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Effectiveness of Padlet-Supported Problem-Based Learning for Biology Students' Critical Thinking

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ABSTRACT

Developing students' critical thinking skills remains a major challenge in higher education, particularly in biology learning, which requires strong analytical and evaluative abilities. The integration of hypermedia such as Padlet within a Problem-Based Learning (PBL) framework has the potential to create interactive and collaborative learning environments that support higher-order thinking. This study aimed to examine the effectiveness of Padlet hypermedia integrated with Problem-Based Learning in enhancing the critical thinking skills of Biology Education students. A quasi-experimental design with a non-equivalent control group was employed involving 60 undergraduate students from the Biology Education program at Surabaya State University. The participants were divided into an experimental group (n = 30) using Padlet-based PBL and a control group (n = 30) using Google Classroom. Data were collected through validated open-ended tests of critical thinking skills, supported by questionnaires and classroom observations. The data were analysed using normality and homogeneity tests, N-gain analysis, and an independent samples t-test. The results showed that students in the experimental group achieved significantly higher critical thinking scores than those in the control group (p = 0.003). The experimental group also demonstrated greater improvement from pre-test to post-test, indicating stronger development in problem analysis, information evaluation, inference, and logical reasoning. These findings suggest that Padlet hypermedia integrated with Problem-Based Learning may provide a more effective learning environment for promoting students' critical thinking skills through interactive, collaborative, and reflective learning processes.

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1. INTRODUCTION

Critical thinking is a crucial competency in higher education in the twenty-first century, yet many students still demonstrate limited ability in analysis, evaluation, and reasoning. International reports such as PISA indicate that students often struggle to construct logical arguments and critically assess information, showing that higher-order thinking remains underdeveloped in many educational settings (Thornhill-Miller et al. 2023). This problem is closely related to the continued use of lecture-based instruction, in which lecturers dominate classroom activities while students mainly listen, take notes, and receive information passively. In such situations, two-way interaction is limited, and students have few opportunities to discuss, question ideas, or independently analyse and solve problems. As a result, conventional learning practices often fail to foster critical thinking skills. More participatory and innovative approaches are therefore needed to improve student engagement and thinking quality. In this regard, reasoning is recognised as one dimension of higher-order thinking skills and as a fundamental competency that students are expected to master in contemporary education (Kariadinata 2012).

Higher education therefore requires learning strategies that actively engage students in analysing problems, evaluating information, and constructing arguments. One promising approach is Problem-Based Learning (PBL) integrated with digital learning media such as Padlet hypermedia (Aufa et al. 2021; Darwin et al. 2024; Trullàs et al. 2022). Padlet, as a form of hypermedia, provides an interactive and flexible collaborative space that can support student participation in the learning process. When designed within a PBL framework,

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Padlet has the potential to create a more engaging and challenging environment that encourages students to think critically while solving authentic problems presented in the classroom (Villarama et al. 2024). In this study, Padlet is used as an interactive medium through which students can collaboratively discuss and solve problems using text, images, and video features (Ofianto et al., 2024). Such integration is expected to contribute to the development of innovative learning models that are more relevant to the current needs of higher education (Simanjuntak et al., 2021; Essien et al., 2024).

Previous studies have consistently shown that Problem-Based Learning is an effective approach for promoting higher-order thinking, especially critical thinking. PBL improves critical thinking by engaging students in analysis, inquiry, collaboration, and decision-making through problem-oriented learning activities (Akçay, 2009). It encourages students to identify problems, evaluate alternative solutions, and justify their decisions, thereby shifting learning from passive reception to active and reflective engagement (Ali et al., 2019). In higher education, lecturers therefore need to design instructional strategies that support students in learning more actively and meaningfully while also encouraging the use of critical thinking and problem-solving skills (Ho et al., 2023). This is especially important because many students still face difficulty when dealing with complex and authentic issues. They often struggle to build arguments, make evidence-based decisions, and propose innovative solutions, even though such capacities are central to twenty-first-century learning (O'Reilly et al., 2022).

The need to strengthen critical thinking is further intensified by the growing integration of digital technology in learning. One digital platform that has attracted increasing attention is Padlet, which supports real-time idea sharing, feedback, and multimedia-based discussion. Studies have shown that Padlet can improve motivation, participation, collaboration, and reflective learning, all of which may contribute to the development of critical thinking skills (Xu et al., 2023; Dita et al., 2021). The integration of Padlet into a Problem-Based Learning framework is therefore pedagogically promising. PBL encourages students to engage in problem-solving, critical analysis, and collaboration, while Padlet strengthens this process by providing a digital space where students can organise ideas, exchange feedback, and reflect on their learning. Through Padlet, students can respond to peers, compare perspectives, and continuously refine their arguments, thereby supporting the development of analysis, evaluation, and reasoning skills in ways that extend beyond classroom time (Rivas et al., 2022; Walter 2024).

Despite this potential, conventional learning models that are still widely used have not fully supported the development of students' critical thinking skills. This condition highlights the need for innovative and technology-based learning approaches, including the use of Padlet hypermedia integrated with Problem-Based Learning (Suradika et al., 2023). However, although many previous studies have examined PBL and Padlet separately, fewer studies have investigated their combination in a way that specifically targets critical thinking development in a comprehensive manner. Existing studies often focus more on general learning outcomes than on the development of critical thinking processes themselves, particularly in higher education settings. This indicates a clear research gap, especially in the context of Biology Education, where students are expected to analyse problems, evaluate evidence, and construct logical explanations in classroom learning.

Against this background, further investigation is needed to determine the extent to which Padlet hypermedia integrated with Problem-Based Learning can significantly improve students' critical thinking skills. The importance of this study lies in its attempt to examine this combination not merely as a technological innovation, but as a pedagogical strategy for creating collaborative, reflective, and problem-based learning experiences. Padlet supports the implementation of PBL by providing a collaborative space where students can share ideas, discuss issues, and reflect on the problems they encounter. Through this process, Padlet may strengthen students' analytical, evaluative, and synthesis skills while supporting the core stages of problem-based inquiry. The contribution of the present study is therefore located in examining Padlet within a PBL framework to support critical thinking through a collaborative and reflective instructional design using experimental and control class procedures. Accordingly, this study aims to determine: (1) the difference in critical thinking skills between students taught using PBL-based Padlet hypermedia and those taught using Google Classroom media, and (2) the effect of using PBL-based Padlet hypermedia on the critical thinking skills of Biology Education students.

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2. MATERIAL AND METHOD

Research Design

This study employed a quasi-experimental non-equivalent control group design to examine the effect of Padlet-based Problem-Based Learning (PBL) on students' critical thinking skills. A quasi-experimental approach was selected because random assignment was not feasible in the existing university setting, as the classes had been administratively formed before the study began. The use of intact classes allowed the study to be conducted in an authentic instructional context without interrupting the regular academic schedule. Accordingly, one class was assigned as the experimental group and received instruction through Padlet hypermedia integrated with PBL, whereas the other class served as the control group and received conventional learning supported by Google Classroom (Sugiyono, 2018). The research procedure, as illustrated in Figure 1, consisted of four main stages. The first stage involved the preparation of the learning media and research instruments, including the development of Padlet-based PBL activities and a critical thinking test, followed by expert validation and reliability testing. The second stage was the administration of a pre-test to both groups to identify their initial level of critical thinking skills. The third stage was the implementation of the treatment, in which the experimental group participated in Padlet-based PBL learning while the control group learned through Google Classroom-supported instruction. The final stage involved administering the post-test, scoring students' responses, and analysing the data using normality and homogeneity tests, N-gain analysis, and an independent samples t-test to determine the effect of the treatment on students' critical thinking skills (Sugiyono, 2018).

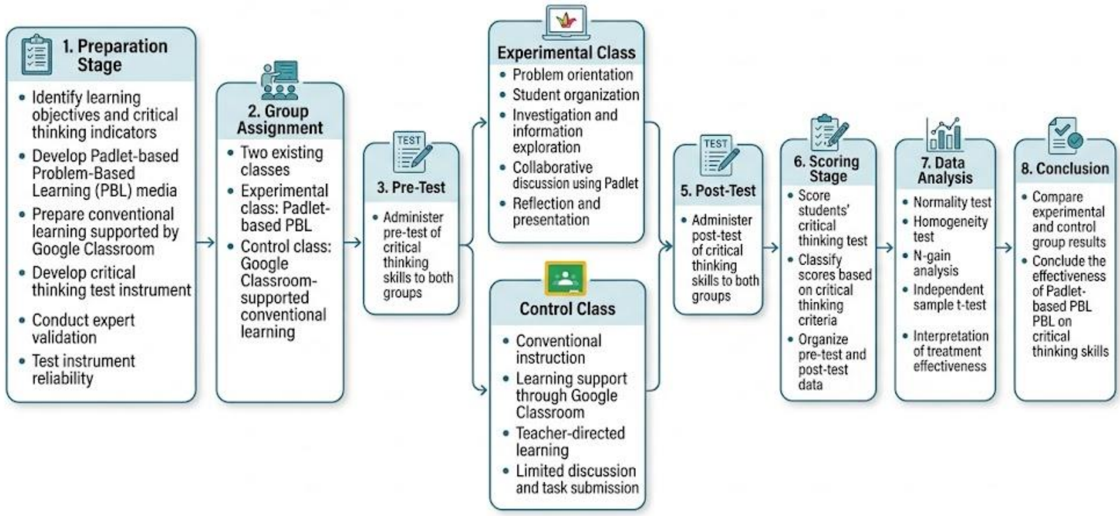

Figure 1. Flow of the Quasi-Experimental Research Procedure

Participants

The participants of this study were undergraduate students from the Biology Education program at Surabaya State University. The sample consisted of 60 students from the 2024 cohort, divided equally into an experimental group (n = 30) and a control group (n = 30). The participants were selected using purposive sampling, as both classes had similar academic characteristics and were taught within the same instructional context. This sampling technique was considered appropriate because the study was conducted in naturally existing classes that could not be reorganised randomly. The study was carried out in a regular classroom setting during the academic semester. All participants were enrolled at the same year level and had relatively similar prior knowledge and learning experiences in the course. Both groups were taught the same course content and followed the same learning objectives, but they received different instructional approaches during the intervention. The experimental group was taught using Padlet-based Problem-Based Learning, whereas the control group was taught using Google Classroom-supported learning. This arrangement allowed the study to compare the effect of the two instructional approaches on students' critical thinking skills under comparable academic conditions.

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Instrumentations

The study employed a critical thinking test as the primary instrument to measure students' critical thinking skills before and after the implementation of the learning treatment. Supporting instruments, including observation sheets, questionnaires, and interviews, were also used to obtain complementary information regarding students' learning processes and the development of their critical thinking patterns during the intervention. The critical thinking test was developed based on five key indicators of critical thinking, namely interpretation, analysis, evaluation, inference, and explanation, because these indicators represent essential dimensions of higher-order thinking required in Biology Education learning. Content validity of the instrument was established through expert judgment involving three experts in biology education, educational technology, and assessment and evaluation. All experts held doctoral degrees and had more than five years of experience in higher education teaching and research. Revisions were made based on the experts' feedback to improve the clarity, relevance, and suitability of the test items for the instructional context. Item validity was further examined using the Product Moment (Pearson) correlation technique, in which an item was considered valid when the obtained *r* value exceeded the *r* table value at the 0.05 significance level. The results showed that all ten test items met the validity criterion, indicating that the instrument was appropriate for measuring students' critical thinking skills. Reliability of the critical thinking test was assessed using Cronbach's alpha, and the analysis yielded a coefficient of 0.82, indicating that the instrument had good internal consistency and was reliable for use in this study. The indicators used in the critical thinking and validity instrument are presented in Table 1.

Table 1. Critical Thinking Instrument and Item Validity

Item Number	Critical Thinking Indicator	Indicator Description	r Count	r Table	Description
1	Interpretation	Ability to understand and explain the meaning of information	0.62	0.36	Valid
2			0.58	0.36	Valid
3	Analysis	Ability to identify relationships between concepts or arguments	0.65	0.36	Valid
4			0.45	0.36	Valid
5	Evaluation	Ability to assess the credibility of information or arguments	0.56	0.36	Valid
6			0.43	0.36	Valid
7	Inference	Ability to draw conclusions from data or facts	0.67	0.36	Valid
8			0.56	0.36	Valid
9	Explanation	Ability to explain reasoning logically	0.40	0.36	Valid
10			0.60	0.36	Valid

Data Collection

Data were collected through pre-test and post-test administration to measure students' critical thinking skills before and after the implementation of the instructional treatment. The pre-test was administered to both the experimental and control groups before the intervention began in order to identify students' initial level of critical thinking and to ensure that both groups started from relatively comparable academic conditions. After the pre-test, the experimental group received instruction through Padlet-based Problem-Based Learning (PBL), while the control group was taught using Google Classroom-supported learning. Both groups studied the same course content, followed the same learning objectives, and participated within the same academic period, but experienced different instructional media and learning processes. At the end of the treatment period, both groups were given the post-test using the same critical thinking instrument as in the pre-test. The post-test was intended to measure the extent of students' improvement in critical thinking skills after the intervention. The scores obtained from the pre-test and post-test were then used as the main data for analysis. These data served as the basis for comparing students' initial and final performance, calculating the level of improvement, and determining whether the use of Padlet-based Problem-Based Learning was more effective than the comparison condition in enhancing students' critical thinking skills.

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Data Analysis Techniques

Data analysis was conducted in three stages. The first stage involved preliminary analysis to test the normality and homogeneity of the data. The second stage involved testing the validity and reliability of the research instruments to ensure that the critical thinking test was appropriate for use in the pre-test and post-test. The third stage was the main data analysis, which aimed to determine the effectiveness of Padlet-based Problem-Based Learning (PBL) in improving students' critical thinking skills. Students' test scores were first converted into percentages using the following formula:

$$S = \frac{number\ of\ correct\ answers}{maximum\ score}\ x\ 100$$

The resulting scores were then classified into critical thinking categories, namely very high, high, moderate, low, and very low, as presented in Table 2. To determine the extent of improvement in students' critical thinking skills after the treatment, the normalized gain (*N-gain*) was calculated using the following formula:

$$\text{N-gain} = \frac{\text{posttest score} - \text{pretest score}}{\text{ideal score} - \text{pretest score}}$$

Table 2. Critical Thinking Criteria

Score Range	**Criteria**
81.25 < x ≤ 100	Very High
71.50 < x ≤ 81.25	High
62.50 < x ≤ 71.50	Moderate
43.75 < x ≤ 62.50	Low
0.00 < x ≤ 43.75	Very Low

The N-gain values were interpreted according to the criteria proposed by Hake (2002), as shown in Table 3, in which values of $\text{N-gain} \le 0.3$are categorized as low, $0.3 < \text{N-gain} \le 0.7$as medium, and $\text{N-gain} > 0.7$as high. Hypothesis testing was then conducted using an independent samples t-test to compare the critical thinking scores of the experimental and control groups after the treatment. The independent samples t-test was applied after the data met the assumptions of normality and homogeneity. This analysis was intended to determine whether there was a statistically significant difference in critical thinking skills between students taught using Padlet-based PBL and those taught using Google Classroom-supported learning. Taken together, the scoring procedure, prerequisite tests, N-gain analysis, and hypothesis testing provided a comprehensive basis for evaluating the effectiveness of the instructional treatment. The formula used is as follows:

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\left(\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\right)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Table 3. N-Gain Criteria

N-gain Value	**Criteria**
N-gain ≤ 0.3	Low
0.3 < N-gain ≤ 0.7	Medium
N-gain > 0.7	High

3. RESULTS

Differences in Critical Thinking Scores Between the Experimental and Control Groups

Pre-test and Post-test Data

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The pre-test and post-test results of students' critical thinking skills are presented in Table 4. The data indicate that the experimental and control groups began the study with relatively similar levels of critical thinking ability prior to the implementation of the treatment. As shown in Table 4, the average pre-test score of the experimental group was 22.06, while the control group obtained a closely comparable mean of 21.74. This pattern suggests that both groups had nearly equivalent initial conditions before the intervention, indicating that any subsequent difference in post-test performance is more likely to be associated with the instructional treatment rather than with substantial differences in prior ability. In terms of score range, the experimental group had pre-test scores ranging from 1.00 to 55.50, whereas the control group ranged from 1.00 to 50.25, indicating that both groups entered the study with similarly low critical thinking performance.

Table 4. Data on Critical Thinking Pretest and Posttes Results

Score	Experimental Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
Average	22.06	80.64	21.74	68,40
Maximum	55.50	88.50	50.25	78.50
Minimum	1.00	66.8	1.00	23.50

After the implementation of the learning treatment, a different pattern emerged. As shown in Table 4, both groups experienced improvement in their post-test scores, but the increase was considerably greater in the experimental group. The experimental group achieved a mean post-test score of 80.64, whereas the control group reached 68.40. This indicates that although learning gains occurred in both classes, students who learned through Hypermedia Padlet integrated with Problem-Based Learning (PBL) demonstrated stronger improvement in critical thinking skills than those who learned through Google Classroom-supported instruction. The post-test maximum score in the experimental group reached 88.50, while the control group achieved a maximum of 78.50. In addition, the minimum post-test score of the experimental group was 66.80, which was substantially higher than that of the control group at 23.50. This pattern suggests not only a higher average achievement in the experimental class, but also a stronger upward shift among lower-performing students. In substantive terms, the data in Table 4 indicate that the use of Padlet-based PBL may have provided a more supportive learning environment for developing critical thinking, particularly by encouraging more active participation in problem-solving, collaborative interaction, and reflective engagement (Akçay, 2009; Ali et al., 2019). These findings also imply that the integration of interactive hypermedia into a PBL framework may help students move beyond passive reception of information toward deeper analytical and evaluative thinking, which is central to critical thinking development in higher education contexts (Xu et al., 2023; Rivas et al., 2022).

Critical Thinking Indicator Analysis

Table 5. Result of Critical Thinking Indicators Analysis

Critical Thinking Indicators	Experimental Class			Control Class		
	Pretest	**Posttest**	**Enhancement**	**Pretest**	**Posttest**	**Enhancement**
Interpretation	2.10	88.50	86.40	2.30	65.20	62.90
Analysis	33.20	85.10	51.90	30.40	72.80	42.40
Evaluation	5.60	82.30	76.70	6.10	63.40	57.30
Inference	52.10	80.50	28.40	54.70	78.20	23.50
Explanation	17.30	66.80	49.50	15.20	62.40	47.20

Further detail regarding students' critical thinking development can be seen in Table 5, which presents the pre-test scores, post-test scores, and enhancement values for each critical thinking indicator in both groups. The data show that improvement occurred across all indicators in the experimental and control classes, but the gains in the experimental class were consistently higher. In the interpretation indicator, for example, the experimental group increased from 2.10 to 88.50, with an enhancement score of 86.40, whereas the control

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group improved from 2.30 to 65.20, with an enhancement of 62.90. A similar pattern appears in the analysis indicator, where the experimental group improved from 33.20 to 85.10 (enhancement = 51.90), while the control group increased from 30.40 to 72.80 (enhancement = 42.40). In the evaluation indicator, the experimental class rose from 5.60 to 82.30, compared with the control class from 6.10 to 63.40. These results indicate that students who learned through Padlet-based PBL showed stronger progress in skills related to interpreting problems, analysing information, and evaluating evidence than those in the control condition.

The same tendency is also visible in the remaining indicators. In the inference indicator, the experimental group improved from 52.10 to 80.50, while the control group increased from 54.70 to 78.20. Although both groups demonstrated progress, the enhancement value in the experimental class (28.40) remained higher than that of the control class (23.50). Similarly, in the explanation indicator, the experimental group increased from 17.30 to 66.80, with an enhancement of 49.50, compared to the control group from 15.20 to 62.40, with an enhancement of 47.20. Taken together, the data in Table 5 suggest that the instructional treatment did not improve only one aspect of critical thinking, but contributed to broader development across multiple dimensions. This pattern is important because it indicates that the effect of Hypermedia Padlet based on Problem-Based Learning (PBL) was not limited to a narrow cognitive outcome, but extended across interpretation, analysis, evaluation, inference, and explanation. In pedagogical terms, these data imply that the treatment supported a more comprehensive cultivation of critical thinking by engaging students in structured problem-solving activities, collaborative discussion, and reflective reasoning. The stronger enhancement values in the experimental group also suggest that Padlet, when integrated into a PBL framework, may function not merely as a digital platform but as an instructional medium that facilitates deeper cognitive engagement and more systematic development of higher-order thinking skills.

Normality Assumption Testing

Table 6. Normality Test

Group	Kolmogorov-Smirnov Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Pre-test Experiment	0.120	30	0.200	0.940	30	0.105
Pre-test Control	0.135	30	0.160	0.938	30	0.110
Post-tests Experiment	0.148	30	0.075	0.949	30	0.175
post-test Control	0.140	30	0.090	0.947	30	0.190

A normality test was conducted to determine whether the pre-test and post-test scores of students' critical thinking skills in the experimental and control groups were normally distributed. The results of the analysis are presented in Table 6, which reports both the Kolmogorov–Smirnov and Shapiro–Wilk statistics. As shown in the table, the significance value for the pre-test in the experimental group was 0.200 based on the Kolmogorov–Smirnov test and 0.105 based on the Shapiro–Wilk test. In the pre-test of the control group, the significance values were 0.160 and 0.110, respectively. For the post-test in the experimental group, the significance values were 0.075 and 0.175, while in the post-test of the control group, the significance values were 0.090 and 0.190. Since all significance values in both tests were greater than 0.05, the data in all groups can be considered normally distributed. These findings indicate that the distribution of critical thinking scores in both the experimental and control groups met the assumption of normality before the hypothesis testing was conducted. This is an important prerequisite because it supports the appropriateness of using parametric statistical analysis, particularly the independent samples t-test, to compare the mean scores between groups. In substantive terms, the normality results suggest that the score patterns in both groups did not deviate substantially from a normal distribution, either before or after the treatment. Therefore, the data were considered suitable for further inferential analysis to examine whether the implementation of Padlet-based Problem-Based Learning produced a statistically significant difference in students' critical thinking skills compared with the use of Google Classroom.

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Homogenity of Variance Critical Thinking Scores

Table 7. Homogeneity Test

Data	Levane Statistic	df1	df2	Sig.
Pre-test	0.652	1	58	0.422
post-test	0.711	1	58	0.402

The homogeneity of variance between the experimental and control groups was assessed using Levene's test to determine whether the critical thinking scores were equally distributed. The results are presented in Table 7. As shown in the table, the significance value for the pre-test data was 0.422, with a Levene statistic of 0.652, while the significance value for the post-test data was 0.402, with a Levene statistic of 0.711. Since both significance values were greater than the threshold of 0.05, the variance of the critical thinking scores in the experimental and control groups can be considered homogeneous for both the pre-test and post-test data. These findings indicate that the assumption of homogeneity of variance was satisfied, meaning that the spread of scores between the two groups was relatively similar before and after the treatment. This result is important because homogeneity of variance is one of the key assumptions required for the use of parametric statistical tests, particularly the independent samples t-test employed in this study. In substantive terms, the results in Table 7 suggest that the difference in score variability between the experimental and control groups was not statistically significant, so the groups were sufficiently comparable in terms of variance. Therefore, the data met the necessary prerequisite for continuing to the main hypothesis test to determine whether the use of Padlet-based Problem-Based Learning produced a significant difference in students' critical thinking skills compared with the use of Google Classroom.

N-Gain Analysis of Students' Critical Thinking Improvement

Table 8. N-gain Test

Group	Pre-test Mean	Post-test Mean	N-Gain	Category
Experimental	22.06	80.64	0.75	High
Control	21.74	68.40	0.60	Moderate

The N-gain analysis was conducted to determine the extent to which students' critical thinking skills improved after the implementation of the learning intervention in both groups. As presented in Table 8, the experimental group showed an increase in the mean score from 22.06 on the pre-test to 80.64 on the post-test, resulting in an N-gain value of 0.75, which falls into the high category. In contrast, the control group improved from a pre-test mean of 21.74 to a post-test mean of 68.40, producing an N-gain value of 0.60, which is categorized as moderate. These results indicate that although both groups experienced progress in their critical thinking skills after instruction, the magnitude of improvement in the experimental group was greater than that in the control group. The relatively similar pre-test means between the two groups suggest that both groups started from comparable initial conditions, thereby strengthening the interpretation that the higher post-test achievement and larger N-gain in the experimental group were associated with the effect of the Padlet-based Problem-Based Learning (PBL) intervention rather than with pre-existing differences. The N-gain value of 0.75 suggests that the treatment was highly effective in promoting students' ability to analyse problems, evaluate information, and construct reasoned responses, which are essential dimensions of critical thinking (Hake, 2002). Meanwhile, the lower N-gain value in the control group indicates that Google Classroom-supported learning was also able to facilitate improvement, but the gain was less substantial than that achieved through the more interactive and collaborative learning environment provided by Padlet-based PBL. Overall, the comparison of N-gain scores demonstrates that the experimental treatment contributed more strongly to the development of students' critical thinking skills, indicating that the integration of Padlet with PBL offered greater instructional benefits than the learning approach used in the control group (Akçay, 2009; Xu et al., 2023).

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Hypothesis Testing Using Independent Samples t-Test

Table 9. Hypothesis Testing

Variable	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval (Lower)	Upper
Critical Thinking Skills (Equal variances assumed)	5.23	58	< 0.001	12.24	2.34	7.56	16.92
Critical Thinking Skills (Equal variances not assumed)	5.23	57.60	< 0.001	12.24	2.34	7.56	16.92

Statistical significance in the difference of critical thinking scores between the experimental and control groups after the implementation of the treatment was examined using an independent samples t-test. The results are presented in Table 9. Under the assumption of equal variances, the analysis produced a t-value of 5.23 with 58 degrees of freedom and a significance value of $p < 0.001$. Since the obtained p-value was lower than 0.05, the null hypothesis was rejected. This indicates that there was a statistically significant difference in students' critical thinking skills between the two groups after the intervention. The mean difference of 12.24 shows that one group achieved a substantially higher average score than the other, and when interpreted together with the descriptive results presented earlier, this difference indicates that the experimental group outperformed the control group. Further evidence of this difference can be seen from the 95% confidence interval, which ranged from 7.56 to 16.92. Because this interval does not include zero, the difference between the two group means can be regarded as statistically meaningful. In addition, the same result was obtained under the assumption of unequal variances, with $t = 5.23$, $df = 57.60$, and $p < 0.001$, indicating that the finding was stable regardless of the variance assumption used in the analysis. These results strengthen the conclusion that the use of Hypermedia Padlet based on Problem-Based Learning (PBL) was more effective than Google Classroom-supported learning in improving students' critical thinking skills. In substantive terms, the findings suggest that students who learned through Padlet-based PBL experienced a stronger development of higher-order thinking processes, particularly because the learning model provided opportunities for active problem analysis, collaborative discussion, reflection, and argument construction (Akçay, 2009; Ali et al., 2019). Therefore, the results in Table 9 provide inferential support for the effectiveness of Padlet-based Problem-Based Learning as an instructional approach for enhancing critical thinking in Biology Education students (Xu et al., 2023; Rivas et al., 2022).

4. DISCUSSION

The difference in critical thinking skills between the Hypermedia Padlet based on Problem-Based Learning (PBL) model and the Google Classroom group

The initial results show that the experimental and control groups began the study with relatively comparable levels of critical thinking, as reflected in the pre-test mean scores of 22.06 and 21.74, respectively. Further analysis presented in Table 4, Table 6, and Table 7 indicates that the data met the assumptions of normality and homogeneity, thereby supporting the validity of the subsequent comparison between groups. Following the intervention, the post-test mean of the experimental group increased to 80.64, while the control group reached 68.40. This pattern suggests that Padlet-based PBL produced a stronger improvement in critical thinking than Google Classroom-supported instruction (Kanchana & Cherukuri, 2024). Previous studies have shown that PBL enhances critical thinking because it engages students in identifying problems, evaluating evidence, and generating solutions through inquiry-based learning (Akçay, 2009; Ali et al., 2019). Digital collaborative platforms also contribute to this process by expanding opportunities for interaction, reflection, and peer response (Xu et al., 2023; Rivas et al., 2022). Taken together, the present findings imply that the higher performance of the experimental group was not merely a technology effect, but rather the result of aligning a collaborative digital environment with a pedagogy that explicitly requires analytical and evaluative thinking (Kanchana & Cherukuri, 2024).

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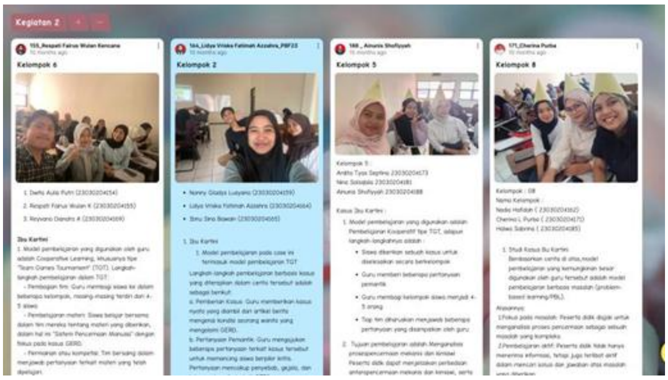

Figure 2. Padlet-based Problem-Based Learning (PBL) hypermedia usage activities

The emergence of this difference can be further understood through the data presented in Figure 2 and Table 5. The results show that students in the experimental class were actively engaged in visible collaborative problem-solving activities through Padlet, including posting ideas, responding to peers, and discussing solutions in groups. Table 5 supports this pattern by showing that the experimental class achieved higher enhancement scores across all critical thinking indicators than the control class. The most pronounced differences appeared in interpretation (86.40 in the experimental class versus 62.90 in the control class), evaluation (76.70 versus 57.30), and analysis (51.90 versus 42.40). These results indicate that the Padlet-based PBL environment was particularly effective in strengthening students' abilities to interpret information, examine evidence, and make judgements (Kanchana & Cherukuri, 2024). Prior research similarly reports that Padlet can support collaborative writing, peer feedback, and interactive discussion, all of which foster active engagement with ideas and strengthen reasoning processes (Ho et al., 2023; Manipatruni et al., 2024; Pin Flores et al., 2024). The implication is that the combination of Padlet and PBL offers not only procedural support for classroom interaction but also cognitive support for critical thinking development, especially in dimensions that require students to articulate, compare, and defend their ideas.

The effect of using the Hypermedia Padlet based on Problem-Based Learning (PBL) model on students' critical thinking skills

The findings demonstrate that the effect of the treatment was not only educationally meaningful but also associated with a stronger improvement in the experimental group. As shown in Table 8, the experimental group obtained an N-gain score of 0.75, whereas the control group achieved 0.60. Although both groups showed meaningful improvement, the experimental group reached the high category, while the control group remained in the moderate category. This finding indicates that Padlet-based PBL generated a stronger improvement in students' critical thinking over the course of the intervention. Previous studies have argued that Padlet is most effective when it is not used merely as a content-sharing platform, but as a collaborative space for organising ideas, responding to feedback, and sustaining reflective interaction (Puspitasari & Arifin, 2024; Pakaja et al., 2024; Nicholus et al., 2023). The present results support this argument by showing that when Padlet is embedded within a problem-based framework, it can intensify students' engagement with reasoning tasks and thereby produce greater learning gains. The pedagogical implication is that technology integration becomes more impactful when it is paired with a student-centred model that structures inquiry, discussion, and decision-making (Deni & Zainal, 2019).

The results further reveal that the gains were not equally distributed across all critical thinking indicators. As presented in Table 5, the strongest improvement occurred in interpretation, evaluation, and analysis, whereas inference showed the smallest enhancement in both groups, although the experimental class still performed better than the control class (28.40 versus 23.50). This pattern suggests that students found it easier to improve in skills related to understanding problems, examining information, and assessing alternatives than in drawing conclusions from multiple pieces of evidence (Saputra et al., 2025). Previous research on collaborative and problem-based learning has similarly noted that higher-order synthesis and conclusion-making often require stronger scaffolding than basic participation or response generation (Rahmawati & Rahmawati, 2024; Susanti & Prasetyo, 2021; Han, 2025). The implication of this finding is that Padlet-based PBL is effective

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for promoting several core aspects of critical thinking, but its implementation should be strengthened with explicit support for inference, such as guiding questions, conclusion frames, or lecturer prompts that help students connect evidence to final judgements (Rahman & Rindrayani, 2024).

Several broader implications emerge from these findings. The first implication is instructional: higher education classrooms benefit when digital platforms are used as spaces for collaborative reasoning rather than as repositories for material delivery alone. The second implication is pedagogical: the quality of the problems and the lecturer's facilitation remain central, because Padlet can only support critical thinking effectively when students are guided to question, compare, and justify ideas throughout the learning process. The third implication is practical: the success of this approach may vary depending on students' digital literacy and access to stable internet, a concern that has also been reported in studies on technology-mediated learning environments (Suherman, 2024; Hussin et al., 2019). Overall, the present study demonstrates that Padlet-based PBL is a promising approach for improving university students' critical thinking, particularly in interpretation, analysis, and evaluation, while also highlighting the need for additional scaffolding to strengthen inference and conclusion-making (Han, 2025).

Inferential Support for the Effectiveness of Padlet-Based PBL

The descriptive and gain-based findings discussed in the previous sections are further strengthened by the inferential evidence presented in Table 9. The independent samples *t*-test showed a statistically significant difference between the experimental and control groups after the intervention, with $t = 5.23$, $df = 58$, and $p < 0.001$ under the assumption of equal variances. The mean difference of 12.24 indicates that the experimental group achieved a substantially higher level of critical thinking performance than the control group. This result confirms that the stronger post-test performance and higher N-gain observed in the experimental class were not merely descriptive tendencies, but were supported by inferential statistical evidence. The 95% confidence interval, which ranged from 7.56 to 16.92, further reinforces this conclusion because the interval does not include zero, indicating that the difference between groups was statistically meaningful (Karki, 2024).

The significance of Table 9 adds an important layer to the interpretation of the study. The result suggests that the superiority of the experimental class should not be understood as a simple consequence of using digital media, but rather as the product of an instructional design that combined interactive hypermedia with problem-based inquiry (Jong & Tan, 2021) . Such a combination appears to have created a learning environment in which students were more actively involved in analysing problems, evaluating evidence, discussing alternative perspectives, and constructing reasoned arguments. Previous studies have similarly shown that Problem-Based Learning strengthens critical thinking by engaging students in inquiry and decision-making processes, while collaborative digital environments enhance participation, reflection, and peer interaction (Akçay, 2009; Ali et al., 2019; Xu et al., 2023). Taken together, the inferential evidence in Table 9 complements the descriptive and N-gain findings by demonstrating that Padlet-based PBL was not only associated with higher scores, but also produced a statistically supported difference that strengthens the claim of its instructional effectiveness (Gill-simmen, 2021).

Limitation

Several limitations should be acknowledged in interpreting the findings of this study. First, the study employed a quasi-experimental design using intact classes, which means that the observed differences should be interpreted as evidence of instructional effectiveness within this context rather than as definitive proof of causality. Second, the sample was limited to 60 Biology Education students from a single institution, which may restrict the generalizability of the findings to other programs, disciplines, or educational settings. Third, the intervention was conducted over a relatively limited period, so the study does not provide evidence regarding the long-term retention of critical thinking skills. Fourth, the study focused primarily on test-based critical thinking outcomes and supporting classroom observations, while other potentially relevant factors such as digital literacy, learning motivation, prior academic ability, and the quality of internet access were not examined in depth. These limitations suggest that the findings should be interpreted with caution, particularly when extending them to broader higher education contexts.

Future research is therefore needed to examine the implementation of Padlet-based Problem-Based Learning over longer instructional periods and across more diverse academic settings. Studies involving larger

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samples from multiple institutions would help strengthen the generalizability of the findings. Further research may also include additional explanatory variables, such as motivation, self-regulated learning, digital literacy, and collaborative engagement, in order to clarify the mechanisms through which Padlet-based PBL influences critical thinking development. In addition, future studies could employ mixed-methods or longitudinal designs to capture not only quantitative changes in critical thinking scores but also the processes through which students develop interpretation, analysis, evaluation, inference, and explanation skills over time. Such work would provide a more comprehensive understanding of how digital collaborative platforms can be integrated effectively into higher education pedagogy to support higher-order thinking.

5. CONCLUSION

This study concludes that Padlet-based Problem-Based Learning (PBL) was more effective than Google Classroom-supported learning in improving Biology Education students' critical thinking skills. The experimental group achieved a higher post-test mean (80.64) than the control group (68.40), a higher N-gain score (0.75 vs. 0.60), and a statistically significant difference in critical thinking performance ($t = 5.23$, $p < 0.001$). These findings indicate that the integration of Padlet with PBL provides a more effective learning environment for fostering critical thinking than conventional digital classroom support alone. The greatest improvements were found in interpretation, evaluation, and analysis, while inference showed relatively lower gains, suggesting that students still need additional scaffolding in drawing conclusions from evidence. Overall, Padlet-based PBL supports critical thinking development by facilitating problem orientation, collaborative discussion, idea sharing, and reflective learning. Therefore, this approach can be recommended as an innovative alternative for higher education instruction, particularly for promoting students' higher-order thinking skills in the 21st century.

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