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Impact of Project-Based Learning on Mathematical Communication and Critical Thinking Skills in Grade VII Statistics Learning

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ABSTRACT

This study addresses the challenge of low levels of mathematical communication and critical thinking among students, often stemming from the widespread use of traditional, teacher-centred instructional methods. The objective of this research is to examine the impact of the Project-Based Learning (PjBL) model on seventh-grade students' mathematical communication and critical thinking skills in statistics. A quasi-experimental design with a Nonequivalent Control Group was applied. Participants included 35 students in the experimental group (Class VII-3, using PjBL) and 35 students in the control group (Class VII-5, using conventional methods) at MTs Al-Jam'iyatul Washliyah Tembung. Data was collected using tests for critical thinking and observation sheets for mathematical communication skills. The results showed significantly higher average scores in the experimental group compared to the control group for both skills. Specifically, the mean scores for mathematical communication were 88.05 (experimental) versus 48.84 (control), and for critical thinking were 74 (experimental) versus 50.28 (control). The Independent-Samples t-Test confirmed significant differences (Sig. 2-tailed = 0.000 < 0.05) for both skills, while ANOVA (F = 43.634, Sig. = 0.000 < 0.05) further confirmed PjBL's significant positive effect on learning outcomes. These findings demonstrate that the Project-Based Learning (PjBL) model is effective in enhancing students' mathematical communication and critical thinking skills.

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1. INTRODUCTION

Education is a fundamental endeavour that shapes human development and well-being [1], aiming to nurture innate physical and spiritual potentials and to acquire the necessary knowledge, skills, and attitudes for life [2], [3]. Mathematics, as a core subject [4], is a science that discusses symbolic language, patterns, and structures [5], and serves both as a foundational discipline and a tool with extensive applications in daily life [6], [7].

Despite its importance, educational observations and student perspectives [8] consistently highlight challenges in developing high-level mathematical abilities [9]. The primary research problem identified is the low level of mathematical communication skills—the ability to express ideas verbally, in writing, or through symbols—and inadequate critical thinking skills, defined as the logical analysis, evaluation, and interpretation of information [10]. This deficit is reflected in students' lack of confidence in explaining solutions and in their difficulty in analyzing complex information.

The learning environment exacerbates the challenge. Field evidence, including interviews with mathematics teachers at MTs Al-Jam'iyatul Washliyah Tembung, indicates the pervasive use of traditional, teacher-centred methods, such as one-way lectures [11]. This conventional approach restricts students' engagement and hinders conceptual understanding, leaving them poorly trained in critical thinking and in applying concepts to real-life situations. This necessity for a more active, student-centred learning model forms the basis for the theoretical study underpinning this research.

To overcome this problem, the authors plan to implement the Project-Based Learning (PjBL) model, which actively engages students in projects addressing real-world issues, such as conducting statistical investigations involving observation and analysis [12]. The viability of PjBL is strongly supported by previous research. Studies have confirmed PjBL's positive impact on critical thinking and communication skills [13], [14], demonstrating that it effectively enhances mathematical communication compared to conventional methods [13]. PjBL also boosts critical thinking by facilitating knowledge construction and skill development [15] and by training students to discover concepts through practical work and problem-solving [16]. This model aligns with the constructivist view that deeper learning is achieved when students actively construct knowledge through direct experience [17].

While the benefits of PjBL in enhancing critical thinking, mathematical communication, and learning outcomes have been broadly corroborated [18], [19], [20]. Previous studies have not examined PjBL specifically on communication and critical thinking simultaneously in statistics learning at the MTs level. This study specifically focuses on measuring the effect of PjBL on both mathematical communication and critical thinking skills simultaneously within the context of statistics material for seventh-grade students at MTs Al-Jam'iyatul Washliyah Tembung.

Therefore, the main objective of this research is to examine the impact of the Project-Based Learning (PjBL) model on seventh-grade students' mathematical communication and critical thinking skills in statistics.

2. METHOD

This quasi-experimental study used a Nonequivalent Control Group Design [21]. The population comprised all seventh-graders at MTs Al-Jam'iyatul Washliyah Tembung. Cluster random sampling was used to select two classes: VII-3 as the experimental class (using PjBL) and VII-5 as the control class (using traditional methods), with 35 students in each.

Prior to the study, formal school permission was obtained from the principal of MTs Al-Jam'iyatul Washliyah Tembung. Informed consent was secured from the mathematics teachers and students' guardians to ensure voluntary participation and adherence to ethical research standards.

Mathematical Communication Skills were operationally defined and measured through indicators such as articulating opinions, using mathematical symbols, and creating visual representations during the learning process.

Critical Thinking Skills were operationally defined as the ability to logically analyse, evaluate, and interpret information, and were measured using essay questions that assessed indicators of mathematical critical thinking.

Data collection approaches in this study were carried out using four methods [22], namely:

a. Tests
   Students' critical thinking skills were assessed through tests administered before and after the treatment. The tests were administered as essay questions assessing indicators of mathematical critical thinking, both in the pretest and posttest.
b. Observation
   Observations were conducted to assess students' mathematical communication skills during the learning process. The researcher used an observation sheet that included indicators of mathematical communication, such as articulating opinions, using mathematical symbols, and creating visual representations.
c. Documentation
   Documentation was used to obtain supporting data, including syllabi, photos of learning activities, teaching modules, and student learning outcome scores.

Project Assessment Rubric: The student projects in the experimental class were assessed based on an assessment rubric covering five aspects: 1. Data accuracy, 2. Table/graph presentation, 3. Data analysis, 4. Group cooperation, and 5. Presentation. Each aspect was scored on a scale of 1 to 4. The following procedures were used in a quantitative analysis of the gathered data:

a. Prerequisite Tests
   A Normality Test was performed using either the Kolmogorov-Smirnov or Shapiro-Wilk test to determine whether the data were regularly distributed. A Homogeneity Test (Levene test) was used to evaluate variance homogeneity between groups.
b. Hypothesis Testing
   The PjBL model's impact on mathematical communication and critical thinking skills was assessed. An Independent Sample t-test was used if the data were normally distributed and homogeneous. The Mann-Whitney test was applied if the data were not normally distributed or homogeneous. Prerequisite tests were performed prior to conducting an ANOVA test. Descriptive analysis was also carried out in conjunction with inferential statistical tests (Rangkuti et al., 2024). These statistical analyses were performed using SPSS version 25.0.

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3. RESULTS AND DISCUSSION

3.1. Results

This research investigates how the Project-Based Learning (PjBL) model affects students' critical thinking and communication abilities in mathematics. Tests of critical thinking, observations of mathematical communication abilities, and learning records from two groups—the experimental and control classes—were used to gather data.

1. Results of Instrument Validity and Reliability Tests

   To ensure the quality and feasibility of the research instruments, validation was carried out by three experts, namely teaching module experts, observation experts, and critical thinking ability test experts, as shown in Table 1 below:

Table 1. Expert Instrument Validation

Validator	Percentage	Criteria
Expert validation of teaching modules	68,75%	Quite decent
Expert validation of observation sheets	71,875%	Quite decent
Validation of critical thinking tests	71,875%	Quite decent

   The validation results show that all instruments are in the "sufficiently feasible" category, based on a feasibility interpretation range of 61% to 80%. The 68.75% score in the teaching module indicates that the content aligns with the learning outcomes but still requires minor improvements in presentation or activity arrangement. Meanwhile, the observation sheet and the critical thinking test each scored 71.875%, indicating that the indicators, format, and content of the instruments are sufficiently representative for research use. Thus, it can be concluded that all research instruments meet the feasibility criteria and can be used to measure variables in research. However, it is recommended that improvements be made based on validator input before field use.

2. Item Validity Test (Empirical)

   The purpose of the instrument's validity test is to verify how closely the specified indicators are reflected in the critical thinking test items. The Pearson Product-Moment correlation method in SPSS version 25.0 was used to perform the validity test. The following were the validity test's decision criteria:

   a. The item was deemed valid if the rhitung value was greater than rtable.
   b. The item was deemed invalid if the rhitung value was less than or equal to rtable.

   There were five products that were tried. With a sample size of 35 and a significance level of 5%, the rtabel value is 0.324. The test results presented in the table, as mentioned earlier, indicate that all items have rhitung values > rtabel. Thus, all items are valid and suitable for measuring students' critical thinking skills. Table 2 below displays the outcomes of the data processing:

Table 2. Summary of item validity test results

No.	r_{xy}	r_{tabel}	Interpretation
1	0,718	0,324	Valid
2	0,705	0,324	Valid
3	0,635	0,324	Valid
4	0,701	0,324	Valid
5	0,769	0,324	Valid

3. Instrument Reliability Test

The consistency of the instrument's measurement results is assessed through reliability testing. Cronbach's alpha was computed in this study using SPSS version 25.0. Table 3 displays the resulting Cronbach's alpha values.

Table 3. Reliability

Reliability Statistics	
Cronbach's Alpha	N of Items
,743	6

Based on the obtained Cronbach's Alpha value of 0.743, which falls within the 0.60–0.79 range, the test instrument demonstrates good reliability and is suitable for research purposes.

Research Data Description

1. Student Mathematical Communication Ability Data

Student Response Data to the PjBL Model

Students' mathematical communication abilities in this study were measured using an observation sheet consisting of several indicators. Observations were conducted throughout the learning process in both the experimental and control classes, implementing the Project-Based Learning (PjBL) model.

Table 4. Descriptive Statistics of Mathematical Communication Skills

Statistics	Experimental	Control
Number of Students	35	35
Minimum Score	81.25	34.38
Maximum Score	96.88	62.5
Mean (Average)	88.05	48.84
Median	87.5	50.0
Standard Deviation	4.46	7.34

The experimental class received an average score of 88.05 (standard deviation = 4.46) in a descriptive statistical analysis of students' mathematical communication abilities. The control group, on the other hand, received an average score of 48.84 (standard deviation = 7.54). The experimental class exhibited minimum and maximum scores of 81.25 and 96.88, respectively, while the control class recorded minimum and maximum scores of 34.38 and 62.5, respectively. Students in the experimental class showed optimal growth in mathematical communication skills, as evidenced by significantly higher average scores and a wider score range. The application of the Project-Based Learning (PjBL) model during instruction is closely linked to this result.

2. Student Critical Thinking Ability Data

Table 5. Descriptive Statistics of the Experimental Class and Control Class

Statistics	Experimental	Control
Number of Students (N)	35	35
Minimum Score	40	25
Maximum Score	100	80
Mean (Average)	74	50.28
Median	75	50
Standard Deviation	15.36	13.06

The experimental class's mean critical thinking score was 74, while the control class's was 50.28, according to descriptive statistical analysis. The median score for the experimental class was 75, indicating that the majority of pupils scored higher than this threshold. The control class, on the other hand, had a median score of 50, suggesting that student performance was concentrated at lower to intermediate levels. The experimental class's standard deviation was 15.36, which was marginally higher than the control class's 13.06. This indicates that, despite the experimental class's greater score variability, the distribution remained centred around a higher average.

Statistical Analysis Prerequisite Tests

1. Normality Test of Mathematical Communication Skills
   A normality test was conducted to determine whether the mathematical communication ability data from the experimental and control classes were normally distributed. The normality test was conducted using the Shapiro-Wilk Test because the sample size per group was less than 50. The following are the results of the normality test for mathematical communication ability data:

Table 6. Normality Test of Mathematical Communication Ability

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistics	df	Sig.	Statistics	Df	Sig.
control_group	,126	35	,278	,956	35	,370
experimental_group	,234	35	,234	,915	35	,211

According to the preceding table, both groups' significance values are greater than 0.05. Because the sample size was fewer than fifty, the Shapiro-Wilk test was chosen.
The majority of posttest data are distributed, allowing analysis of group differences using parametric tests such as the t-test.

2. Mathematical Communication Skills Homogeneity Test
   To determine whether the differences in mathematical communication abilities between the experimental and control groups were comparable, a homogeneity test was run. The SPSS result shows that Levene's Test for Equality of Variances was used. The following significant values were obtained from the test:

Table 7. Test of Homogeneity of Mathematical Communication Skills Test of Homogeneity of Variances

		Levene Statistics	df1	df2	Sig.
mathematical_communication_ability_score	Based on Mean	11,115	1	68	,201
	Based on Median	11,026	1	68	,201
	Based on Median and with adjusted df	11,026	1	60,413	,102
	Based on trimmed mean	11,214	1	68	,201

The results for mathematical communication skills show homogeneous variance between the experimental and control groups, as all significant values are greater than 0.05. As a result, the homogeneity condition is met, enabling additional statistical analysis under the equal-variance assumption using the t-test.

3. Students' Critical Thinking Ability Normality Test
   To determine if the data on critical thinking skills in the experimental and control groups followed a normal distribution, a normality test was run. Because there were less than 50 students in each group, the Shapiro-Wilk Test was chosen. The results of the normality test for the critical thinking ability data are shown below.

Table 8. Normality Test of Students' Critical Thinking Ability

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistics	Df	Sig.	Statistics	df	Sig.
pretest_control	,196	35	,201	,910	35	,237
posttest_control	,144	35	,266	,963	35	,275
pretest_exprimental	,290	35	,300	,847	35	,234
posttest_exprimental	,125	35	,181	,956	35	,171

Based on the table above, it can be seen that:

a. The pretest data for both the control and experimental classes show normal distributions (Sig. > 0.05).
b. The posttest data in both classes exhibit significance values greater than 0.05, indicating normal distribution.

Therefore, because most posttest data are typically distributed, parametric tests such as the t-test remain appropriate for analysing group differences.

4. Test of Homogeneity of Students' Critical Thinking Skills
   A homogeneity test was performed to assess whether the variance in critical thinking skills between the experimental and control groups was equivalent. Levene's Test for Equality of Variances was utilised, as presented in the SPSS output. The test results yielded the following significance values:

Table 9. Test of Homogeneity of Students' Critical Thinking Skills Test of Homogeneity of Variances

		Levene Statistics	df1	df2	Sig.
critical_thinking_score	Based on Mean	3,725	1	68	,058
	Based on Median	3,435	1	68	,068
	Based on Median and with adjusted df	3,435	1	66,922	,068
	Based on trimmed mean	3,639	1	68	,061

The significant value (Sig.) of Levene's Test is 0.058, according to the homogeneity test results. It can be inferred that the variance of the critical thinking ability data is homogeneous between the experimental and control classes, as the p-value is greater than 0.05 (0.058 > 0.05). As a result, the homogeneity assumption is met, and the t-test can be used for further data analysis under the assumption of equal variances.

Hypothesis Testing

1. Analysis of Mathematical Communication Ability Using t-test

Table 10. Independent Samples t-test Results for Mathematical Communication Ability

		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference
mathematical_communication_skills_score	Equal variances assumed	11,115	,001	- 25,985	68	,000	12,314
	Equal variances not assumed	11,115	,001	- 25,985	54,45 1	,000	12,314

The Independent Samples t-Test produced a significance value (Sig. 2-tailed) of 0.000 in the Equal variances assumed row. Since 0.000 is less than 0.05, this result indicates a statistically significant difference between the control and experimental classes regarding students' mathematical communication skills.

Analysis of t-Test Results for Students' Critical Thinking Skills

Table 11. Independent Samples t-Test of Critical Thinking Skills

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Critical_thinking_score	Equal variances assumed	3,725	,058	6,606	68	,000	23,714	3,590	16,550	30,878
	Equal variances not assumed			6,606	63,983	,000	23,714	3,590	16,542	30,886

In the Equal variances assumed row, the Independent Samples t-Test produced a significance value (Sig. 2-tailed) of 0.000. There is a statistically significant difference between the experimental and control groups in students' critical thinking abilities, as indicated by the Sig. value. (2-tailed) = 0.000 is less than 0.05.

2. ANOVA Test

Before conducting the ANOVA test, a test of variance homogeneity was first performed using Levene's Test. The test results showed significance values based on various calculations (mean, median, median with adjusted df, and trimmed). All values exceeded the 0.05 significance threshold, indicating that the data originated from a population with homogeneous variance. Therefore, the assumption of homogeneity required for the ANOVA test was satisfied. The ANOVA test table is presented below:

Table 12. Test ANOVA

ANOVA

value

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9841,429	1	9841,429	43,634	,000
Within Groups	15337,143	68	225,546		
Total	25178,571	69			

(Sumber: SPSS 25.0)

The ANOVA test produced an F value of 43.634 and a significance value of 0.000, which is less than 0.05, as shown in the table above. These findings show that there was a statistically significant difference between the treatment groups. As a result, the alternative hypothesis (H_1) is accepted and the null hypothesis (H_0), which asserts that there is no difference between the groups, is rejected. We may conclude that the treatment used in this study had a substantial impact on students' learning outcomes.

Results of Student Projects

Instruction in the experimental class used the Project-Based Learning (PjBL) model, implemented over two project sessions. At each meeting, students were divided into several groups and given project assignments related to statistics, such as collecting data from the surrounding environment, compiling frequency distribution tables, creating bar and circle graphs, and preparing reports to present to the class. Project assessment was based on an assessment rubric covering five aspects, namely:

a. Data accuracy,
b. Table/graph presentation,
c. Data analysis,
d. Group cooperation,
e. Presentation.

Each aspect is scored from 1 to 4, and the final project score is calculated from the accumulated scores of the two meetings. The scores are then converted into percentages to facilitate the classification of student achievement. The following table summarises the project scores of the experimental class students based on their groups:

Table 13. Summary of Student Project Results

Group	Average score (%) Meeting 1	Average score (%) Meeting 1	Category
Group 1	91,6%	91,6%	Very Good
Group 2	95,8%	95,8%	Very Good
Group 3	95,8%	95,8%	Very Good
Group 4	89,3%	89,3%	Good
Group 5	91,6%	91,6%	Very Good
Group 6	95,8%	95,8%	Very Good
Group 7	87,3%	91,6%	Good-Very Good
Group 8	95%	95,5%	Very Good
Group 9	91,6%	95%	Very Good

In general, the project scores of all groups were in the "Very Good" category, with the highest scores obtained by Groups 2, 3, and 6 at 95.8%, while the lowest scores of 87.3% were obtained by Groups 4 and 7. This shows that project-based learning successfully increased student participation and understanding of statistical material. To clarify the distribution of project scores between groups.

3.2. Discussion

The study's findings, which demonstrated that the Project-Based Learning (PjBL) model significantly improved both students' mathematical communication and critical thinking skills compared to conventional methods, validate the effectiveness of PjBL in a statistics education context. The observed improvement is not merely a statistical artefact but a direct consequence of the PjBL model's core pedagogical mechanisms, which align with contemporary learning theories [23], [24].

The success of PjBL in enhancing these dual skills can be explained through several key theoretical principles embedded within its structure:

Inquiry and Problem-Solving Process:

The PjBL structure, which begins with a challenging, real-world statistical problem (e.g., collecting and analysing real data), inherently fosters critical thinking [25]. Students are compelled to engage in the full cycle of inquiry, including defining the problem, gathering relevant data, analysing information, and synthesising a solution [15]. This sustained engagement with authentic tasks—unlike the passive reception of information in the control group—develops their ability to analyse, evaluate, and interpret data logically.

Scaffolding and Collaboration:

PjBL necessitates intensive group work and iterative project phases. Within these groups, scaffolding occurs naturally, where more capable peers support others in mastering new statistical concepts or tools (e.g., constructing a frequency distribution or graph). Crucially, the collaborative nature of PjBL requires students to continually explain their methods, justify their interpretations of the data, and negotiate findings with peers [26]. This active process of externalising thought is the engine for developing strong mathematical communication skills, forcing students to use precise mathematical language, symbols, and visual representations [27].

Constructivism and Ownership: By putting students in charge of their project—from design to presentation—PjBL activates the principles of constructivist learning [17]. Students actively construct statistical knowledge rather than passively receiving it. This ownership leads to deeper motivation and a more meaningful understanding of statistical concepts, which is essential for both applying critical thought and communicating complex ideas clearly.

4. CONCLUSION

This study firmly concludes that implementing the Project-Based Learning (PjBL) model significantly and simultaneously enhances both mathematical communication and critical thinking skills of seventh-grade students in statistics learning compared to conventional teaching methods. The integrated, inquiry-based approach of PjBL effectively shifts students from passive recipients of information to active constructors of knowledge, thereby facilitating the development of these crucial high-order thinking skills.

The findings carry several important implications for education stakeholders:

1. For Mathematics Teachers: The study provides empirical evidence that PjBL is an effective, student-centred pedagogical tool for statistics. Teachers are encouraged to adopt PjBL to move away from rote learning and engage students in authentic data investigation projects that naturally foster communication (through collaboration and presentation) and critical analysis (through data interpretation).

2. For Curriculum Designers: The results suggest that curriculum and instructional design documents, particularly those related to statistics and data analysis, should formally integrate project-based learning methodologies. Curriculum materials should prioritise tasks that require students to solve complex, open-ended problems and communicate their findings rigorously.
3. For Future Research: Given the study's limitations regarding sample size and duration, future research should focus on conducting longitudinal studies across multiple schools and diverse student populations to test the long-term retention and generalizability of PjBL's impact. Additionally, future work could explore the specific moderating role of different PjBL phases (e.g., scaffolding techniques, presentation methods) on the development of these dual skills.

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