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The Effectiveness of Learning Style–Based Problem-Based Learning on Students' Critical and Creative Thinking in Ecology and Indonesian Biodiversity Topics

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Abstract

Background: Critical and creative thinking skills are essential competencies in biology learning, particularly in complex topics such as ecology and Indonesian biodiversity. However, conventional learning often does not sufficiently accommodate students' different learning styles, which may limit the development of higher-order thinking skills. Therefore, implementing Problem-Based Learning that is aligned with students' learning styles is expected to enhance students' critical and creative thinking abilities.
Methods: This study employed a quasi-experimental design using a nonequivalent control group design involving 80 students, consisting of 40 students in the experimental class and 40 students in the control class. The research instruments included essay tests to measure students' critical and creative thinking skills through pretest and posttest assessments, as well as a learning style questionnaire to identify students' visual, auditory, and kinesthetic learning preferences. Data analysis included the Shapiro–Wilk normality test, Levene's homogeneity test, N-Gain calculation, and the Wilcoxon Signed Rank Test.
Results: The results showed that the average critical thinking score in the experimental class increased from 36.00 to 84.32 with an N-Gain of 0.73 (high category), while the control class increased from 13.92 to 50.20 with an N-Gain of 0.42 (moderate category). The Wilcoxon test indicated significant differences in both classes (experimental class: $Z = -6.168$, $p = 0.000$; control class: $Z = -6.085$, $p = 0.000$). For creative thinking skills, the experimental class score increased from 38.80 to 82.64 with an N-Gain of 0.68 (moderate category, approaching high), whereas the control class increased from 24.72 to 57.88 with an N-Gain of 0.43 (moderate category). The Wilcoxon test also revealed significant differences in both classes (experimental class: $Z = -6.156$, $p = 0.000$; control class: $Z = -6.142$, $p = 0.000$), with more consistent improvement in the experimental class.
Conclusion: Learning style–based Problem-Based Learning is more effective than conventional learning in improving students' critical and creative thinking skills in ecology and Indonesian biodiversity topics. This approach can support the development of higher-order thinking skills by accommodating students' diverse learning preferences and promoting active problem-solving activities.

INTRODUCTION

The development of Higher Order Thinking Skills (HOTS), particularly critical and creative thinking skills, has become a major focus in 21st-century learning. Critical thinking skills include the ability to analyze, evaluate, and solve problems, while creative thinking skills involve fluency, flexibility, originality, and elaboration in generating new ideas (Mulyadi, 2024). Both are considered essential competencies for addressing complex challenges in environmental and scientific contexts, such as ecosystem degradation and the loss of biodiversity in Indonesia (Maskun et al., 2021).

Preliminary observations conducted at the research site indicated that approximately 72.5% of students achieved critical thinking scores below the minimum competency threshold, and 67.5% demonstrated low performance in creative thinking assessments. These initial data reflect a systemic gap in instructional design: conventional learning approaches have not been sufficiently adapted to accommodate students' diverse cognitive styles, thereby limiting the development of higher-order thinking skills. This research gap underscores the urgency of designing an innovative, adaptive learning model that simultaneously addresses both critical and creative thinking within contextually relevant biology topics.

The Problem-Based Learning (PBL) model has been widely studied as a potential approach for developing HOTS because it positions authentic problems as the primary trigger for learning (Fitriyah et al., 2024). Studies indicate that the integration of PBL in science learning can improve students' critical thinking skills more effectively than conventional learning (Fadhilah et al., 2022; Rijal et al., 2021) and can also enhance students' creativity in solving complex problems and developing alternative solutions (Fathonah et al., 2024). However, the effectiveness of PBL varies depending on the context of implementation and student characteristics.

One individual characteristic that influences learning success is learning style (Tandiongan et al., 2025). Differentiated learning based on students' learning styles, such as the visual, auditory, and kinesthetic model, is believed to increase student engagement and understanding during the learning process (Silaban et al., 2024). Research combining PBL and learning style–based approaches has shown positive effects on students' creative thinking abilities, indicating that learning strategies aligned with students' learning styles can maximize learning outcomes (Zahra & Jumini, 2024).

Although many studies report the positive impact of PBL on critical and creative thinking separately (Fonna & Nufus, 2024), there remains a research gap in integrating learning styles as a moderating variable in PBL implementation, particularly in contextual biology topics such as ecology and Indonesian biodiversity. Several studies have shown that PBL significantly improves critical thinking skills (Ahdhianto et al., 2024; Razak, 2022) and that PBL integrated with scientific literacy is effective in improving students' integrative HOTS competencies (Andriani et al., 2024). However, few studies have examined the simultaneous relationship among learning styles, critical thinking, and creative thinking within a comprehensive research framework.

Ecology and Indonesian biodiversity topics have contextual and real-world characteristics that are directly relevant to both research variables. In terms of critical thinking, these topics require students to analyze complex ecosystem interactions, evaluate empirical conservation data, and draw evidence-based conclusions regarding environmental degradation in Indonesia (Prayogo et al., 2024). From the perspective of creative thinking, the breadth of Indonesian biodiversity provides rich contextual stimuli for generating novel conservation strategies, developing original solutions to habitat loss, and elaborating on alternative environmental management approaches (Fiel'ardh et al, 2023). The multifaceted nature of these topics renders them particularly suitable for PBL implementation, where authentic ecological problems serve as primary triggers for

learning while simultaneously demanding both analytical rigor and creative ideation from students. Therefore, research that evaluates the effectiveness of learning style based PBL in improving critical and creative thinking skills in this context is necessary (Nasrulloh et al., 2023). This gap indicates that previous studies have generally focused on a single aspect of thinking skills or a specific learning context without integrating them simultaneously within an adaptive learning framework (Sembiring, 2025; Correia et al, 2024).

Based on this gap, this study aims to analyze the effectiveness of Problem-Based Learning adapted to students' learning styles in improving students' critical and creative thinking skills in ecology and Indonesian biodiversity topics (Rahma, 2022; Manuaba et al, 2022). Specifically, this study aims to: 1) analyze whether learning style based Problem-Based Learning is more effective than conventional learning in improving students' critical thinking skills; 2) examine whether learning style based PBL is more effective than conventional learning in improving students' creative thinking skills; and 3) determine the significance of differences in critical and creative thinking skill improvement between the experimental and control classes in ecology and Indonesian biodiversity topics.

METHODS

This study employed a quantitative approach with a quasi-experimental design using a nonequivalent control group design (Ball & Stanley, 2021; Creswell & Creswell, 2018). This design was selected because the researcher did not conduct individual randomization of participants but instead used existing classroom groups. The study aimed to examine the effectiveness of learning style–based Problem-Based Learning in improving students' critical and creative thinking skills in ecology and Indonesian biodiversity topics.

The research participants consisted of 80 tenth-grade high school students. They were divided into two groups: 40 students in the experimental class and 40 students in the control class. The sample was selected using purposive sampling by considering the equivalence of initial academic abilities based on students' biology scores from the previous semester.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental (n = 40)	O_1	X	O_2
Control (n = 40)	O_1	C	O_2

Notes:
O_1 = Pretest
O_2 = Posttest
X = Learning style–based Problem-Based Learning
C = Conventional learning

In the experimental class, learning was conducted using the Problem-Based Learning syntax which includes:
(1) orientation to contextual problems,
(2) organizing students for learning,
(3) independent and group investigation,
(4) development and presentation of solutions, and
(5) reflection and evaluation of the problem-solving process.

Learning style–based adaptation was carried out through differentiation of learning media and activities based on the results of students' learning style identification questionnaires (visual, auditory, and kinesthetic) (Nasrul et al., 2025; Winarti et al, 2024). Meanwhile, the control class received conventional learning in the form of lectures, guided discussions, and assignments without integrating problem-based approaches or learning style differentiation.

The research instruments consisted of three components: a critical thinking test, a creative thinking test, and a learning style questionnaire. The critical thinking test was developed based on indicators of analysis, evaluation, inference, and conclusion drawing. The creative thinking test referred to four main indicators: fluency, flexibility, originality, and elaboration. The learning style questionnaire was used to identify each student's dominant learning style (visual, auditory, or kinesthetic) as a basis for differentiating learning media and activities. The content validity of the instruments was evaluated by biology education experts, while reliability was calculated using internal consistency coefficients before the instruments were used for data collection.

Data collection was conducted through pretests administered before the treatment and posttests conducted after the learning intervention was completed. Data were analyzed using descriptive and inferential statistics. Descriptive analysis included the calculation of mean scores, minimum values, and maximum values. To determine the level of improvement in learning outcomes, the Normalized Gain (N-Gain) was calculated using the following formula:

$$g = (S_{post} - S_{pre}) / (S_{maks} - S_{pre}) \quad (1)$$

where g is the N-Gain score; S_{post} and S_{pre} are the posttest and pretest scores, respectively; and S_{maks} is the maximum possible score (Hake, 1999). With interpretation criteria:

$g \geq 0.70$ (high),
$0.30 \leq g < 0.70$ (moderate),
$g < 0.30$ (low).

The normality test was conducted using the Shapiro–Wilk test to determine the distribution of the data, while the homogeneity of variance was tested using Levene's Test. The Shapiro–Wilk test results showed that the data in both classes were not normally distributed (experimental class pretest: $W = 0.927$, $p = 0.012$; experimental class posttest: $W = 0.941$, $p = 0.038$; control class pretest: $W = 0.918$, $p = 0.007$; control class posttest: $W = 0.933$, $p = 0.021$), with all significance values falling below $\alpha = 0.05$. Levene's Test confirmed homogeneity of variance between the two classes ($F = 2.341$, $p = 0.130$). Since all data groups failed the normality assumption, the nonparametric Wilcoxon Signed Rank Test was applied to analyze the difference between pretest and posttest scores at a significance level of 0.05. The statistical decision was determined based on the significance value (Sig. 2-tailed) < 0.05, which indicates a significant difference.

All statistical analyses were performed using statistical data processing software with a 95% confidence level. This procedure ensured that the effectiveness of learning style based Problem Based Learning in improving students' critical and creative thinking skills could be empirically and quantitatively tested.

RESULT AND DISCUSSION

The results of the descriptive analysis of critical thinking skills showed that the average score of the experimental class increased from 36.00 in the pretest to 84.32 in the posttest. Meanwhile, the control class increased from 13.92 to 50.20. The improvement in the experimental

class was significantly higher than that in the control class, indicating the effectiveness of learning style–based Problem-Based Learning in improving students' analytical, evaluative, and inferential abilities in ecology and Indonesian biodiversity topics.

Table 2. Descriptive Statistics Recapitulation of Critical Thinking

Class	N	Mean Pretest	Mean Posttest	Improvement	N-Gain (%)	Category
Experimental	40	36.00	84.32	48.32	72.70	High
Control	40	13.92	50.20	36.28	41.65	Moderate

The N-Gain calculation shows that the experimental class achieved a high category (72.70%), while the control class was in the moderate category (41.65%). This value indicates that the improvement in the experimental class was not only statistically significant but also pedagogically meaningful.

The Wilcoxon Signed Rank Test showed a significance value of 0.000 ($p < 0.05$) in both classes, with $Z = -6.168$ in the experimental class and $Z = -6.085$ in the control class, indicating a significant difference between pretest and posttest scores. All students in the experimental class (40 students) showed improvement, while in the control class one student experienced a decrease and one student had no change in score. The more consistent improvement in the experimental class indicates that learning style based differentiation contributes to more evenly distributed learning outcomes.

The descriptive results show that the average score of the experimental class increased from 38.80 to 82.64, while the control class increased from 24.72 to 57.88. The improvement of 43.84 points in the experimental class indicates that students were able to generate ideas with greater fluency, flexibility, originality, and elaboration after the implementation of problem-based learning.

Table 3. Descriptive Statistics Recapitulation of Creative Thinking

Class	N	Mean Pretest	Mean Posttest	Improvement	N-Gain (%)	Category
Experimental	40	38.80	82.64	43.84	67.52	Moderate
Control	40	24.72	57.88	33.16	42.63	Moderate

The N-Gain score of the experimental class (67.52%) falls within the moderate category approaching high, while the control class achieved 42.63% within the moderate category. Although both classes fall into the same category, the difference in scores indicates higher effectiveness in the experimental class.

The Wilcoxon test on creative thinking skills also showed a significance value of 0.000 ($p < 0.05$) in both classes, with $Z = -6.156$ in the experimental class and $Z = -6.142$ in the control class, indicating a significant difference between pretest and posttest scores. All students in the experimental class experienced score improvements, while one student in the control class experienced a decrease. This consistent improvement indicates that the integration of PBL and learning styles not only increases average scores but also promotes more equitable creative learning outcomes.

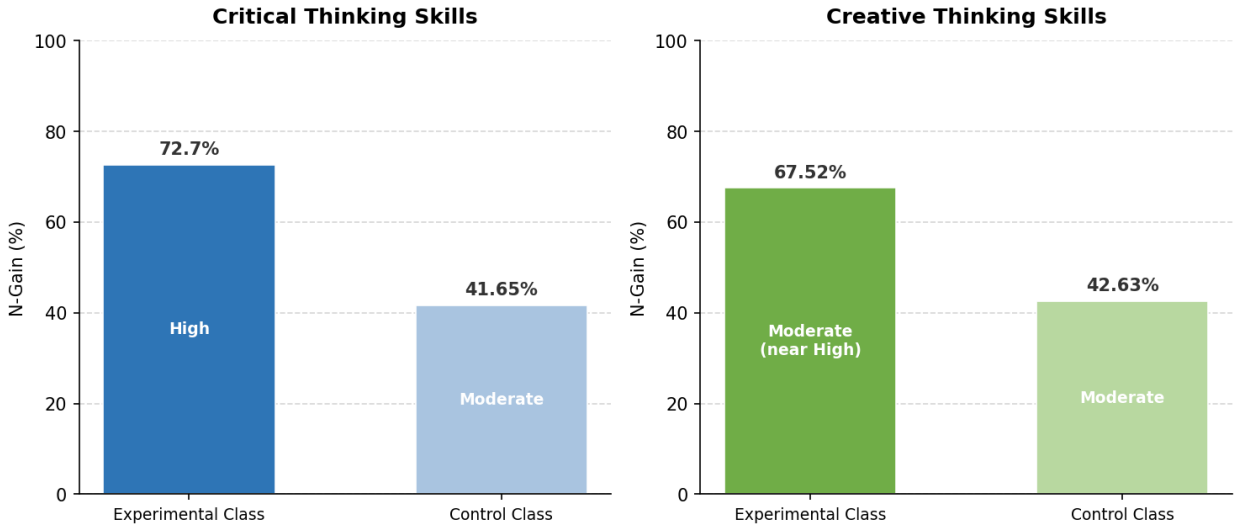

Figure 1. N-Gain Comparison of Experimental and Control Classes for Critical and Creative Thinking Skills

Overall, the results indicate that learning style-based Problem-Based Learning is more effective in improving students' critical and creative thinking skills compared to conventional learning. This effectiveness is reflected in higher N-Gain scores, more consistent individual improvements, and statistically significant Wilcoxon test results across both variables.

The substantial improvement in critical thinking scores in the experimental class confirms that learning style-based Problem-Based Learning is more effective than conventional instruction in developing students' analytical, evaluative, and inferential abilities. This result is consistent with previous studies demonstrating that PBL significantly improves students' critical thinking skills compared to conventional learning models (Fadhilah et al., 2022; Fonna & Nufus, 2024; Ahdhianto et al., 2024). Fadhilah et al. (2022) reported a significant N-Gain improvement in critical thinking skills through STEM-PBL integration among biology education students, while Fonna and Nufus (2024) confirmed that PBL enhances 21st-century skills, including critical analysis, across diverse learning contexts. More specifically, Wulandari et al. (2020), who examined the effect of PBL on critical thinking in biodiversity material, likewise reported a significant improvement following PBL implementation, reinforcing the suitability of biodiversity-related topics as authentic problem contexts for cultivating critical thinking. The systematic integration of PBL syntax orientation to contextual problems, organization for learning, guided investigation, and reflection appears to provide students with more structured opportunities to practice analysis, evaluation, and evidence-based reasoning than the lecture-based activities used in the control class, supporting earlier conclusions that systematic PBL implementation meaningfully contributes to the development of HOTS.

The more consistent improvement observed among students in the experimental class, compared with the two anomalous cases in the control class, further points to the added value of learning style–based differentiation. This pattern aligns with Setiana and Purwoko (2020), who reported that students' critical thinking performance differs systematically according to their dominant learning style, suggesting that instruction which fails to accommodate this variability tends to produce uneven outcomes precisely the pattern observed in the control class of the present study. By contrast, differentiating learning media and activities according to students' visual, auditory, and kinesthetic preferences, as implemented in the experimental class, appears to have reduced this variability and supported more equitable gains, consistent with studies suggesting that instruction adapted to students' individual learning characteristics increases engagement and academic achievement.

For creative thinking, the experimental class likewise demonstrated a markedly larger improvement than the control class, with its N-Gain approaching the high category. This finding supports previous research indicating that PBL provides opportunities for idea exploration that encourage students' divergent thinking and is consistent with research confirming that combining PBL with differentiation strategies can enhance students' creativity more optimally than conventional instruction. A comparable pattern was reported by Komalasari et al. (2024), who found that a problem/project-oriented learning model significantly fostered students' creativity encompassing fluency, flexibility, originality, and elaboration among high school biology students, reinforcing the conclusion that authentic, problem-centered biology instruction is conducive to creative idea generation. Compared with findings by Zahra and Jumini (2024), who reported a creative thinking N-Gain of approximately 52% through PBL with learning style differentiation, the experimental class in this study achieved a notably higher N-Gain of 67.52%, suggesting that the contextual richness of ecology and Indonesian biodiversity topics provides stronger stimuli for creative ideation than the topics examined in earlier studies. It is also worth noting that although both classes were classified within the "moderate" N-Gain category for creative thinking, the gap between the experimental class (67.52%) and the control class (42.63%) is educationally meaningful; the near-high N-Gain attained by the experimental class indicates that the combined PBL and learning style–based approach substantially advanced creative thinking, whereas the control class remained at the lower end of the moderate range. This pattern underscores the importance of reporting N-Gain values transparently rather than relying solely on categorical labels, which may otherwise mask meaningful differences between groups.

Nasrulloh et al. (2023) similarly reported moderate N-Gain improvements in critical thinking through differentiated PBL in biology, a pattern consistent with the control class results in the present study and one that further highlights the added pedagogical value contributed specifically by learning style–based adaptation rather than by PBL alone. Taken together, the integration of contextual ecological problems with learning style differentiation appears to enable students to construct knowledge more actively, analytically, and creatively, corroborating Andriani et al. (2024) and Sembiring (2025), whose findings affirm the effectiveness of HOTS-oriented, adaptive biology instruction across diverse Indonesian school contexts.

Overall, these results indicate that the effectiveness of Problem-Based Learning in improving HOTS is not solely a function of the instructional model itself but is substantially shaped by the extent to which the model accommodates students' individual learning characteristics. The convergence of statistically significant Wilcoxon test results, higher N-Gain scores, and more consistent individual-level improvement in the experimental class across both critical and creative thinking provides converging evidence that learning style–based differentiation amplifies the pedagogical benefits of PBL beyond what either component achieves alone, thereby addressing the research gap identified in the Introduction regarding the limited integration of learning styles as a moderating variable in PBL implementation within contextual biology topics.

CONCLUSION

In accordance with the research objectives, this study concludes that learning style–based Problem-Based Learning is significantly more effective than conventional learning in improving students' critical thinking skills in ecology and Indonesian biodiversity topics, as evidenced by a high N-Gain of 72.70% in the experimental class compared to a moderate N-Gain of 41.65% in the control class, and is also significantly more effective in improving students' creative thinking skills, with the experimental class achieving an N-Gain of 67.52% (moderate, approaching high) compared to 42.63% (moderate) in the control class a difference that is pedagogically meaningful despite sharing the same categorical label; these gains are further supported by the Wilcoxon Signed Rank Test, which confirmed statistically significant improvements in both critical thinking ($Z = -6.168$, p

= 0.000) and creative thinking (Z = −6.156, p = 0.000) in the experimental class, validating the effectiveness of the intervention. The improvement in critical thinking skills is reflected in students' ability to analyze ecological problems systematically, evaluate information based on data, and draw logical conclusions regarding contextual environmental issues, while the improvement in creative thinking skills is reflected in students' ability to generate more diverse, flexible, original, and elaborated solutions; the integration of learning style differentiation within the PBL syntax contributes to more equitable improvements in learning outcomes, as students gain learning experiences that match their individual learning characteristics. Conceptually, this study strengthens the argument that the effectiveness of a learning model is determined not only by the pedagogical approach used but also by how well the model is adapted to students' individual characteristics; therefore, the combination of Problem-Based Learning and a learning style–based approach represents an innovative strategy for optimizing the simultaneous development of Higher Order Thinking Skills (HOTS).

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