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The Effect of the Inquiry-Based Learning Model on Students' Mathematical Communication Skills: A Quasi-Experimental Study

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ABSTRACT

Mathematical communication skills are essential in mathematics learning because they enable students to express mathematical ideas, use representations, explain solution processes, and construct logical arguments. This study aimed to examine the effect of the Inquiry-Based Learning (IBL) model on students' mathematical communication skills. A quantitative approach with a quasi-experimental pretest–posttest control group design was employed. The participants were 68 Grade XI students of SMA Negeri 1 Sedayu, consisting of an experimental group that received Inquiry-Based Learning and a control group that received conventional instruction. Data were collected using a five-item open-ended mathematical communication test developed based on mathematical communication indicators. The instrument demonstrated acceptable validity and reliability, with Cronbach's alpha coefficients of 0.870 for the pretest and 0.704 for the posttest. Data were analyzed using descriptive statistics, prerequisite tests, analysis of covariance (ANCOVA), N-Gain analysis, and Cohen's d effect size. The ANCOVA results showed that, after controlling for students' initial abilities, the instructional group had a significant effect on posttest mathematical communication scores ($F(1,65)=25.477$, $p<0.001$, partial $\eta^2=0.282$). The experimental group also obtained a higher average N-Gain score (44.14%, moderate category) compared with the control group (25.39%, low category), with a large effect size ($d=1.23$). These findings indicate that Inquiry-Based Learning provides a meaningful learning approach for supporting students' mathematical communication skills by encouraging them to express ideas, use mathematical representations, explain reasoning, and construct arguments.

Keywords: Inquiry-Based Learning; Mathematical Communication Skills; Mathematics Education; Quasi-Experimental Study; Senior High School.

INTRODUCTION

Mathematics learning plays an important role in developing students' logical, systematic, and critical thinking abilities (OECD, 2023). However, mathematics learning does not only require students to understand mathematical concepts but also to communicate their ideas and reasoning processes clearly. Mathematical communication is an essential component of mathematics learning because it enables students to organize and express mathematical thinking, use appropriate representations, explain reasoning, and communicate solutions systematically (National Council of Teachers of Mathematics [NCTM], 2000). Therefore, students need to develop mathematical communication skills as part of their ability to understand and solve mathematical problems.

Mathematical communication skills include students' ability to express mathematical ideas through mathematical language, symbols, tables, diagrams, and other representations. Students with strong mathematical communication skills are generally better able to understand concepts, explain problem-solving processes, and provide logical justification for their answers (Rahmi et al., 2024). Thus, developing mathematical communication skills requires learning environments that provide opportunities for students to actively construct, discuss, and communicate mathematical ideas.

However, students' mathematical communication skills remain a challenge in mathematics learning. Based on a preliminary study conducted at SMA Negeri 1 Sedayu involving 36 students, the average mathematical communication skill score was 38.75 on a 100-point scale. This result indicates that students' mathematical communication skills were still relatively low. Among the 36 students, 26 students (72.22%) were categorized as having very low mathematical communication skills, 8 students (22.22%) were in the low category, and only 2 students (5.56%) reached the sufficient category. No students achieved the good or very good category.

The preliminary study results also showed that students experienced difficulties in expressing mathematical ideas and explaining their reasoning processes. The lowest score obtained by students was 22%, while the highest score was only 59%. Students were not yet accustomed to presenting solution steps systematically, using mathematical representations appropriately, and explaining the reasons behind their answers.

Further analysis based on the five indicators of mathematical communication showed that students experienced difficulties across all aspects. The first indicator obtained an average score of 8.64 (43.19%), the second indicator 8.28 (41.39%), the third indicator 8.14 (40.69%), the fourth indicator 5.78 (28.89%), and the fifth indicator 7.92 (39.58%). The fourth indicator represented the lowest achievement, indicating that students experienced the greatest difficulties in explaining solution processes, relating mathematical concepts, and constructing logical arguments based on mathematical problems.

One factor contributing to students' low mathematical communication skills is the learning process that still tends to emphasize teacher explanations and procedural exercises. In such learning situations, students may understand mathematical procedures but have limited opportunities to ask questions, discuss ideas, formulate predictions, and communicate their reasoning independently (Kurniasih et al., 2020). Therefore, mathematics learning requires an approach that provides students with opportunities to actively engage in investigation, discussion, and explanation of mathematical ideas.

One learning model that has the potential to address this issue is Inquiry-Based Learning (IBL). Inquiry-Based Learning emphasizes students' active involvement in constructing knowledge through questioning, investigation, information gathering, analysis, and communication of findings (Duran & Dökme, 2016). According to Pedaste et al. (2015), inquiry-based learning consists of several phases, including orientation, conceptualization, investigation, conclusion, and discussion. These phases encourage students to actively explore problems, develop explanations, and communicate the results of their investigations. In this learning model, the teacher acts as a facilitator who guides students throughout the inquiry process rather than merely delivering information (Acar & Tuncdogan, 2019; Aras et al., 2024).

The characteristics of Inquiry-Based Learning are closely related to the development of mathematical communication skills. During the orientation and conceptualization phases, students are encouraged to understand problems and formulate mathematical questions. During the investigation phase, students practice using mathematical symbols, representations, and reasoning strategies. In the conclusion and discussion phases, students communicate solution processes, justify their ideas, and draw conclusions based on mathematical contexts. Therefore, Inquiry-Based Learning provides learning experiences that are aligned with important aspects of mathematical communication skills (Izzati, 2023; Zohriah et al., 2024).

Several previous studies have demonstrated the potential of Inquiry-Based Learning in mathematics education. Opticia et al. (2022) found that guided inquiry-based mathematics learning tools supported the development of students' critical thinking skills in linear programming. Ningtias and Soraya (2022) reported that Inquiry-Based Learning influenced students' mathematical communication skills in the topic of two-variable linear equations. Zohriah et al. (2024) examined the relationship between Inquiry-Based Learning and mathematical communication skills by considering students' self-efficacy. Furthermore, Erviana et al. (2025) demonstrated that STEM-integrated guided inquiry learning improved junior high school students' mathematical communication skills.

Although previous studies have demonstrated the positive contribution of Inquiry-Based Learning to students' mathematical communication skills, several limitations remain. First, previous research has predominantly examined elementary or junior high school students, while evidence regarding the effectiveness of Inquiry-Based Learning among senior high school students remains relatively limited. Second, several studies have investigated mathematical communication skills alongside other factors, such as self-efficacy or STEM integration, making it difficult to isolate the contribution of the Inquiry-Based Learning model itself. Third, limited attention has been given to learning contexts where students initially demonstrate low mathematical communication abilities, particularly in geometry-related topics that require students to use representations, explain reasoning, and construct mathematical arguments. Therefore, further investigation is needed to examine whether Inquiry-Based Learning can effectively improve mathematical communication skills among senior high school students.

Therefore, this study aims to examine the effect of the Inquiry-Based Learning model on students' mathematical communication skills at the senior high school level. The contribution of this study lies in providing empirical evidence regarding the effectiveness of Inquiry-Based Learning in improving students' ability to express mathematical ideas, use mathematical representations, explain solution procedures, and construct logical arguments. The findings of this study are expected to contribute to the development of more active mathematics learning practices that support students' mathematical reasoning and communication abilities.

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental method with a pretest–posttest control group design. The study involved two groups: an experimental group and a control group. The experimental group received instruction using the Inquiry-Based Learning (IBL) model, while the control group received conventional instruction. Both groups were administered a pretest before the treatment and a posttest after the treatment to measure changes in students' mathematical communication skills.

Research Setting and Participants

This research was conducted at SMA Negeri 1 Sedayu during the 2025/2026 academic year. The population consisted of all Grade XI students from nine parallel classes (XI-1 to XI-9), with a total of 324 students.

The sample selection was conducted using purposive sampling followed by random assignment. Initially, classes with relatively comparable academic characteristics were identified through consultation with the mathematics teacher. From these classes, two intact classes were selected and randomly assigned as the experimental and control groups. Class XI-2 was assigned as the experimental group, while class XI-3 was assigned as the control group.

The main research sample consisted of 68 students, including 34 students in the experimental group and 34 students in the control group. In addition to the main sample, two different groups of students were involved in the preliminary stages of the research. A preliminary study was conducted involving 36 students to identify initial problems related to students' mathematical communication skills. Furthermore, an instrument trial was conducted involving 31 students who were not included in the main research sample. The trial data were used to examine the validity and reliability of the research instrument.

Research Procedure

The research was conducted in four meetings, with each meeting lasting 2 × 45 minutes. The first meeting was used to administer the pretest. The second and third meetings were used to implement the instructional treatments, and the fourth meeting was used to administer the posttest.

The learning materials focused on triangles and quadrilaterals formed by tangent lines to circles. Both groups received the same learning materials and instructional duration.

In the experimental group, learning activities were implemented using the Inquiry-Based Learning model. The learning process consisted of problem orientation, problem formulation, formulation of initial assumptions, investigation and data collection, analysis of findings, conclusion drawing, and communication of results.

During the orientation stage, students were introduced to contextual mathematical problems related to tangent lines and circles. Students were guided to identify relevant information, formulate mathematical problems, and develop initial ideas. During the investigation stage, students worked collaboratively to explore solutions, use mathematical representations and symbols, and construct mathematical arguments. Students then presented their findings and conclusions. The teacher acted as a facilitator by providing guidance, stimulating questions, and reinforcing mathematical concepts.

The control group received conventional learning through direct instruction. The teacher explained mathematical concepts, provided examples, guided students through problem-solving procedures, and assigned exercises. Students followed explanations, took notes, discussed problems, and completed exercises.

The same researcher conducted learning activities in both groups to maintain consistency in instructional delivery, classroom management, and learning duration. The implementation of both instructional models was monitored using observation sheets completed by an observer.

Research Variables and Instrument

The independent variable in this study was the Inquiry-Based Learning model, while the dependent variable was students' mathematical communication skills.

Students' mathematical communication skills were measured using a five-item open-ended test. The instrument was developed based on mathematical communication indicators, including:

1. writing mathematical ideas;
2. visualization of mathematical information;
3. expressing mathematical ideas using symbols or mathematical models;
4. explaining mathematical concepts and solution procedures; and
5. constructing arguments and drawing conclusions.

Each test item was assessed using an analytical scoring rubric. Student responses were evaluated based on the completeness and accuracy of mathematical ideas, the appropriateness of mathematical representations, the use of symbols and formulas, the coherence of solution steps, the logic of arguments, and the accuracy of conclusions.

The scoring rubric used a scale from 0 to 8 for each item. The maximum total score of the five-item test was 40. The obtained raw scores were converted into a 0–100 scale using the following formula:

$$\text{Final Score} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100$$

Instrument Validity and Reliability

The instrument was validated through expert validation and empirical validation. Expert validation was conducted by three Grade XI mathematics teachers at SMA Negeri 1 Sedayu. The validators assessed the instrument based on content suitability, construction, language clarity, and alignment with mathematical communication indicators.

The validity of the instrument was analyzed using Aiken's V. The pretest instrument obtained average validity coefficients of 0.800 for content, 0.817 for construction, and 0.717 for language. Meanwhile, the posttest instrument obtained average coefficients of 0.883 for content, 0.867 for construction, and 0.750 for language. These results indicated that the instruments were valid and suitable for use.

Empirical validity testing was conducted using data from 31 students outside the main research sample. Item validity was examined using Pearson product-moment correlation. The criterion for item validity was that the calculated correlation coefficient must exceed the critical value of 0.355.

All five pretest items were declared valid, with correlation coefficients ranging from 0.766 to 0.873. Similarly, all five posttest items were valid, with correlation coefficients ranging from 0.465 to 0.865.

The reliability of the instruments was analyzed using Cronbach's alpha. The pretest instrument obtained a reliability coefficient of 0.870, while the posttest instrument obtained a reliability coefficient of 0.704. These results indicate that both instruments had acceptable internal consistency.

Observation of Instructional Implementation

The implementation of the instructional treatments was evaluated using observation sheets completed by an observer during the learning process.

The observation instrument used a four-point scale:

- 4 = very well implemented;
- 3 = implemented;
- 2 = partially implemented;
- 1 = not implemented.

The implementation of Inquiry-Based Learning showed high consistency across learning activities. The orientation stage achieved implementation percentages of 93.75% and 87.50%, investigation activities achieved 85.00% and 87.50%, and closing activities achieved 100.00% and 91.67% across the two treatment meetings.

The conventional learning implementation also showed high consistency, with introductory activities achieving 95.00%, core activities 90.00%, and closing activities 100.00% and 91.67%.

Data Analysis

Data analysis was conducted using IBM SPSS Statistics. Descriptive statistics were calculated to describe students' mathematical communication scores, including means, standard deviations, minimum scores, and maximum scores.

Before inferential analysis, normality and homogeneity tests were conducted to examine statistical assumptions. The improvement of students' mathematical communication skills was analyzed using normalized gain (N-Gain). The N-Gain score was calculated using the following formula:

$$g = \frac{Posttest - Pretest}{Maximum\ Score - Pretest}$$

The N-Gain values were interpreted as:

- low: $g < 0.30$;
- moderate: $0.30 \leq g \leq 0.70$;
- high: $g > 0.70$.

Cohen's d effect size was also calculated to determine the magnitude of differences between groups. The effect size was interpreted as very small, small, moderate, and large based on Cohen's criteria.

To examine the effect of Inquiry-Based Learning while controlling for students' initial mathematical communication ability, an analysis of covariance (ANCOVA) was conducted. The posttest score was used as the dependent variable, instructional group as the fixed factor, and pretest score as the covariate.

The interaction between group and pretest score was initially examined to test the homogeneity of regression slopes assumption. Since the interaction effect was not significant, the final ANCOVA model was analyzed without the interaction term.

RESULTS

The results of this study are presented to examine the effect of the Inquiry-Based Learning model on students' mathematical communication skills. The data were obtained from the experimental and control classes through pretest and posttest assessments. The results are presented through descriptive analysis, prerequisite tests, analysis of covariance (ANCOVA), effect size analysis, and N-Gain analysis.

Data Description

The descriptive analysis was conducted to provide an overview of students' mathematical communication skills before and after the learning process. The results of the descriptive analysis are presented in Table 1.

Table 1. Descriptive Statistics of Students' Mathematical Communication Skills

Class	Score	Minimum	Maximum	Mean	Standard Deviation
Experimental	Pretest	40	72	56.44	8.638
	Posttest	60	90	76.56	7.684
Control	Pretest	40	70	55.76	7.080
	Posttest	52	82	67.53	6.934

Based on Table 1, the experimental and control groups had relatively similar initial mathematical communication skills, with mean pretest scores of 56.44 and 55.76, respectively. After the learning process, the mean posttest score of the experimental group increased to 76.56, while the control group increased to 67.53. Descriptively, the increase in the experimental group was higher than that in the control group.

The standard deviation values decreased after the learning process in both groups, from 8.638 to 7.684 in the experimental group and from 7.080 to 6.934 in the control group, indicating that students' scores became more evenly distributed after the intervention.

Prerequisite Tests

Prerequisite tests were conducted before inferential analysis to ensure that the data met the assumptions required for parametric analysis. The tests included normality and homogeneity tests.

Normality Test

A normality test was conducted to determine whether the pretest and posttest scores in both groups were normally distributed. The results are presented in Table 2.

Table 2. Normality Test Results

Data	Sig.	Interpretation
Experimental pretest	0.306	Normal
Control pretest	0.589	Normal
Experimental posttest	0.867	Normal
Control posttest	0.960	Normal

Based on Table 2, all significance values were greater than 0.05, indicating that the pretest and posttest data were normally distributed.

Homogeneity Test

A homogeneity test was conducted to determine whether the variance between the experimental and control groups was equivalent. The results are presented in Table 3.

Table 3. Homogeneity Test Results

Data	Sig.	Interpretation
Pretest	0.348	Homogeneous
Posttest	0.452	Homogeneous

The significance values for the pretest and posttest data were greater than 0.05, indicating that the variance between groups was homogeneous. Therefore, the data met the assumptions for further parametric analysis.

Preliminary Analysis of Initial Ability

An independent samples *t*-test was conducted on the pretest scores to determine whether the experimental and control groups had comparable initial mathematical communication skills before the treatment.

Table 4. Independent Samples t-Test of Pretest Scores

Data	t	df	Sig. (2-tailed)	Cohen's d
Pretest	0.353	66	0.725	0.09

The pretest comparison showed no significant difference between the experimental and control groups, $t(66)=0.353$, $p=0.725$. The effect size was very small ($d=0.09$), indicating that both groups had comparable initial mathematical communication skills before the intervention.

Analysis of Covariance (ANCOVA)

An ANCOVA was conducted to examine the effect of the Inquiry-Based Learning model on students' posttest mathematical communication scores while controlling for their initial abilities based on pretest scores.

Before conducting the final ANCOVA, the homogeneity of regression slopes assumption was examined through the interaction between group and pretest scores. The interaction effect was not statistically significant (p=0.449), indicating that the assumption was satisfied. Therefore, the final ANCOVA model was analyzed without the interaction term.

Table 5. ANCOVA Results

Source	F	df	Sig.	Partial η^2
Pretest	1.457	1,65	0.232	0.022
Group	25.477	1,65	<0.001	0.282

The ANCOVA results showed that the overall model was statistically significant, $F(2,65)=13.758$, $p<0.001$, with an R^2 of 0.297. After controlling for pretest scores, the instructional group had a statistically significant effect on students' posttest mathematical communication scores, $F(1,65)=25.477$, $p<0.001$, partial $\eta^2=0.282$.

These results indicate that students who received Inquiry-Based Learning demonstrated significantly different posttest mathematical communication performance compared with students who received conventional learning after controlling for their initial abilities.

Paired Samples t-Test

A paired samples t-test was conducted to examine changes in mathematical communication skills within each group before and after the learning process.

Table 6. Paired Samples t-Test Results

Class	Mean Difference	t	df	Sig. (2-tailed)
Experimental	-20.118	-10.543	33	<0.001
Control	-11.756	-7.984	33	<0.001

The results showed that both groups experienced statistically significant improvements after the learning process ($p<0.001$). The experimental group showed a larger mean improvement compared with the control group (20.118 points versus 11.756 points). These findings indicate that both instructional approaches improved students' mathematical communication skills, with a greater descriptive improvement observed in the Inquiry-Based Learning group.

Effect Size Analysis

Cohen's d was calculated to determine the magnitude of the difference between groups. The pretest effect size was very small (d=0.09), confirming that the groups had similar initial abilities. Meanwhile, the posttest effect size was large (d=1.23), indicating a substantial difference in mathematical communication performance between the experimental and control groups after the learning process.

N-Gain of Mathematical Communication Skills

N-Gain analysis was conducted to determine the level of improvement in students' mathematical communication skills after the intervention.

Table 7. N-Gain Results of Mathematical Communication Skills

Class	Mean (%)	Standard Deviation	Minimum	Maximum	Category
Experimental	44.14	19.74	0.00	80.00	Moderate
Control	25.39	16.82	2.50	58.33	Low

The experimental group obtained an average N-Gain score of 44.14%, categorized as moderate, while the control group obtained 25.39%, categorized as low. These results descriptively indicate that students who received Inquiry-Based Learning experienced greater improvement in mathematical communication skills compared with students who received conventional learning.

DISCUSSION

The results of this study indicate that the implementation of the Inquiry-Based Learning (IBL) model was associated with significantly higher students' mathematical communication performance. The ANCOVA results showed that, after controlling for students' initial mathematical communication skills, the instructional group had a significant effect on posttest scores, $F(1,65)=25.477$, $p<0.001$, partial $\eta^2=0.282$. This finding indicates that students who received Inquiry-Based Learning demonstrated better mathematical communication outcomes compared with students who received conventional instruction. The descriptive results also supported this finding, as the experimental group obtained a higher posttest mean score (76.56) than the control group (67.53), with a higher N-Gain value (44.14%) compared with the control group (25.39%).

The improvement in students' mathematical communication skills can be explained through the characteristics and stages of Inquiry-Based Learning. According to Pedaste et al. (2015), inquiry-based learning involves several interconnected phases, including orientation, conceptualization, investigation, conclusion, and discussion. These phases encourage students to actively construct knowledge through questioning, exploration, interpretation of findings, and communication of results. In the present study, these inquiry processes provided opportunities for students to develop mathematical communication skills through active engagement with mathematical problems.

In the orientation and problem formulation stages, students were encouraged to understand contextual mathematical problems, identify relevant information, and formulate mathematical questions. These activities supported students' ability to express mathematical ideas and organize their initial understanding of the problem. During the hypothesis formulation stage, students were guided to propose possible solutions and provide logical reasons for their assumptions. This process encouraged students to develop mathematical arguments and justify their thinking.

During the investigation stage, students collected information, discussed solution strategies, and analyzed mathematical problems using various mathematical representations, including symbols, equations, diagrams, and other models. These activities supported students' ability to use mathematical expressions and representations appropriately. Furthermore, through the conclusion and communication stages, students practiced explaining solution procedures, presenting their mathematical reasoning, and drawing conclusions based on the problem context.

These findings are consistent with the concept of mathematical communication emphasized by the National Council of Teachers of Mathematics (NCTM, 2000). Mathematical communication involves organizing and consolidating mathematical thinking, expressing mathematical ideas coherently, using mathematical representations, and explaining mathematical reasoning. The inquiry activities implemented in this study provided students with opportunities to communicate mathematical ideas, discuss solution strategies, and present their reasoning, which are essential components of mathematical communication development.

The findings also support previous studies regarding the contribution of inquiry-based learning to mathematical communication development. Izzati (2023) explained that inquiry-based learning encourages students to ask questions, explore information, and communicate the results of their investigations. Similarly, Ningtias and Soraya (2022) reported that the Inquiry-Based Learning model improved students' mathematical communication skills. Zohriah et al. (2024) also found that Inquiry-Based Learning contributed to students' mathematical communication development by considering students' self-efficacy. Furthermore, Erviana et al. (2025) demonstrated that STEM-integrated guided inquiry learning improved mathematical communication skills among junior high school students. Therefore, the current findings extend previous research by demonstrating that Inquiry-Based Learning is relevant for developing mathematical communication skills among senior high school students, particularly in geometry-related learning.

The difference between the experimental and control groups may be explained by the different learning experiences provided in each instructional approach. Students in the Inquiry-Based Learning group were actively involved in identifying problems, developing assumptions, exploring solutions, using mathematical representations, discussing findings, and communicating conclusions. These activities provided more opportunities for students to practice mathematical communication. In contrast, conventional learning placed greater emphasis on teacher explanations and procedural exercises, which may have provided fewer opportunities for students to express and justify their mathematical thinking.

Although the experimental group demonstrated higher improvement, the N-Gain results showed that the increase was categorized as moderate rather than high. This suggests that Inquiry-Based Learning contributed positively to students' mathematical communication skills, but the relatively short intervention duration and limited learning sessions may have influenced the magnitude of improvement. Future studies involving longer intervention periods, different mathematical topics, and larger samples may provide further evidence regarding the sustained effect of Inquiry-Based Learning.

CONCLUSION

The findings of this study indicate that the Inquiry-Based Learning model significantly improved students' mathematical communication skills in the context of senior high school mathematics learning. The ANCOVA results showed that, after controlling for students' initial mathematical communication skills, the instructional model had a significant effect on students' posttest scores. This finding indicates that students who participated in Inquiry-Based Learning demonstrated better mathematical communication performance compared with students who received conventional instruction.

The improvement in students' mathematical communication skills can be attributed to the inquiry activities that encouraged students to actively formulate problems, develop initial ideas, investigate solutions, use mathematical representations, explain reasoning processes, and communicate conclusions. Through these learning experiences, students had greater opportunities to express mathematical ideas, use symbols and representations appropriately, and construct logical mathematical arguments.

Practically, Inquiry-Based Learning can be considered an alternative instructional approach for mathematics teachers who aim to develop students' mathematical communication skills. Teachers can implement this model by presenting contextual problems, facilitating student investigation, encouraging discussion, and providing opportunities for students to explain and justify their mathematical thinking.

This study has several limitations. The research was conducted in only one school with a limited sample size and focused on specific geometry-related materials. Therefore, further studies are recommended involving broader samples, different mathematical topics, and longer intervention periods. Future research may also incorporate qualitative data, such as classroom observations or interviews, to provide deeper understanding of how Inquiry-Based Learning supports the development of students' mathematical communication skills.

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