encouraging them to analyze and investigate the issues in depth. Students examine problems using various sources of information, including textbooks, scientific journals, news articles, internet resources, and observational findings. They then participate in group discussions, exchange arguments and perspectives, and present the results of their discussions to their peers. Following the completion of the learning session, students' understanding is evaluated by the teacher, who also reviews the essential concepts discussed. The Problem-Based Learning model promotes teamwork in problem-solving activities, enabling students to strengthen their critical thinking abilities through active collaboration (Nurbayti et al., n.d.).

In line with previous research findings Previous studies have demonstrated that the implementation of the Problem-Based Learning (PBL) model in Biology education can improve students' critical thinking skills. Nevertheless, studies exploring the influence of gender on the development of critical thinking skills remain scarce. A previous study examining gender differences in academic performance found that gender plays a significant role in shaping students' learning outcomes, which may be attributed to variations in the structure and functioning of the male and female brain. These differences are believed to contribute to

variations in learning processes and academic performance between male and female students (Yani et al., 2023). The implementation of the Problem-Based Learning (PBL) model revealed variations in problem-solving performance between male and female students, suggesting that gender may contribute to differences in students' problem-solving capabilities (Asri & Ratnaya, 2024). Problem-solving strategies may be influenced by gender differences, which in turn can affect individuals' critical thinking processes. Previous research has shown that gender significantly influences the average level of critical thinking skills, indicating that an individual's problem-solving strategies and abilities may be affected by gender differences (Ananda & Fauziah, 2022).

The Human Circulatory System was selected as the context of this study because it represents one of the Biology topics that requires students to integrate multiple concepts and apply scientific reasoning to authentic health-related problems. Understanding the circulatory system involves analyzing the relationships among the heart, blood vessels, blood components, oxygen transport, and various cardiovascular disorders. These interconnected concepts provide opportunities for students to engage in problem identification, evidence evaluation, hypothesis formulation, and decision-making processes, which are central components of critical thinking. Furthermore, the topic offers numerous real-life contexts, such as hypertension, coronary heart disease, anemia, and lifestyle-related cardiovascular risks, making it highly compatible with the Problem-Based Learning (PBL) approach. Previous studies have also suggested that gender-related differences in critical thinking and problem-solving may vary across Biology topics, including the Human Circulatory System, indicating that this topic provides a relevant context for examining how instructional approaches and gender jointly influence students' critical thinking development (Windari & Yanti, 2021).

Beyond its conceptual complexity, the Human Circulatory System provides a distinctive context for investigating the relationship between instructional approaches and gender because it combines abstract biological mechanisms with real-world health issues that students frequently encounter in daily life. Unlike topics that rely primarily on memorization of structures or classifications, the circulatory system requires students to interpret symptoms, analyze causal relationships, evaluate evidence, and propose solutions to health-related problems. These cognitive demands closely align with the core processes emphasized in Problem-Based Learning and critical thinking development. Furthermore, previous studies have suggested that gender-related differences in learning outcomes and problem-solving performance may vary depending on the nature of the scientific content being studied. Therefore, examining the effectiveness of Problem-Based Learning within the context of the Human Circulatory System offers an opportunity not only to evaluate instructional effectiveness but also to explore whether gender-related differences in critical thinking emerge differently in a topic characterized by high conceptual integration and authentic problem contexts.

Drawing on the findings of earlier studies and the identified research gap, this study aims to examine the effectiveness of the Problem-Based Learning (PBL) model in improving students' critical thinking skills and to investigate whether gender differences contribute to variations in critical thinking performance in Biology learning, particularly on the topic of the Human Circulatory System.

METHOD

A quasi-experimental research design with a pretest–posttest control group format was employed in this study. The participants were drawn from two existing eleventh-grade classes and were assigned to either an experimental or a control group based on classroom groupings previously established by the teacher. This grouping procedure was chosen because the classes shared relatively similar student characteristics. In addition to assessing the impact of the

Problem-Based Learning (PBL) model on critical thinking skills, the study considered gender as an independent variable, categorizing students into male and female groups. The study was conducted at a Madrasah Aliyah Negeri (MAN) in Cianjur, West Java, Indonesia, during the first semester of the 2025/2026 academic year. The experimental group consisted of 36 students from Class XI-C (17 males and 19 females) who experienced learning through the PBL model, whereas the control group consisted of 36 students from Class XI-B (16 males and 20 females) who received conventional classroom instruction.

Because the study was conducted in an authentic school setting, random assignment of students to experimental and control groups was not feasible. The use of existing classroom groupings may introduce potential threats to internal validity, particularly selection bias. To minimize this limitation, the researchers selected classes with relatively similar academic characteristics based on diagnostic test results provided by the Biology teacher and administered a pre-test before the intervention to establish baseline equivalence between groups. To measure students' critical thinking skills, the researchers employed a written essay test consisting of ten items focused on the Human Circulatory System topic. The assessment framework was developed based on five critical thinking indicators identified by [15], including reasoning, argument analysis, hypothesis testing, evaluation of probability and uncertainty, and problem-solving accompanied by decision-making processes.

Prior to its implementation, the essay test instrument was validated using Anates software. The validation process included item validity analysis, reliability testing, item discrimination analysis, and item difficulty analysis. The results indicated that all ten essay items met the established validity criteria and demonstrated satisfactory reliability. Furthermore, the discrimination and difficulty indices showed that the items were appropriate for distinguishing different levels of students' critical thinking skills and represented a balanced range of item difficulty. Therefore, all items were retained and administered in both the pre-test and post-test.

The study was organized into three main phases. The first phase focused on the preparation of instructional materials, such as teaching modules, student worksheets (LKPD), and presentation media. In the second phase, the learning intervention was implemented. Before the intervention began, students were required to complete a pre-test comprising ten essay items to determine their initial critical thinking abilities. Learning activities were conducted over three meetings. The experimental class received instruction through the Problem-Based Learning (PBL) approach, supported by worksheets and PowerPoint presentations on the Human Circulatory System topic, whereas the control class was taught using conventional instructional methods.

In the third stage, following the completion of the instructional activities, students were administered a post-test consisting of 10 essay questions aligned with the critical thinking skill indicators. Data were collected through classroom observation, documentation, and critical thinking skill tests. The test was administered within a duration of 60 minutes. Students' responses were scored based on a predetermined scoring rubric. Test performance was evaluated using a score range of 0–5 for each item, which was subsequently converted into a scale ranging from 0 to 100. The conversion of raw scores into final scores was calculated using Formula 1 (Suharyani et al., 2023).

$$Nilai = \frac{skor\ yang\ diperoleh}{total\ skor}\ x\ 100 \quad [1]$$

The resulting scores were then interpreted to determine students' levels of critical thinking skills according to the score interpretation criteria presented in Table 1:

Table 1. Critical Thinking Skills Interpretation Criteria

Category	Score Interval
Very High	81.25 < x ≤ 100
High	71.5 < x ≤ 81.25
Moderate	62.5 < x ≤ 71.5
Low	43.75 < x ≤ 62.5
Very Low	0 < x ≤ 43.75

The assessment of students' critical thinking skills was based on the results of the pre-test and post-test administered to participants in both study groups. Statistical analysis was carried out using a Two-Way ANOVA procedure in IBM SPSS Statistics version 26. Prior to hypothesis testing, assumption testing was undertaken through normality and variance homogeneity analyses to confirm the suitability of the data for parametric testing. Permission to conduct the study was obtained from the school administration prior to data collection. Students participated voluntarily, and consent was obtained from parents or guardians through the procedures established by the school. All data were collected anonymously and used solely for research purposes. Ethical approval from a university ethics committee or Institutional Review Board (IRB) was not required for this study because the research involved routine educational activities conducted within the normal school curriculum and did not include medical procedures, psychological interventions, or the collection of sensitive personal data. The study was conducted in accordance with the ethical principles for educational research involving minors. Permission was obtained from the school administration, parental consent was secured through the school's established procedures, student participation was voluntary, and all data were collected and reported anonymously.

RESULTS AND DISCUSSION

The descriptive statistical data on students' critical thinking skills, including the mean, median, and standard deviation, are presented in Table 2.

Table 2. Results of Descriptive Statistical Analysis

Dependent Variable: Critical Thinking Skills

Learning Model	Gender	Mean	Std. Deviation	N
PBL	Male	77.9412	4.69668	17
	Female	81.0526	5.91114	19
	Total	79.5833	5.52591	36
Conventional	Male	68.4375	3.96600	16
	Female	74.5000	7.59155	20
	Total	71.8056	6.88194	36
Total	Male	73.3333	6.45497	33
	Female	77.6923	7.50843	39
	Total	75.6944	7.33051	72

The descriptive statistics presented in Table 2 compare the critical thinking skill scores of students in the experimental and control groups. The experimental group received instruction through the Problem-Based Learning (PBL) model, whereas the control group participated in conventional learning activities. The results indicate that female students in the PBL class obtained a higher average critical thinking score (81.05) than male students (77.94). A similar pattern was observed in the control class, where the mean score of female students (74.50) exceeded that of male students (68.44). These findings align with earlier studies reporting that female students generally exhibit stronger critical thinking abilities than male students (Utami & Yonanda, 2020) Previous research has also suggested that gender may significantly contribute to differences in students' academic performance. This relationship may be attributed to slight

differences in the structure and functioning of the male and female brain, which can affect learning processes and cognitive performance. As a result, female students tend to demonstrate higher academic achievement than their male counterparts. The results of the descriptive analysis of the critical thinking skills test, including the tests of normality and homogeneity, are presented in Tables 3 and 4.

Table 3. Results of the Normality Test

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Standardized Residual for Critical Thinking	.109	72	.303	.977	72	.220

The results displayed in Table 3 indicate that the standardized residuals met the assumption of normality. This conclusion was supported by significance values of 0.303 obtained from the Kolmogorov–Smirnov test and 0.220 from the Shapiro–Wilk test, both of which were greater than 0.05. In addition, variance homogeneity was assessed through Levene's test, with the corresponding results summarized in Table 4.

Table 4. Results of the Homogeneity Test

		Levene Statistic	df1	df2	Sig.
Critical Thinking Category	Based on Mean	2.559	3	68	.062
	Based on Median	2.164	3	68	.100
	Based on Median and with adjusted df	2.164	3	62.955	.101
	Based on trimmed mean	2.490	3	68	.068

Based on Table 4, the results of Levene's Test of Equality of Error Variances show that the significance value (Sig.) based on the mean is 0.062. Since this value is greater than 0.05, it can be concluded that the variance of the critical thinking skill scores is homogeneous. The prerequisite test results indicate that the data on students' critical thinking skills are normally distributed and exhibit homogeneous variances. Therefore, the data met the assumptions required for further hypothesis testing using a Two-Way Analysis of Variance (Two-Way ANOVA) with the assistance of IBM SPSS Statistics version 26. A summary of the hypothesis testing results is presented in Table 5.

Table 5. Results of the Two-Way ANOVA

Dependent Variable: Critical Thinking Skills

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1502.452[a]	3	500.817	14.725	.000
Intercept	407057.090	1	407057.090	11967.991	.000
Learning Model	1151.146	1	1151.146	33.845	.000
Gender	375.796	1	375.796	11.049	.001
Learning Model * Gender	38.886	1	38.886	1.143	.0288
Error	2312.826	68	34.012		
Total	416350.000	72			
Corrected Total	3815.278	71			

The ANOVA results summarized in Table 5 revealed a p-value of 0.000 for the learning model factor. Because this value was lower than the established significance criterion of 0.05, the effect of the instructional model on critical thinking skills was considered statistically

significant. This finding suggests that students in the PBL class and those in the conventional class differed significantly in their critical thinking performance.

During the observation period, students in the experimental group who participated in the Problem-Based Learning (PBL) activities were actively engaged in the learning process. They responded positively to the instructional activities and completed the tasks assigned by the teacher. Furthermore, students collaborated with their peers in group discussions to solve the problems presented during the lessonsThe use of the Problem-Based Learning strategy created a more interactive learning environment by encouraging students to participate actively and remain engaged during classroom activities. This positive learning experience was reflected in the higher critical thinking scores achieved by students in the PBL group compared with those receiving traditional instruction. The findings obtained in this study indicate that (Saputri, 2020) The present study provides evidence that students' critical thinking skills can be enhanced through the implementation of the Problem-Based Learning model.

The effectiveness of this approach is closely related to its emphasis on authentic problem situations that encourage learners to think analytically and develop appropriate solutions. Rather than functioning solely as information providers, teachers guide students throughout the investigation process and facilitate learning activities that are relevant to the problems being examined. This interpretation is in line with previous research highlighting the role of PBL in fostering critical thinking through cooperative learning and problem-centered instructional practices previous studies have reported that the Problem-Based Learning (PBL) model enables students to construct their own knowledge, develop higher-order thinking skills, and enhance their self-confidence (Pratiwi & Setyaningtyas, 2020). Observations conducted in the control group, which received conventional instruction, revealed that students tended to be passive throughout the learning process and primarily listened to the teacher's explanations. They were not sufficiently challenged to think critically, which often resulted in boredom, low motivation, lack of enthusiasm, and limited engagement during classroom activities. This was evident from the fact that several students did not pay attention while the teacher was explaining the lesson.

Conventional instruction generally relies on a lecture-based approach in which the teacher serves as the central source of knowledge. Students predominantly receive information rather than actively participating in the learning process, which may limit their engagement and involvement. Traditional teaching approaches generally place greater emphasis on remembering and reproducing information than on encouraging analytical thinking and independent problem-solving. As a consequence, the development of critical thinking and creativity may be constrained. The statistical analysis presented in the Tests of Between-Subjects Effects table showed that gender had a significant effect on students' critical thinking skills, as indicated by a p-value of 0.001. This result confirms the existence of meaningful differences in critical thinking performance between male and female students. The statistical analysis presented in the Tests of Between-Subjects Effects table showed that gender had a significant effect on students' critical thinking skills ($p = 0.001$). This finding indicates that male and female students differed significantly in their critical thinking performance. However, the interaction between learning model and gender was not statistically significant ($F = 1.143$, $p = 0.288$). Therefore, although both the learning model and gender independently influenced students' critical thinking skills, the effectiveness of the instructional approach did not differ significantly across gender groups. The non-significant interaction effect indicates that the impact of the instructional model on students' critical thinking skills did not depend on gender. Although female students achieved higher mean scores than male students, the magnitude of improvement associated with Problem-Based Learning was relatively similar across both gender groups. Therefore, gender did not function as a moderating variable in the relationship between learning model and critical thinking performance.

The statistical analysis confirmed the existence of meaningful differences in critical thinking outcomes between male and female students. Similar findings have been reported in earlier studies, which identified gender as an important factor contributing to the development of critical thinking abilities female students are often observed to be more actively engaged and motivated during classroom activities, which may support their learning performance (Azizah & Rosdiana, 2022). The statistical analysis confirmed the existence of meaningful differences in critical thinking outcomes between male and female students. Similar findings have been reported in earlier studies, which identified gender as an important factor contributing to the development of critical thinking abilities (Ananda & Fauziah, 2022). Female students are often observed to be more actively engaged and motivated during classroom activities, which may support their learning performance. Although significant main effects of learning model and gender were identified, the interaction effect between these variables was not statistically significant. The absence of a statistically significant interaction between learning model and gender suggests that the effectiveness of Problem-Based Learning (PBL) in improving critical thinking skills was relatively consistent across male and female students. Although female students achieved higher average scores than male students, both groups benefited from the implementation of PBL. These findings indicate that gender may contribute to differences in critical thinking performance, but it does not substantially alter the effectiveness of the instructional model. Therefore, PBL can be considered an effective approach for developing critical thinking skills regardless of students' gender.

From a theoretical perspective, the absence of a significant interaction effect contributes to the growing body of literature on Problem-Based Learning by suggesting that the cognitive mechanisms underlying critical thinking development may operate similarly across gender groups. While previous studies have frequently reported differences in critical thinking performance between male and female students, the present findings indicate that such differences do not necessarily alter the effectiveness of instructional approaches designed to promote higher-order thinking. This result strengthens the view that Problem-Based Learning primarily enhances critical thinking through learning processes such as problem analysis, collaborative inquiry, evidence evaluation, and reflective reasoning, which are accessible to students regardless of gender. Consequently, the findings extend previous research by emphasizing that gender may influence the level of critical thinking achievement, but it does not appear to substantially moderate the impact of Problem-Based Learning on critical thinking development.

The absence of a significant interaction effect indicates that the advantages of Problem-Based Learning were observed consistently across both male and female students. This finding suggests that although gender was associated with differences in critical thinking performance, it did not substantially modify the effectiveness of the instructional model. Therefore, the benefits of Problem-Based Learning appear to be broadly applicable across gender groups, supporting its use as an inclusive instructional approach for developing students' critical thinking skills in Biology education.

The analysis further showed that female students outperformed male students in critical thinking assessments, indicating that gender may influence the development of higher-order thinking abilities. In addition, the findings highlight the contribution of both instructional method and gender to students' learning outcomes. Figure 1 illustrates the interaction between these two factors in affecting critical thinking performance.

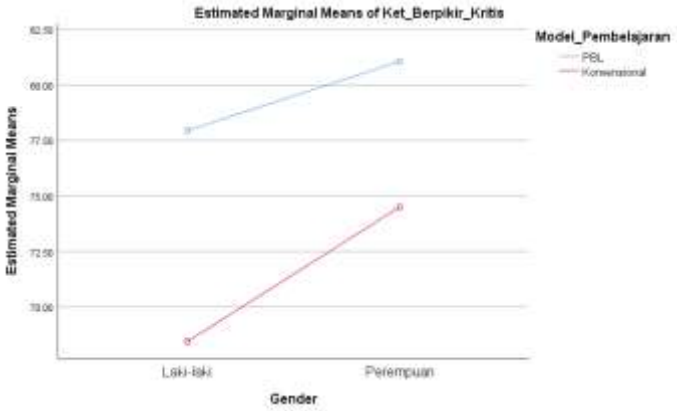

Figure 1. Mean Critical Thinking Scores by Learning Model and Gender

As presented in Figure 1, students' critical thinking outcomes were influenced by both the learning model and gender. The PBL approach resulted in better performance than conventional teaching methods for male and female students alike, as reflected in the higher average scores obtained by the experimental group. The figure also demonstrates that female students outperformed male students under both instructional conditions. Overall, the results highlight the contribution of instructional strategy and gender to students' critical thinking development.

The mean scores of students' critical thinking skills are presented in Figure 2.

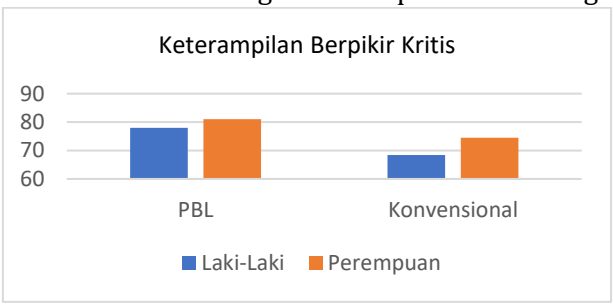

Figure 2. Mean Scores of Critical Thinking Skills by Gender

The data displayed in Figure 2 indicate that female students consistently outperformed male students in critical thinking assessments. This pattern was observed in both instructional settings, including the PBL class and the conventional learning class, although the difference was more pronounced in the PBL group. These differences in mean scores may be attributed to the ability of female students to provide better responses in analyzing information and drawing conclusions during the critical thinking skills assessment. Several factors may influence the development of students' critical thinking skills, including age, knowledge, experience, learning environment, and gender. Previous studies have suggested that certain cognitive abilities differ between male and female students. These findings are consistent with previous research, which reported that previous research has reported that female students demonstrate higher problem-solving skills than male students (Ngongo & Efendi, 2021). This difference may be attributed to variations in levels of seriousness, caution, and accuracy when addressing and resolving problems, which ultimately influence students' problem-solving performance.

Other studies have also found that female students exhibit higher critical thinking skills than male students. This may be explained by the tendency of female students to be more detailed and meticulous when responding to assessment tasks. In addition, differences in cognitive processing and thinking patterns between males and females may contribute to variations in critical thinking performance (Yanti et al., 2019). Female students tend to be more open to sharing their views and considering the perspectives of others during discussions,

which may enrich the critical thinking process. In contrast, male students may be more inclined to maintain their positions during discussions. Although these tendencies are not universal, differences in communication styles and the exchange of ideas may influence the development and application of critical thinking skills. Academic achievement is the result of a complex process influenced by multiple interrelated factors. Among the various factors affecting students' academic performance, gender has been identified as one of the variables that may contribute to differences in learning outcomes and academic achievement (Utami & Yonanda, 2020), (Ananda & Fauziah, 2022). Female students' higher levels of self-confidence in completing academic tasks may also contribute to their academic achievement. Academic achievement is essential for students as it supports the development of their cognitive, affective, and psychomotor domains. The results of the critical thinking skills assessment based on each indicator for the Problem-Based Learning (PBL) class and the conventional learning class are presented below.

Table 6. Critical Thinking Skill Indicators of Students in the PBL and Conventional Learning Classes

Critical Thinking Skill Indicators	PBL Class		Conventional Class	
	Percentage Score	Category	Percentage Score	Category
Reasoning	77.5	High	71	Moderate
Argument Analysis	84	High	73.5	High
Hypothesis Testing	69	High	60.4	Low
Analysis of Probability and Uncertainty	79	High	76	High
Problem Solving and Decision Making	84.5	High	78	High

The percentage scores of students' critical thinking skills obtained from the calculations were subsequently classified according to the critical thinking skill percentage categories presented in Table 7.

Table 7. Interpretation of Students' Critical Thinking Skill Test Scores in the PBL and Conventional Learning Classes

Interval	Category	PBL Class		Conventional Class	
		Number of Students	Percentage	Number of Students	Percentage
81.25 < x ≤ 100	Very High	9	25 %	4	11.11 %
71.5 < x ≤ 81.25	High	24	66.67 %	10	27.78 %
62.5 < x ≤ 71.5	Moderate	3	8.33 %	20	55.56 %
43.75 < x ≤ 62.5	Low	0	0 %	2	5.55 %
0 < x ≤ 43.75	Very Low	0	0 %	0	0 %
Total		36	100 %	36	100 %

The results of the analysis of students' critical thinking skills for each indicator in both the Problem-Based Learning (PBL) class and the conventional learning class are presented in Figure 3.

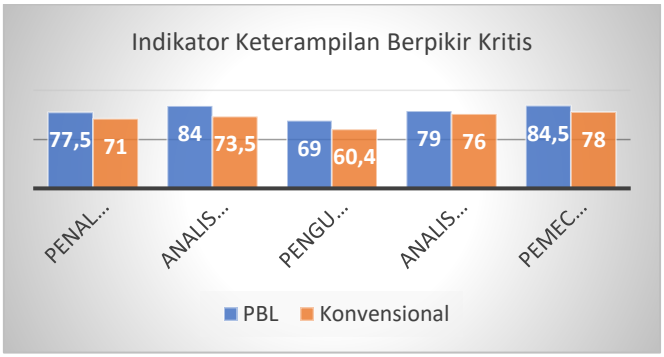

Figure 3. Critical Thinking Skill Indicators in the PBL and Conventional Learning Classes

Based on Figure 3, it can be observed that the mean scores for each critical thinking skill indicator were higher in the Problem-Based Learning (PBL) class than in the conventional learning class. These findings indicate that the Problem-Based Learning model is effective in enhancing students' critical thinking skills. Among the five critical thinking skill indicators assessed in the PBL class, the reasoning indicator was classified as high, with a mean score of 77.5. The argument analysis indicator was categorized as very high, with a mean score of 84. The hypothesis testing indicator was classified as moderate, with a mean score of 69. The analysis of probability and uncertainty indicator was categorized as high, with a mean score of 79. Finally, the problem-solving and decision-making indicator achieved the highest performance and was classified as very high, with a mean score of 84.5. In the conventional learning class, the reasoning indicator was categorized as moderate, with a mean score of 71. The argument analysis indicator was classified as high, with a mean score of 73.5. The hypothesis testing indicator was categorized as low, with a mean score of 60.4. The analysis of probability and uncertainty indicator was classified as high, with a mean score of 76. The problem-solving and decision-making indicator was also categorized as high, with a mean score of 78.

Among all indicators, the problem-solving and decision-making indicator achieved the highest mean score. This indicator encompasses several skills, including identifying the most appropriate option among multiple alternatives for addressing a problem, evaluating potential solutions, and making well-reasoned decisions. The findings suggest that students were able to apply critical thinking beyond merely identifying solutions; they were also capable of evaluating the quality of those solutions before making final decisions (Triwulandari & U.S, 2022). In Problem-Based Learning (PBL) activities, students do not merely learn from instructional materials; rather, they learn through the investigation of phenomena commonly encountered in everyday life. The role of the teacher is to provide appropriate stimuli that encourage students' curiosity and engagement, thereby fostering the development of their critical thinking skills (Rahman, 2018), (Ika Putra Viratama et al., 2025).

The ability to think critically involves evaluating information, interpreting evidence, and reaching conclusions through logical reasoning. Rather than relying solely on memorization, critical thinking requires individuals to understand underlying concepts, relate different ideas, and make informed decisions. This competency is increasingly important in both academic and real-world contexts, where individuals are expected to solve problems and make sound judgments (Arifah et al., 2021), (Seftiani et al., 2021) Earlier studies have demonstrated that Problem-Based Learning (PBL) promotes active participation by encouraging learners to seek relevant information and analyze issues independently. Such learning experiences contribute to the enhancement of both critical thinking and creative abilities. Consistent with these findings eported that PBL provides an effective framework for cultivating critical thinking during the learning process (Ayunda et al., 2023). Consequently, the choice of instructional strategy plays a crucial role in developing students' cognitive skills. The PBL approach is particularly beneficial because it engages learners in identifying problems, exploring alternatives, and formulating innovative solutions.

The development of critical thinking can be facilitated through the use of innovative learning approaches, particularly Problem-Based Learning (PBL). When educators effectively integrate such instructional strategies into classroom practice, students are provided with greater opportunities to engage in analytical and reflective thinking. The findings obtained from this study suggest that evidence from the present study suggests that students' critical thinking performance improves significantly when learning is conducted through the Problem-Based Learning (PBL) model, indicating a meaningful positive relationship between the instructional approach and critical thinking development (Patricia Angelina et al., 2023).

Based on the discussion above, like any instructional approach, the Problem-Based Learning model possesses both strengths and limitations. Some of the major advantages of the Problem-Based Learning model include the following:

1. Promoting active learning, as students are required to actively participate in the learning process and seek solutions to the problems presented.
2. Developing higher-order thinking skills, including critical thinking, analytical thinking, creativity, and problem-solving abilities.
3. Enhancing relevance to real-life situations, through the use of authentic and contextual problems in the learning process.
4. Encouraging collaboration, as students work together in groups, thereby improving their communication and teamwork skills.
5. Increasing learning motivation, by engaging students in meaningful and challenging learning activities.
6. Promoting deeper learning, as students are encouraged to explore information more extensively and integrate various concepts that they have previously learned (Pertiwi et al., 2023).

Despite its advantages, the Problem-Based Learning (PBL) model also has several limitations. First, not all subject matter is suitable for implementation through the PBL approach. Second, the model generally requires a longer period of time to complete learning activities and achieve the intended learning objectives. In addition, students who are not accustomed to analyzing and solving problems may experience difficulties when participating in PBL activities, as not all learners possess the same level of motivation or readiness to engage in problem-solving tasks. Consequently, teachers may encounter challenges in managing learning activities and assigning tasks effectively. These challenges may become more pronounced in classrooms with a large number of students, where monitoring participation and facilitating group interactions can be more demanding (Magdalena et al., 2024), (Safirah et al., 2024)

If teachers are able to manage their classrooms effectively, positive outcomes can be achieved for their students. High levels of student motivation are likely to contribute to improved learning outcomes and overall academic performance. To achieve an effective and efficient learning process, teachers are required to possess the skills necessary to design and implement instructional strategies that are aligned with students' interests, abilities, and developmental stages. This also includes the effective utilization of a variety of learning resources and instructional media to support meaningful learning experiences and enhance student engagement (Putra Aryana, 2020).

Several limitations of this study should be acknowledged. First, the research was conducted in only one Madrasah Aliyah Negeri, which may limit the generalizability of the findings to other educational contexts. Second, the study focused exclusively on the Human Circulatory System topic; therefore, the effectiveness of Problem-Based Learning and gender-related differences in critical thinking may vary across other Biology topics. Third, the use of existing classroom groupings in the quasi-experimental design prevented random assignment of participants, which may have introduced potential selection bias despite the administration of a pre-test. Finally, the relatively small sample size may limit the broader applicability of the findings. Future studies are encouraged to involve multiple schools, larger samples, and additional Biology topics to further validate and extend the present findings.

CONCLUSIONS

The results of this research demonstrate that the use of the Problem-Based Learning (PBL) approach contributed more effectively to the development of students' critical thinking than conventional teaching methods. Gender-related differences were also observed, as female students outperformed male students in both instructional settings. Furthermore, significant

differences were observed between male and female students, with female students demonstrating higher critical thinking scores. However, no statistically significant interaction was found between learning model and gender, indicating that the effectiveness of the Problem-Based Learning approach was relatively consistent across gender groups. These findings highlight the value of PBL as an instructional strategy for Biology education, particularly in supporting the enhancement of higher-order thinking skills.

Despite these findings, several limitations should be acknowledged. This study was conducted in only one Madrasah Aliyah Negeri and focused exclusively on the Human Circulatory System topic. In addition, the quasi-experimental design relied on existing classroom groupings, which prevented random assignment of participants and may have introduced potential selection bias. Therefore, caution should be exercised when generalizing the findings to broader educational contexts. Future research is recommended to involve multiple schools, larger sample sizes, and a wider range of Biology topics to improve the generalizability of the findings. Longitudinal studies may also be conducted to examine the long-term impact of Problem-Based Learning on students' critical thinking skills. Furthermore, future investigations could explore additional learner characteristics, such as learning motivation, self-regulated learning, academic achievement, and learning styles, to provide a more comprehensive understanding of factors influencing critical thinking development.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the administration, Biology teacher, and eleventh-grade students of the participating Madrasah Aliyah Negeri in Cianjur, West Java, Indonesia, for their cooperation and support throughout the research process. The authors also appreciate the parents and guardians who provided consent for the students' participation in this study.

AUTHOR CONTRIBUTION STATEMENT

NN contributed to the conceptualization, research design, instrument development, data collection, data analysis, interpretation of the findings, manuscript preparation, and critical revision; TWA contributed to the conceptualization, research design, instrument development, data collection, data analysis, interpretation of the findings, manuscript preparation, and critical revision; and UJ contributed to the conceptualization, research design, instrument development, data collection, data analysis, interpretation of the findings, manuscript preparation, and critical revision. All authors contributed equally, reviewed and approved the final version of the manuscript, and agreed to be accountable for the accuracy and integrity of the work.

AI DISCLOSURE STATEMENT

Generative artificial intelligence tools were used solely to support language editing, improve grammatical accuracy, and enhance the clarity and readability of the manuscript. Artificial intelligence was not used to formulate the research questions, design the methodology, collect or fabricate data, perform the statistical analysis, interpret the findings, or make scholarly conclusions. All AI-assisted content was critically reviewed, verified, and revised by the authors, who retain full responsibility for the accuracy, originality, integrity, and final content of the manuscript.

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