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The Effect of the Project-Based Learning (PjBL) Model on Students' Analytical Thinking Skills

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Abstract: Analytical thinking is a higher-order thinking skill required for understanding complex biological concepts, including the nervous system. This study aimed to examine the effect of Project-Based Learning (PjBL) on students' analytical thinking skills. A quantitative approach was employed using a quasi-experimental method with a nonequivalent control group design. The sample was selected through purposive sampling and comprised 61 eleventh-grade students at SMAN 1 Gunungsari, including 30 students from class XI F as the experimental group and 31 students from class XI D as the control group. Data were collected using essay tests based on five indicators of analytical thinking skills, observation sheets, and documentation. The data were analyzed using the Shapiro–Wilk test to assess normality, Levene's test to assess homogeneity of variance, the Mann–Whitney U test to examine differences between groups, and normalized gain (N-gain) analysis to determine the level of improvement. The mean score of the experimental group increased from 52.8 to 73.6, whereas that of the control group increased from 50.6 to 61.9. The Mann–Whitney U test yielded $U = 64.500$, $Z = -5.925$, and $p < 0.001$, indicating a significant difference between the two groups. The experimental group achieved an N-gain of 0.44, categorized as moderate, whereas the control group obtained an N-gain of 0.23, categorized as low. These findings indicate that PjBL resulted in significantly higher analytical thinking skills and greater improvement than conventional instruction in learning the nervous system.

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Introduction

Analytical thinking skills are a component of higher-order thinking that enables students to break down information, distinguish relevant elements, organize relationships among components, and explain conceptual connections logically. In the revised cognitive taxonomy, analyzing refers to the ability to decompose information into constituent parts and determine how those parts are related. These skills are particularly important in biology education because biological phenomena are generally organized as living systems composed of interacting components. The nervous system, for example, requires students to connect neuronal structure, mechanisms of impulse transmission, communication among neurons, organ coordination, and neurological disorders. Because of this complexity, the nervous system is prone to fragmented understanding and misconceptions when instruction focuses primarily on memorizing terms and structures (Anderson & Krathwohl, 2001; Momsen et al., 2022; Kvello & Gericke, 2021; Kvello, 2024).

In this study, the analytical thinking framework was operationalized through five indicators that were applied consistently in instrument development and data interpretation: differentiating, organizing, connecting, understanding concepts, and identifying. Differentiating refers to the ability to distinguish relevant from irrelevant information; organizing involves arranging information into a meaningful structure; connecting reflects the ability to relate concepts, data, or evidence; understanding concepts refers to the ability to explain the meaning and application of a concept; and identifying concerns the recognition of characteristics, key information, or problems that need to be addressed. Analytical thinking is closely related to critical thinking, but the two are not identical. Analytical thinking focuses more specifically on breaking information into parts and determining relationships among them, whereas critical thinking also includes interpretation, evaluation of evidence, assessment of credibility, inference, and accountable decision-making (Anderson & Krathwohl, 2001; Facione, 2020).

Preliminary observations underlying this study indicated that biology instruction at the research site still relied primarily on teacher explanations and structured assignments. These practices did not consistently provide students with opportunities to formulate questions, seek and process evidence, develop products, and justify academic decisions. Instruction dominated by passive reception of information tends to limit students' opportunities to examine relationships among concepts and apply knowledge to problem-solving situations. In contrast, learning that incorporates authentic activities, collaboration, inquiry, and reflection can enhance student engagement while supporting the development of higher-order thinking skills. Therefore, a learning model is needed that integrates conceptual analysis with contextual, collaborative, and problem-oriented activities (Almulla, 2020; Zhang & Ma, 2023).

One model that is consistent with these needs is Project-Based Learning (PjBL). PjBL uses projects as the primary vehicle for learning concepts through the formulation of driving questions, activity planning, investigation, information collection and analysis, product development, presentation, and reflection. This sequence provides opportunities for students to distinguish important information, organize tasks and data, connect evidence with concepts, and identify causes and alternative solutions to the problems being investigated. The effectiveness of PjBL is influenced by the clarity of project objectives, the relevance of projects to real-life contexts, task distribution, the availability of learning resources, teacher guidance, structured scheduling, and transparent assessment. In the context of science education in West Nusa Tenggara, PjBL has also been implemented through the development of practical learning tools designed to connect abstract concepts with concrete products (Kokotsaki et al., 2016; Almulla, 2020; Arifin et al., 2023).

Previous studies have shown that PjBL has positive effects on learning outcomes, student engagement, problem-solving abilities, and higher-order thinking skills. Meta-analytic evidence indicates that project-based learning generally produces better academic outcomes than teacher-centered instruction, although the magnitude of its effect may vary according to educational level, subject area, duration of intervention, group size, and implementation quality. However, most previous studies have involved different topics, educational levels, and indicators of thinking skills. Studies specifically measuring five indicators of analytical thinking in nervous system instruction at SMAN 1 Gunungsari remain limited. The nervous system was selected because it is abstract and systemic and requires an understanding of neural network architecture, synaptic communication, the initiation and transmission of impulses, and the coordination of different parts of the body (Chen & Yang, 2019; Zhang & Ma, 2023; Kvello, 2024).

Accordingly, the contribution of this study lies in examining the implementation of PjBL in nervous system instruction by assessing analytical thinking skills comprehensively and reporting achievement for each indicator. This study aimed to analyze differences in analytical thinking skills between students who participated in PjBL and those who received conventional instruction.

Research Method

Research Design

This study employed a quantitative approach using a quasi-experimental method. According to Sugiyono (2017), quasi-experimental research is used to examine the effect of a treatment on another variable under conditions in which the researcher cannot fully control all relevant variables. This method was selected because the school setting did not allow students to be randomly assigned to experimental groups. The existing classes were therefore maintained in accordance with school policy to avoid disrupting the ongoing instructional process. Consequently, two intact classes were designated as the experimental and control groups to compare the effects of Project-Based Learning (PjBL) on students' analytical thinking skills.

Although the study involved a comparison group, it was not possible to control all variables that might have influenced the research outcomes. Differences in students' initial characteristics, including academic ability, learning motivation, learning styles, and prior learning experiences, could not be fully controlled. External factors, such as the learning environment, interactions among students, and classroom conditions during the intervention, were also beyond the researcher's complete control. To minimize the influence of these potential confounding variables, both groups were taught the same subject matter, assessed using the same instruments, and provided with equivalent instructional time. A pretest was also administered before the intervention to assess the initial comparability of the experimental and control groups.

Research Design

This study employed a quasi-experimental design using a nonequivalent control group design. According to Sugiyono (2017), this design involves two pre-existing groups—an experimental group and a control group—that are not selected through random assignment. Both groups are administered a pretest and a posttest to determine changes in learning outcomes following the intervention.

Before the treatment, both groups completed a pretest to assess their initial analytical thinking skills. The experimental group then received instruction using the Project-Based Learning (PjBL) model, whereas the control group received conventional instruction. At the end of the instructional period, both groups completed a posttest to measure their analytical thinking skills in the nervous system topic. The effect of PjBL was determined by comparing the analytical thinking scores of the experimental and control groups after the intervention while considering their initial performance.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
A	X_1	Y_1	X_2
B	X_3	Y_2	X_4

Notes:
A = Experimental group
B = Control group
X_1 = Pretest administered to the experimental group
X_2 = Posttest administered to the experimental group

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X_3 = Pretest administered to the control group
X_4 = Posttest administered to the control group
Y_1 = Treatment using the Project-Based Learning model
Y_2 = Treatment using conventional instruction

Population and Sample

The population of this study comprised all eleventh-grade students at SMAN 1 Gunungsari during the 2025/2026 academic year. This population was selected because eleventh-grade students were considered to have reached a cognitive level that supports the development of analytical thinking skills through the implementation of Project-Based Learning (PjBL). The sample was selected using purposive sampling. This technique was employed because the selected classes met the criteria relevant to the objectives of the study. Specifically, the students had completed the prerequisite material required for learning the nervous system and had relatively comparable academic abilities based on information provided by the biology teacher. Based on these considerations, two classes were selected: class XI F as the experimental group and class XI D as the control group. The selection of these classes also considered the similarity of the curriculum, the biology teacher, and the instructional conditions. These criteria were applied to minimize differences between the groups that could influence the research outcomes. Therefore, the two classes were considered appropriate for comparing the effects of Project-Based Learning on students' analytical thinking skills.

Research Setting and Duration

This study was conducted during the 2025/2026 academic year over a period of one month. The research activities included preparation, implementation of the Project-Based Learning (PjBL) model, data collection through an analytical thinking skills test, and data analysis. All research procedures were adjusted to the school's established instructional schedule. The study was carried out at SMAN 1 Gunungsari, located in Gunungsari District, West Lombok Regency, West Nusa Tenggara, Indonesia. The school was selected because its eleventh-grade students met the characteristics required as research participants and because it had adequate facilities to support the implementation of the Project-Based Learning model.

Research Instruments

1) Analytical Thinking Skills Test

The test instrument consisted of essay questions designed to measure students' analytical thinking skills. The items were developed based on five indicators of analytical thinking: differentiating, organizing, connecting, understanding concepts, and identifying. The test was administered as a pretest and posttest to determine changes in students' analytical thinking skills before and after the learning intervention.

2) Observation Sheet

The observation sheet was used during the implementation of Project-Based Learning (PjBL) to directly assess students' analytical thinking skills and participation while completing the project. The observed aspects included:

a. the ability to identify problems;
b. the ability to collect and distinguish relevant information;
c. the ability to organize project procedures systematically; and

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d. the ability to analyze results and draw logical conclusions.

3) *Project Assessment Sheet*

The project assessment sheet was used to evaluate both the process and the outcomes of students' project work. It contained systematic and structured assessment criteria covering project planning, implementation, collaboration, data analysis, presentation, and the quality of the final product. This instrument enabled a comprehensive evaluation of students' performance throughout the different stages of the project.

Data Collection Techniques

1) *Test*

A test was administered to measure the analytical thinking skills of eleventh-grade students in the nervous system topic. The test was given as a pretest before the intervention and as a posttest after the implementation of Project-Based Learning (PjBL). The items were developed based on indicators of analytical thinking skills, including the abilities to identify problems, analyze relationships among concepts, organize relevant information, and draw conclusions based on scientific evidence. The instrument consisted of essay and case-based questions aligned with the Biology Learning Outcomes of the *Kurikulum Merdeka*. The test results were used to determine differences in students' analytical thinking skills between the experimental and control groups.

2) *Observation of Student Activities*

Student activities during the implementation of PjBL were observed systematically throughout the learning process. The observation focused on students' participation in group discussions, including their ability to express ideas and respond to others' opinions; organize ideas and formulate project procedures systematically; collaborate through interaction and equitable task distribution; and apply biological concepts by connecting theoretical knowledge with practical project activities. Students' abilities to analyze project results and formulate logical conclusions were also observed. The observation data provided supporting information regarding students' engagement and the development of their analytical thinking skills during the PjBL process.

3) *Documentation*

Documentation was used to obtain supporting data for the study. The collected documents included student identity data, attendance records, instructional materials, students' work, photographs of PjBL activities, and assessment records produced during instruction on the nervous system. These data were used to support and complement the findings obtained from the tests and classroom observations.

Data Analysis Techniques

1) *Normality Test*

The normality test was conducted to determine whether the students' analytical thinking skill scores were normally distributed. Normality is one of the assumptions required for applying parametric statistical procedures, such as the independent-samples t-test. In this study, data normality was examined using the Shapiro–Wilk test with the assistance of SPSS.
The hypotheses for the normality test were formulated as follows:

a. H_0: The data are normally distributed.
b. H_1: The data are not normally distributed.

The decision-making criteria were:

a. If the significance value (p) was greater than 0.05, H_0 was retained, indicating that the data were normally distributed.
b. If the significance value (p) was equal to or less than 0.05, H_0 was rejected, indicating that the data were not normally distributed.

2) *Homogeneity of Variance Test*

Levene's test was used to determine whether the experimental and control groups had equal variances. Homogeneity of variance is an important assumption for comparing two independent groups using parametric statistical analysis.

The hypotheses were:

a. H_0: The variances of the groups are homogeneous.
b. H_1: The variances of the groups are not homogeneous.

The decision-making criteria were:

a. If $p > 0.05$, H_0 was retained, indicating homogeneous variances.
b. If $p \leq 0.05$, H_0 was rejected, indicating heterogeneous variances.

When the assumptions of normality and homogeneity were satisfied, an independent-samples *t*-test could be used. When these assumptions were not satisfied, a nonparametric statistical test was applied.

3) *Hypothesis Testing*

The research hypothesis was tested using the Mann–Whitney U test at a significance level of 5% ($\alpha = 0.05$). This nonparametric test was selected because the data did not meet the assumption of normality. The test was used to determine whether students' analytical thinking skill scores differed significantly between the experimental group taught through Project-Based Learning (PjBL) and the control group taught through conventional instruction.

The statistical hypotheses were:

a. H_0: There is no significant difference in analytical thinking skills between students in the PjBL group and those in the control group.
b. H_a: There is a significant difference in analytical thinking skills between students in the PjBL group and those in the control group.

The decision-making criteria were:

a. If the Asymp. Sig. (2-tailed) value was greater than 0.05, H_0 was retained and H_a was rejected.
b. If the Asymp. Sig. (2-tailed) value was less than or equal to 0.05, H_0 was rejected and H_a was accepted.

All statistical analyses were performed using SPSS.

4) *Normalized Gain Analysis*

Normalized gain (N-gain) analysis was used to determine the magnitude of improvement in students' analytical thinking skills from the pretest to the posttest. The N-gain scores were interpreted according to the criteria presented in Table 2.

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Table 2. N-Gain Classification

N-gain range	Improvement category
N-gain > 0.70	High
0.30 ≤ N-gain ≤ 0.70	Moderate
N-gain < 0.30	Low

Source: Hake (1999).

Result and Discussion

Implementation of the Learning Process

The implementation of the learning process was observed throughout the instructional activities to determine the extent to which the stages of the Project-Based Learning (PjBL) model were carried out in accordance with the planned learning syntax. The observations were conducted by an observer using a learning implementation checklist developed based on the stages of Project-Based Learning.

The observation results showed that the learning activities in each meeting were implemented in accordance with the procedures specified in the teaching module. The observation data were subsequently presented in tabular form to show the percentage of learning implementation achieved at each meeting.

Table 3. Results of Learning Implementation

Component	Control Group				Experimental Group			
Meeting	I	II	III	IV	I	II	III	IV
Total Score	31	37	40	40	34	38	40	40
Maximum Score	40	40	40	40	40	40	40	40
Percentage	77.50%	92.50%	100%	100%	85%	95%	100%	100%
Category	Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good

Based on the learning implementation results presented in Table 4.1, the control group achieved an implementation percentage of 77.50% in the first meeting, categorized as good. This percentage increased to 92.50% in the second meeting and reached 100% in both the third and fourth meetings, categorized as very good. These results indicate a gradual improvement in the implementation of learning activities in the control group from the first to the final meeting.

Meanwhile, the experimental group achieved a very good category in all meetings, with implementation percentages of 85% in the first meeting, 95% in the second meeting, and 100% in both the third and fourth meetings. These findings demonstrate that the Project-Based Learning (PjBL) model was implemented successfully and consistently in accordance with the planned instructional syntax.

Results of the Analytical Thinking Skills Analysis

The results of the analysis of students' analytical thinking skills for each indicator are presented in Table 4.

Table 4. Results of the Per-Indicator Analysis of Analytical Thinking Skills

Group	Class and Test	A	B	C	D	E
Control	XI D Pretest	56	55	44	49	53
Control	XI D Posttest	70	65	53	60	70
Experimental	XI F Pretest	61	60	54	47	40
Experimental	XI F Posttest	74	70	73	75	72

Notes:
A = Differentiating
B = Organizing
C = Connecting
D = Understanding concepts
E = Identifying

Based on the comparison between the pretest and posttest results, both groups showed improvement across all indicators of analytical thinking skills. However, greater improvement was observed in class XI F, particularly in the indicators of connecting, understanding concepts, and identifying. Class XI D also demonstrated improvement in all indicators, with the highest gains occurring in differentiating and identifying. These findings indicate that the implemented instruction improved students' analytical thinking skills across all measured indicators.

Table 5. Results of the Analytical Thinking Skills Analysis

Category	Pretest		Posttest	
	Control	Experimental	Control	Experimental
Number of Students	31	30	31	30
Mean Score	50.6	52.8	61.9	73.6

Based on Table 5, the mean pretest score was 50.6 for the control group and 52.8 for the experimental group, indicating that the initial analytical thinking skills of the two groups were relatively comparable. Following the instructional intervention, the mean posttest score increased to 61.9 in the control group and 73.6 in the experimental group. These results show that both groups demonstrated improvement; however, the experimental group achieved a greater increase than the control group.

Normality Test Results

The normality test was conducted to determine whether the research data were normally distributed. In this study, data normality was examined using the Shapiro–Wilk test with the assistance of SPSS version 25. The Shapiro–Wilk test was selected because it is considered appropriate and sufficiently sensitive for relatively small to moderate sample sizes. The decision regarding data normality was based on the significance value (*p* or Sig.). The results of the normality test are presented in the following table.

Table 6. Results of the Normality Test

Tests of Normality							
		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Class	Statistic	df	Sig.	Statistic	df	Sig.
Analytical Thinking Skills Score	1	.173	31	.019	.825	31	<.001
	2	.210	31	.001	.924	31	.029
	3	.148	30	.094	.947	30	.137
	4	.226	30	<.001	.926	30	.038

Based on the Shapiro–Wilk normality test results presented in Table 6, the significance values were < 0.001 for Class 1, 0.029 for Class 2, 0.137 for Class 3, and 0.038 for Class 4. Using the criterion that data are considered normally distributed when the significance value is greater than 0.05, only the data from Class 3 were normally distributed. In contrast, the data from Classes 1, 2, and 4 did not meet the normality assumption. Therefore, most of the research data were not normally distributed, indicating that the overall dataset did not satisfy the assumption of normality.

Homogeneity of Variance Test Results

The homogeneity of variance test was conducted using Levene's test on the pretest and posttest scores of the experimental and control groups with the assistance of SPSS version 25. This test aimed to determine whether the variances of the data across the groups were equal. The data were considered homogeneous when the significance value (p) was greater than 0.05. Conversely, when the significance value was less than or equal to 0.05, the variances were considered heterogeneous. The results of the homogeneity of variance test are presented in the following table.

Table 7. Results of the Homogeneity of Variance Test

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.[a]
Analytical Thinking Skills Score	Based on Mean	11.252	3	118	<.001
	Based on Median	10.410	3	118	<.001
	Based on Median and with adjusted df	10.410	3	85.090	<.001
	Based on trimmed mean	11.523	3	118	<.001
a. Confidence Interval: 0%					

Based on the homogeneity test results presented in Table 7, Levene's test based on the mean yielded a Levene statistic of 11.252 with a significance value of $p < 0.001$. Since the significance value was lower than 0.05, the variances across the groups were significantly different and therefore not homogeneous. Thus, the assumption of homogeneity of variance for the analytical thinking skills scores was not met.

Mann–Whitney U Test Results

The Mann–Whitney U test is a nonparametric statistical procedure used to determine whether a significant difference exists between two independent groups. It serves as an alternative to the independent-samples *t*-test when the data do not satisfy the assumptions of normality or homogeneity of variance. The decision was based on the significance value (Asymp. Sig.). A significance value below 0.05 indicated a statistically significant difference between the two groups, whereas a significance value above 0.05 indicated no statistically significant difference. The results of the Mann–Whitney U test are presented in the following table.

Table 8. Hasil Uji *Mann-Whitney U*
Panel A. Ranks

Ranks				
	Class	N	Mean Rank	Sum of Ranks
Analytical Thinking Skills Score	1	31	18.08	560.50
	2	30	44.92	1392.50
	Total	61		

Panel B. Test Statistics

Test Statistics[a]	
	Analytical Thinking Skills Score
Mann-Whitney U	64.500
Wilcoxon W	560.500
Z	-5.925
Asymp. Sig. (2-tailed)	<.001
a. Grouping Variable: Class	

Panel A presents the rank distribution for the two groups, showing that the experimental group (Class 2) obtained a higher mean rank of 44.92 and a sum of ranks of 1,392.50 than the control group (Class 1), which obtained a mean rank of 18.08 and a sum of ranks of 560.50. These results indicate that the analytical thinking skills scores of students in the experimental group tended to be higher than those of students in the control group. Panel B presents the Mann–Whitney U test statistics, yielding a Mann–Whitney U value of 64.500, a Z value of −5.925, and an Asymp. Sig. (2-tailed) value of $p < 0.001$. Because the significance value was lower than 0.05, the null hypothesis was rejected, indicating a statistically significant difference in analytical thinking skills between the experimental and control groups.

N-Gain Test Results

Table 9. Results of the N-Gain Analysis

Group	Pretest	Posttest	N-Gain	N-Gain Category
Control (n = 31)	50.6	61.9	0.23	Low
Experimental (n = 30)	52.8	73.6	0.44	Moderate

Based on the N-Gain analysis presented in Table 4.7, the control group showed an increase in the mean score from 50.6 on the pretest to 61.9 on the posttest, with an N-Gain score of 0.23, which was categorized as low. Meanwhile, the experimental group showed an increase from 52.8

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on the pretest to 73.6 on the posttest, with an N-Gain score of 0.44, which was categorized as moderate. These results indicate that both groups experienced improvement in analytical thinking skills after instruction; however, the experimental group demonstrated a greater level of improvement than the control group. Thus, Project-Based Learning produced a higher descriptive improvement in students' analytical thinking skills than conventional instruction.

Discussion

1) Implementation of Project-Based Learning

Based on the observation results presented in Table 3, learning activities in both the control and experimental groups were implemented in the good to very good categories. In the control group, the implementation percentage increased from 77.50% in the first meeting to 92.50% in the second meeting and reached 100% in the third and fourth meetings. Meanwhile, the experimental group achieved 85% in the first meeting, 95% in the second meeting, and 100% in both the third and fourth meetings.

These findings indicate that the planned learning activities were generally implemented consistently in both groups. However, the experimental group maintained the very good category from the first meeting, suggesting that the stages of Project-Based Learning (PjBL) could be implemented in accordance with the instructional plan. The gradual increase observed in the control group may reflect the teacher's and students' adjustment to the learning procedures across meetings.

The structured stages of PjBL, including formulating a driving question, planning the project, conducting investigations, developing a product, presenting results, and reflecting on the learning process, may have supported systematic classroom activities. These stages also provided opportunities for students to collaborate, communicate ideas, and assume responsibility for completing group tasks. Nevertheless, the implementation percentages primarily indicate the extent to which the planned instructional procedures were carried out and should not, by themselves, be interpreted as direct evidence of improved learning outcomes. This interpretation is consistent with Kokotsaki et al. (2016), who emphasized that clearly organized project stages, appropriate teacher guidance, collaboration, and reflection are important conditions for the successful implementation of PjBL.

2) Students' Analytical Thinking Skills Following the Implementation of PjBL

The results showed an increase in analytical thinking scores in both groups. The mean score of the control group increased from 50.6 on the pretest to 61.9 on the posttest, whereas the mean score of the experimental group increased from 52.8 to 73.6. The relatively similar pretest means suggest that the two groups had broadly comparable initial analytical thinking skills at the descriptive level. Following the intervention, students in the experimental group achieved higher posttest scores than those in the control group.

Improvement was also observed across all five indicators of analytical thinking skills. In the experimental group, the largest increases occurred in connecting, understanding concepts, and identifying. These results suggest that project activities provided students with opportunities to relate evidence to biological concepts, interpret information, and recognize key features of problems associated with the nervous system. Through project planning, investigation, discussion, and presentation, students were required to process information rather than merely recall biological terms.

The control group also demonstrated improvement across the measured indicators, particularly in differentiating and identifying. This finding indicates that conventional instruction also supported students' learning to some extent. However, the increase was descriptively lower than that observed in the experimental group. The N-gain results supported this pattern: the experimental group obtained an N-gain of 0.44, categorized as moderate, whereas the control group obtained an N-gain of 0.23, categorized as low. Because the N-gain values were interpreted descriptively, they indicate a greater level of improvement in the experimental group but do not independently establish statistical significance.

The higher outcomes in the experimental group may be associated with the learning experiences provided through PjBL. Students were involved in identifying problems, collecting and organizing information, relating concepts, analyzing project findings, and presenting conclusions. These activities correspond closely to the analytical thinking indicators assessed in this study. In contrast, conventional instruction provided relatively fewer opportunities for sustained investigation and project-based problem-solving.

These findings are consistent with Ware and Rohaeti (2018), who reported that student-centered problem-solving activities supported the development of analytical thinking skills. Yustina et al. (2020) also found that PjBL facilitated higher-order thinking through investigation, collaboration, and project completion. Therefore, the present findings support the view that students participating in PjBL may achieve stronger analytical thinking outcomes than those participating in conventional instruction, particularly when project activities are aligned with the skills being assessed.

3) *Assumption Testing and Statistical Comparison*

The Shapiro–Wilk test showed that only one of the four datasets met the normality criterion, whereas the remaining datasets had significance values below 0.05. Thus, the analytical thinking data generally did not satisfy the assumption of normality. Levene's test also yielded a significance value of $p < 0.001$, indicating that the variances across the groups were not homogeneous. Because the assumptions required for parametric comparison were not fulfilled, the Mann–Whitney U test was used to compare the two independent groups.

The non-normal distribution may reflect variations in students' initial abilities, learning experiences, and responses to analytical thinking questions. However, these possible explanations were not directly examined in the present study and should therefore be interpreted cautiously. Similarly, the heterogeneous variances indicate that the spread of scores differed across the groups, but this result should not automatically be attributed solely to the instructional treatment.

Based on the reported Mann–Whitney U output, the test produced a significance value of $p < 0.001$, indicating a statistically significant difference in analytical thinking scores between the control and experimental groups. The experimental group obtained a higher mean rank of 44.92 than the control group, which obtained a mean rank of 18.08. This result indicates that the distribution of analytical thinking scores in the experimental group was higher than that in the control group.

The findings are consistent with Fitriyah and Ramadani (2021), who reported significant differences in higher-order thinking outcomes between students participating in PjBL-based instruction and those receiving conventional instruction. Fisher et al. (2021) similarly found differences between PjBL and comparison groups using nonparametric analysis when statistical assumptions were not satisfied. Overall, the present results indicate that students who participated in PjBL achieved higher analytical thinking outcomes than students who received conventional instruction. Nevertheless, because this study used intact classes without random assignment, the findings should be interpreted as evidence of differences associated with the instructional intervention rather than as proof that PjBL was the sole cause of the observed outcomes.

Conclusion

Based on the findings and discussion regarding the implementation of Project-Based Learning (PjBL) and students' analytical thinking skills, the following conclusions can be drawn:

1) Students in the experimental group demonstrated an improvement in analytical thinking skills, as indicated by an increase in the mean score from 52.8 on the pretest to 73.6 on the posttest. Improvement was also observed across all measured indicators of analytical thinking and was descriptively greater than that observed in the control group.
2) The Mann–Whitney U test yielded an Asymp. Sig. (2-tailed) value of $p < 0.001$, indicating a statistically significant difference in analytical thinking skills between the experimental and control groups. Students who participated in PjBL achieved higher analytical thinking outcomes than those who received conventional instruction.

Overall, the implementation of PjBL was associated with greater improvement and higher analytical thinking outcomes among eleventh-grade students at SMAN 1 Gunungsari. However, because this study employed a quasi-experimental design without random assignment, the findings should be interpreted cautiously, as the possible influence of factors beyond the instructional treatment could not be fully controlled.

Recommendations

Based on the findings of this study, the following recommendations are proposed.

1) For teachers, Project-Based Learning (PjBL) may be used as an alternative approach in biology instruction, particularly for topics that require students to connect concepts, analyze information, identify problems, and develop solutions. Its implementation should be supported by clear project guidelines, appropriate task distribution, sufficient instructional time, and continuous guidance throughout the investigation process.
2) For schools, the implementation of PjBL should be supported by adequate learning resources, instructional media, facilities, and policies that enable students to conduct investigations, collaborate effectively, and present their project outcomes.
3) For future researchers, similar studies should involve larger samples from multiple schools to improve the generalizability of the findings. Future research may also employ a stronger experimental design, control students' initial abilities more rigorously, and examine additional variables such as learning motivation, collaboration skills, and student engagement.
4) Future studies are also recommended to use a longer intervention period, conduct delayed posttests to examine the retention of learning outcomes, and complement quantitative data with interviews, classroom observations, or project-product analysis to provide a more comprehensive explanation of the development of students' analytical thinking skills.

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