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# THE EFFECT OF THINK PAIR SHARE COOPERATIVE LEARNING MODEL ON STUDENTS' MATHEMATICAL COMMUNICATION ABILITY

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**ABSTRACT**

Mathematical communication is a critical competence that enables students to express ideas, use precise language, and construct logical reasoning. However, current conditions in many schools reveal a gap: students taught through direct instruction struggle to represent, explain, or visualize concepts, which limits their problem-solving and understanding, underscoring the need for innovative teaching approaches. To address this issue, the present study investigated the effect of the Think-Pair-Share (TPS) cooperative learning model on students' mathematical communication ability using an explanatory sequential mixed-methods design. The research was conducted in two eighth-grade classes at SMPS Bina Satria Medan, each with 30 students. The experimental class used TPS, while the control class received direct instruction. Quantitative data were collected through pre-test and post-test assessments, while qualitative insights were obtained from classroom observations, interviews, and students' written work. The results showed that the experimental group achieved a higher post-test mean score (75.10) compared to the control group (65.77). An independent t-test confirmed a statistically significant difference ($t = 3.5785$, $p = 0.0007$), with a large effect size (Cohen's $d = 0.92$), indicating an 82% practical impact of the TPS model. Qualitative analysis revealed that TPS supported students in representing mathematical ideas more fluently, constructing clearer visualizations, and articulating their reasoning more confidently. Collaborative stages within TPS promoted peer discussion, reflection, and structured explanation, benefiting students across all ability levels. These findings highlight the effectiveness of TPS in improving mathematical communication through both individual and social learning processes.

Keywords: *Think Pair Share, Direct Instruction, Mathematical Communication, Mathematics, Cooperative Learning*

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## INTRODUCTION

Education is an important pillar in striving for a competent and competitive next generation of the nation (Frisnoiry, 2024). Through education, individuals are equipped with the knowledge, attitudes, and skills needed to face increasingly complex challenges. As the core of the educational process, learning is effective when it involves practice, experience, and interaction with objects of study, engaging multiple senses to construct knowledge (Sariani *et al.*, 2021). In this process, knowledge is formed through cognitive construction involving certain schemes, categories, concepts, and structures based on real-world experiences or events

(Siregar & Suastra, 2024). Effective learning also requires meaningful interaction between learners and their environment, enabling them to connect knowledge with real-life contexts as preparation for adapting and developing in a dynamic world (Famulaqih & Lukman, 2024).

Instructional design supports the learning process by guiding teachers to plan continuous activities with suitable strategies and resources, enabling students to explore and construct knowledge (Nurwanci *et al.*, 2025). In this process, students act as central subjects, while teachers serve as facilitators. Learning becomes more effective when communication is multidirectional, making it active, interactive, and enjoyable (Cahyani *et al.*, 2020).

In the context of learning, mathematics as a deductive universal science plays a crucial role, not only as a mandatory subject taught at all levels of education, but also as an expression of ideas in conveying information in a structured manner, developing arguments based on valid data, and making the right decisions (Nuranti, 2023). This equips students as social beings to interact with their environment by expressing thoughts clearly so that all conditions or problems can be communicated and explained, both verbally in the form of demonstrations, conversations and discussions or in writing in the form of symbols, diagrams, tables, graphs, equations, illustrations or images, and other forms that are easy to understand to draw joint decisions (Jazuli, 2024). Thus, mathematics supports efficient communication by reducing ambiguity and serving as a universal language that unites disciplines.

The importance of mathematical communication is emphasized by the NCTM, which identifies it as one of the competency standards in mathematics learning (Islamijawati, 2022). Similarly, the Partnership for 21st Century Skills (P21) formulates communication as a key ability for students to adapt to 21st-century challenges (Hanisyah & Munahefi, 2024). Ginting & Sihombing (2023) highlight that mathematics serves as a tool to present ideas concisely and accurately, while also being a social activity requiring interaction between students or between teachers and students. Thus, mathematical communication is an important aspect that affects students' mathematics learning outcomes (Hasibuan & Syahputra, 2023).

In learning mathematics, students not only instantly use the available formulas, but also elaborate by generating ideas, compiling structured solution procedures, describing or illustrating objects as explanations of relationships or patterns between elements in a mathematical problem, and being able to discuss their findings accompanied by strong evidence in writing or orally (Hia & Sinambela, 2023). Such activities help them draw appropriate conclusions when solving complex problems, as mathematics is hierarchical, progressing from concrete basics to higher abstract concepts (Sihombing *et al.*, 2025). These abilities form the basis of students' mathematical communication.

Mathematical communication is measured by three indicators: representation, drawing, and explaining/writing. Representation reflects students' ability to transform problems into mathematical models and use mathematical symbols related to solving problems, while drawing shows their capacity to present ideas visually through diagrams, tables, or graphs. Explaining/writing states students' ability to arrange solutions systematically and logically, as well as to convey or demonstrate their findings to others. For this reason, mathematical communication maximizes students' freedom of expression, self-confidence, collaboration, critical and logical thinking, appreciation of opinions, and creativity (Ginting, 2022).

However, a significant gap exists between the ideal of mathematical communication and actual classroom conditions. Evidence from international surveys, observations, interviews, and diagnostic assessments highlights this issue. In PISA 2022, Indonesia scored 366 in mathematics, ranking 64th of 81 countries, far below the OECD average of 472 (OECD, 2023). This continues a negative trend from 386 in 2015 and 379 in 2018 (Siregar *et al.*, 2024). Pre-research at SMPS Bina Satria Medan, grade 8, also showed low mathematics achievement, with only 38 out of 122 students meeting the passing score of 75.

Interviews with Ms. Nova Rastika Ayu, S.Pd., a mathematics teacher at SMPS Bina Satria Medan, revealed several problems: students struggle to understand word problems, hesitate to express ideas when problems differ from examples, rely on memorization rather than true understanding, and tend to be passive during learning. In addition, observations on October 30, 2024, also showed that mathematics teaching relied on direct instruction focused on explanation and narration, limiting opportunities for exploration. This lack of opportunity hinders students from developing essential mathematical communication skills, such as expressing information, modeling problems, using symbols, visualizing objects, and explaining solutions systematically. This does not provide an adequate forum for students to develop essential mathematical communication abilities, such as modeling problems, visualizing objects, and explaining solutions systematically (Tambunan, 2021).

The diagnostic test administered to 25 students of class 8-2 provided clear evidence of limited mathematical communication abilities. The test, constructed around three indicators and assessed with a rubric, required a minimum score of 75 (equivalent to 9 of 12 points) for mastery. Results showed that only 6 students (24%) achieved mastery, while 19 students (76%) did not. At the indicator level, 36% demonstrated adequate representation, 20% succeeded in drawing, and merely 12% attained proficiency in explaining or writing, highlighting substantial deficiencies across all aspects.

The low level of mathematical communication is reflected in students' work when solving real-world problems on two-variable linear equation systems. The errors displayed indicate weaknesses across the three indicators.

**Figure 1.** Student A's Work

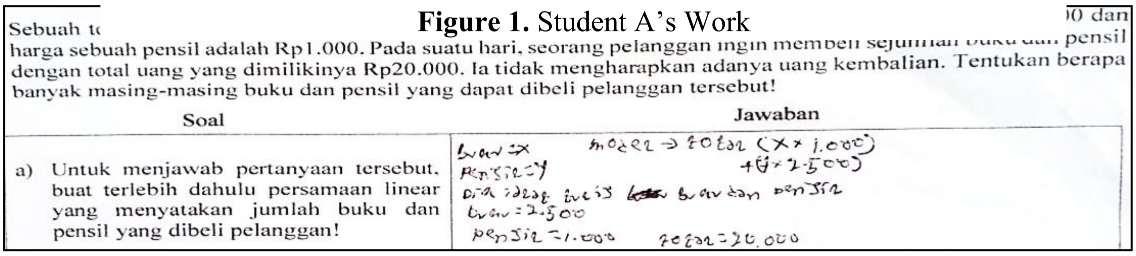



Figure 1 demonstrates student's inability to represent problems accurately. The student misused information by assigning incorrect prices, Rp2,500 for notebooks (x) and Rp1,000 for pencils (y), and omitted essential mathematical symbols, such as the equals sign, resulting in flawed models and solutions.

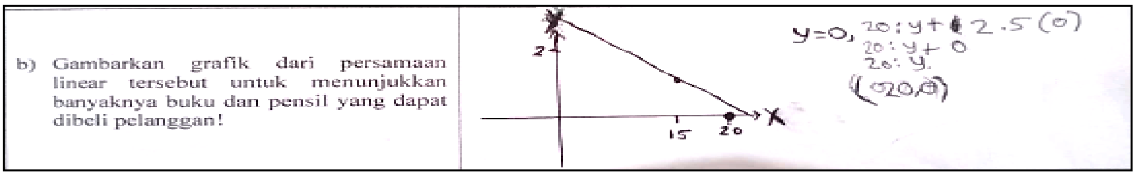
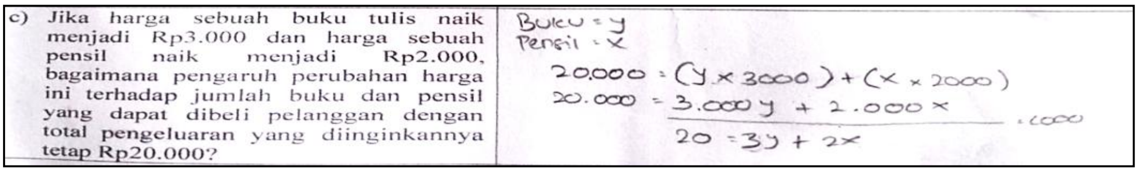



**Figure 2.** Student B's Work

Figure 2 highlights student's difficulties in visualization. The student produced incomplete and unclear graphs, misused symbols by writing "÷" instead of "=," and made substitution errors, such as inserting x-values incorrectly when y = 0.



| | |
|---|---|
| c) Jika harga sebuah buku tulis naik menjadi Rp3.000 dan harga sebuah pensil naik menjadi Rp2.000, bagaimana pengaruh perubahan harga ini terhadap jumlah buku dan pensil yang dapat dibeli pelanggan dengan total pengeluaran yang diinginkannya tetap Rp20.000? | Buku = y<br>Pensil = x<br>20.000 = (y × 3000) + (x × 2000)<br>20.000 = 3.000 y + 2.000 x  : 1.000<br>20 = 3y + 2x |

**Figure 3.** Student C’s Work

Figure 3 reveals shortcomings in explaining solutions. The student failed to present ideas systematically, omitting key information, logical reasoning, and structured arguments. Consequently, the solutions did not meet the problem’s objective, particularly regarding price increases and purchasing capacity.

The analysis of student errors shows persistent difficulties in expressing mathematical ideas symbolically, visually, and in written form, indicating that direct instruction limits opportunities for structured reasoning, precise language, and coherent communication. In such settings, students remain passive listeners while teachers dominate explanations, resulting in one-way communication. Such one-way learning hinders the growth of mathematical communication abilities, as also evidenced by the findings of a study by Nasution & Batubara (2020) at SMAN 2 Medan. Therefore, varied learning models are needed that position teachers as facilitators and prioritize student activity, enabling interactive knowledge construction and effective problem-solving communication (Sembiring & Siregar, 2020).

Learning models serve as guidelines for lesson planning, which include curriculum development, material organization, and teacher instructions to ensure that the teaching and learning activities that are prepared yield maximum benefits for students and education (Harefa *et al.*, 2022). The application of the Think Pair Share (TPS) cooperative learning model is one of effective models to improve students' mathematical communication ability (Nufus *et al.*, 2022). TPS promotes active student interaction through discussions, where learners exchange ideas, respond, gather information, and collaboratively construct well-reasoned solutions to mathematical problems (Arifino & Hasratuddin, 2024).

The TPS cooperative learning model, rooted in constructivist theory, emphasizes democratic practice and peer interaction as central elements (Talib *et al.*, 2023). Learning outcomes are achieved through purposeful cooperation and mutual support, while the teacher motivates students, ensures a conducive environment, guides discussions, appreciates efforts, and provides confirmation at the end. TPS engages students in three main stages: first, thinking deeply as an individual; second, working in pairs with a peer; and third, sharing knowledge in writing or orally with other groups or the whole class (Purba & Rajagukguk, 2024). Through this process, students not only apply mathematical concepts but also enhance communication, self-efficacy, and interaction in expressing mathematical ideas effectively.

Several studies in Indonesia have highlighted the effectiveness of the Think Pair Share (TPS) cooperative learning model in mathematics. Anggraeni, Wulandari, and Ilmi (2023) conducted an experimental pre-test-post-test control study, finding a significant difference in mathematical communication (Sig = 0.00), with experimental mean 82.75 versus control 56.69. Evi Yanti Siregar and Nurhasanah Siregar (2023) compared TPS with Numbered Head Together (NHT) using a quasi-experimental pre-test–post-test design and found significant gains in students' post-test scores under TPS. Likewise, Purba & Rajagukguk (2024) employed a quasi-experimental control group design and confirmed that TPS improved mathematical communication ability more effectively than conventional teaching. International evidence also supports the benefits of TPS. Niyibizi *et al.* (2024) applied a mixed-methods study with 86 students and 4 teachers across four schools, integrating test results, surveys, and interviews. Their findings showed modest improvements in academic performance (2.77%) and engagement (5.0%), with both teachers and students recognizing TPS as effective in enhancing collaboration, participation, and achievement in secondary mathematics classrooms.

While previous studies confirm the effectiveness of TPS, most emphasize quantitative outcomes, providing limited insight into how students develop mathematical communication ability during learning. To fill this gap, the present study adopts an explanatory sequential mixed-method design, combining quasi-experimental analysis with qualitative exploration through observation, interviews, and students' written work. Based on these issues, this study investigates "**The Effect of Think Pair Share Cooperative Learning Model on Students' Mathematical Communication Ability**". This research is expected to provide valuable insights into the potential of the TPS cooperative learning model in enhancing students' ability to convey mathematical ideas clearly and effectively in a learning environment.

## METHOD

This study employed an explanatory sequential mixed-method design. The quantitative phase employed a quasi-experimental pretest–posttest control-group design, whereas the qualitative phase involved interviews, observations, and students' written work. A total of 60 eighth-grade students at SMPS Bina Satria Medan (academic year 2024/2025) were selected through cluster sampling: class VIII-1 (30 students) as the experimental group and class VIII-2 (30 students) as the control group. The experimental group received Think-Pair-Share (TPS), whereas the control group received direct instruction. Each class received two sessions of learning on statistics, specifically measures of central tendency and dispersion.

Instruments included modules, worksheets, observation sheets, interview guides, and tests of mathematical communication ability. The test was validated by experts, examined for validity, reliability, item difficulty, and discrimination. Quantitative data were examined using normality tests, homogeneity tests, independent t-tests, and effect sizes, while qualitative data were analyzed thematically to complement the statistical findings. This study assessed students' achievement in the cognitive domain using the scoring rubric presented in Table 1.

**Table 1.** Rubric for Scoring Students' Mathematical Communication Ability

| Mathematical Communication Ability Indicators | Student Response | Mark |
|---|---|---|
| Representation (Able to express ideas in mathematical models and use mathematical symbols related to problem solving) | No answer given or not readable. | 0 |
| | The answer exists, but with many errors in using information and representing ideas. | 1 |
| | Expressing ideas using mathematical symbols and models completely but incorrectly. | 2 |
| | The answer is correct, but incomplete or some strategies are not appropriate. | 3 |
| | Correct, clear, and complete with proper terms, symbols, and effective operations. | 4 |
| Drawing | Does not provide a depiction of problem-solving. | 0 |
| | Depicts form, but unclear and incomplete | 1 |

| | | |
|---|---|---|
| (Able to transform mathematical ideas into images, graphs, tables, or other forms) | The object is fully visualized but inaccurate. | 2 |
| | Correct visualization, but incomplete. | 3 |
| | Complete, precise, and clear visualization. | 4 |
| Writing/Explaining (Able to systematically arrange solutions to a problem accompanied by logical and rational arguments) | No answer / only copies data, but no evidence of any strategy shown, used, or explained. | 0 |
| | Shows strategy, but incomplete, unstructured, ambiguous, and incorrect results. | 1 |
| | Arranging a complete solution to a problem, but not achieving the correct result | 2 |
| | Structured ideas (known, asked, theory, conclusion) with minor flaws. | 3 |
| | Systematic, accurate concepts and algorithms, precise results, clear explanation. | 4 |

The test instrument underwent validity testing to ensure accurate measurement, in which the items had to be relevant and representative of all aspects being assessed. By using the Pearson Product-Moment correlation, the formula is as follows:

$$R_{count} = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{(n\sum X^2 - (\sum X)^2)\,(n\sum Y^2 - (\sum Y)^2)}}$$

Info : $R_{count}$ = Pearson Product-Moment correlation coefficient, n = number of samples, X = item score, Y = total score of all items for the n-th student.

**Table 2.** Results of the Instrument Validity Test

| Item | $\boldsymbol{R\_count}$ | Conclusion |
|---|---|---|
| 1 | 0.920 | Valid (Very High) |
| 2 | 0.845 | Valid (Very High) |
| 3 | 0.826 | Valid (Very High) |
| 4 | 0.898 | Valid (Very High) |

After validity was confirmed, reliability testing was required to ensure consistent and trustworthy measurements. Reliability was calculated using Cronbach's Alpha :

$$r_{11} = \left(\frac{k}{k-1}\right)\left[1 - \frac{\sum \sigma_i^2}{\sigma_t^2}\right]$$

Info : $r_{11}$ = alpha coefficient, k = total items, $\sigma_t^2$ = variance of the overall sample $\left(\sigma_t^2 = \frac{\sum Y^2 - \frac{(\sum Y)^2}{n}}{n}\right)$, $\sum \sigma_i^2$ = total variance of each item $\left(\sum \sigma_i^2 = = \sum_{i=1}^{k} \frac{\sum Xi^2 - \frac{(\sum Xi)^2}{n}}{n}\right)$

**Table 3.** Results of the Instrument Reliability Test

| Item | | | | $\sum \boldsymbol{\sigma_i}^2$ | $\boldsymbol{\sigma_t}^2$ | $\boldsymbol{r_{11}}$ | Conclusion |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 2.218 | 6.714 | 0.893 | Reliable (Very High) |
| 0.662 | 0.4 | 0.442 | 0.714 | | | | |

The instrument difficulty level analysis is also essential in this research to ensure a balanced assessment that accurately reflects students' abilities. The formula used is:

$$Difficulty\ Index = \frac{Mean}{Maximum\ Score}$$

Info : $Mean =$ The total score on a particular item divided by the number of students

**Table 4.** Results of the Instrument Difficulty Level Analysis

| Item | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Difficulty Index | 0.69 | 0.45 | 0.57 | 0.52 |
| Conclusion | Moderate | Moderate | Moderate | Moderate |

This suggests that the instrument was well-calibrated to accommodate a range of student ability levels. The discrimination index was also performed to determine how well a question can distinguish between high-performing and low-performing students. Participants were divided into two groups: the upper group (top 27%) and the lower group (bottom 27%). The formula used is as follows:

$$D = (\bar{x}\_upper\ \ - \bar{x}\_lower)/(maximum\ score)$$

Info : $\bar{x}\_upper =$ Mean of the upper group, $\bar{x}\_lower =$ Mean of the lower group

**Table 5.** Results of the Instrument Discrimination Index Analysis

| Item | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Discrimination Index | 0.393 | 0.321 | 0.357 | 0.393 |
| Conclusion | Good | Good | Good | Good |

Based on the item analysis, the instrument was deemed appropriate for use in this study, supported as well by expert validation from both lecturers and teacher. Subsequently, statistical data processing was carried out using the R programming language. The data were examined through the Shapiro-Wilk test for normality and the F-test for homogeneity, both of which are required to meet the assumptions of parametric analysis. Conversely, if violated, a non-parametric alternative, such as the Mann-Whitney U test, is considered.

This study applied an independent t-test to determine whether the mean difference between two independent classes was statistically significant. The null hypothesis ($H_0 : \mu_1 = \mu_2$) stated no difference in mathematical communication ability between the experimental (TPS) and control (direct instruction) classes, while the alternative ($H_a :\ \mu_1 \neq \mu_2$) indicated a significant difference. Additionally, an effect size test using Cohen's $d$ was employed to measure the magnitude of this difference, showing how substantial the TPS model's effect was compared to direct instruction.

Following the quantitative analysis, qualitative data were examined to explore how the TPS model affected students' mathematical communication, focusing on representation, drawing, and writing/explaining indicators. Data from interviews, observations, and written work were analyzed through open coding, axial coding, theme identification, and triangulation. Guided by the procedures of Creswell (2013), this systematic process organized codes into categories and themes, ensuring credible insights into students' mathematical communication during TPS learning. For clarity, this study followed the sequence outlined in Figure 4.

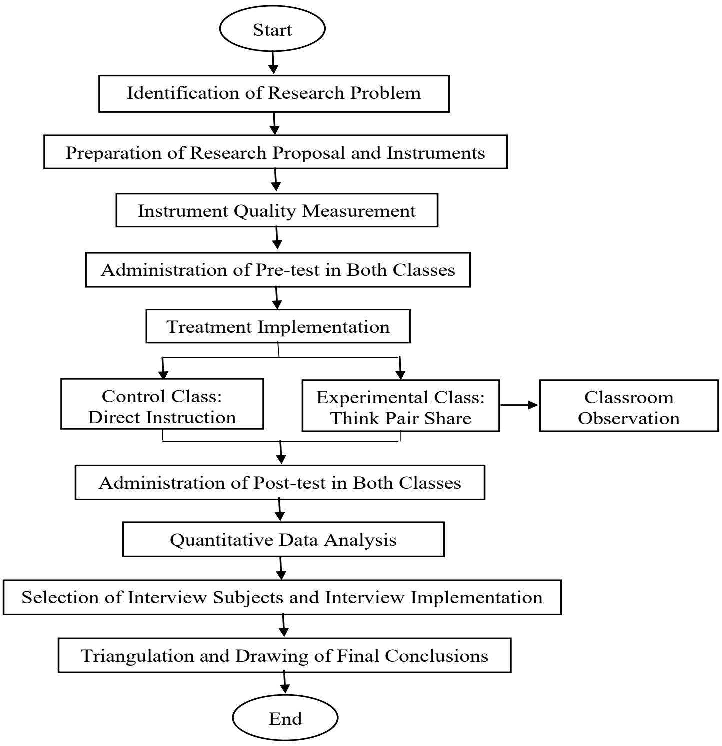



**Figure 4**. Research Procedures

## RESULT

Descriptive statistics of pre-test and post-test scores were analyzed to capture students' initial and final mathematical communication abilities, providing a general overview of performance trends and serving as a foundation for interpreting the effectiveness of the TPS cooperative learning model.

**Table 6.** Descriptive Statistical Analysis of Pre-test and Post-test Results

| Statistical Measures | Experiment | | Control | |
|---|---|---|---|---|
| | Pre-Test | Post-Test | Pre-Test | Post-Test |
| Mean | 25.03 | 75.10 | 25.17 | 65.77 |
| Median | 25 | 75 | 25 | 66 |
| Mode | 25 | 75 | 25 | 63 |
| Standard Deviation | 9.51 | 9.57 | 8.52 | 10.60 |
| Variance | 90.45 | 91.68 | 72.63 | 112.39 |
| Max | 46 | 94 | 50 | 88 |
| Min | 4 | 56 | 8 | 44 |
| Sum | 751 | 2253 | 755 | 1973 |

Descriptive analysis showed that both classes began at a similar level (means of 25.03 and 25.17). After the intervention, the experimental class achieved a higher post-test mean (75.10 vs. 65.77), with supporting median, mode, and maximum values. Variance rose in both groups, but the experimental class displayed more stable dispersion (SD from 9.51→9.57 vs. 8.52→10.60). Students in the experimental class demonstrate more consistent results. The higher score sum (2253 vs. 1973) further supports the idea that Think-Pair-Share contributed to a higher level of achievement. Subsequently, a Normality Test was conducted using the Shapiro-Wilk procedure, which is appropriate for small to medium sample sizes, to assess whether the dataset conformed to a normal distribution.

**Table 7.** Results of the Shapiro-Wilk Normality Test

| Data | Class | W | P-value | Decision | Conclusion |
|---|---|---|---|---|---|
| Pre-test | Experiment | 0.980 | 0.834 | Accept $H_0$ | Normal |
| | Control | 0.958 | 0.282 | Accept $H_0$ | Normal |
| Post-test | Experiment | 0.959 | 0.273 | Accept $H_0$ | Normal |
| | Control | 0.969 | 0.503 | Accept $H_0$ | Normal |

The Shapiro-Wilk test showed that all pre- and post-test datasets had p-values above 0.05 with W values near 1, confirming normal distribution assumptions for parametric analysis. Normal distribution curves are also generated to offer a broader visualization of score dispersion patterns across groups, as shown in Figure 5.

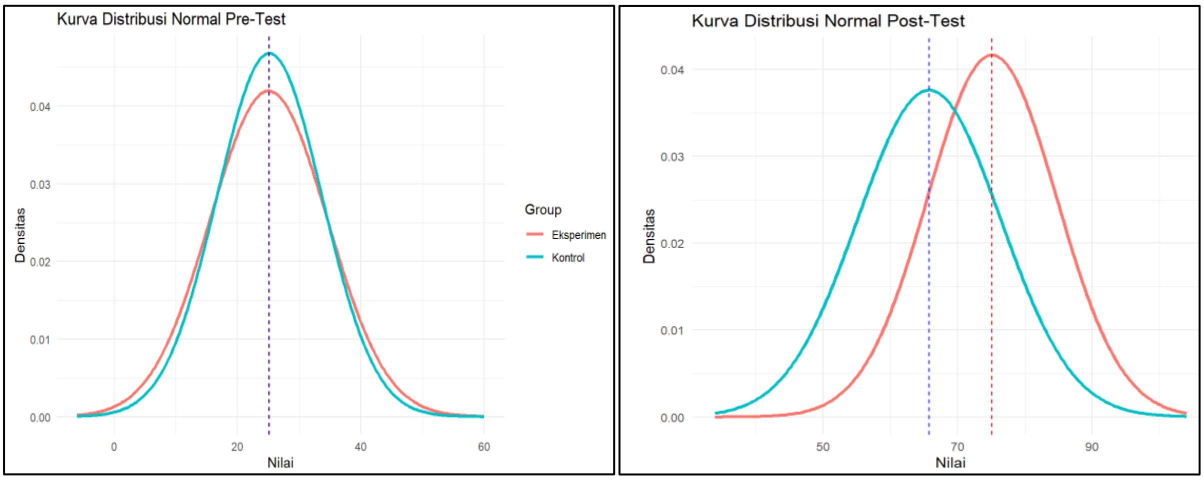



**Figure 5.** Normal Distribution Curves of Pre-Test and Post-Test Scores

Figures 5 illustrate the normal distribution curves of pre- and post-test scores for experimental (red) and control (blue) groups. Both initially showed similar bell-shaped, symmetric distributions, indicating comparable baseline conditions. Post-test curves remained normal; however, the experimental group showed a higher peak, a narrower spread, and lower variability. These visual patterns, supported by the Shapiro-Wilk test, confirm normality and comparability. Afterward, the homogeneity test using the F-test examined variance equality in pre- and post-test scores.

**Table 8.** Results of the F-Test for Homogeneity

| Data | Class | F-Calculated | F-Critical | P-value | Decision | Conclusion |
|---|---|---|---|---|---|---|
| Pre-test | Experiment<br>Control | 1.245 | 1.861 | 0.608 | Accept $H_0$ | The data are homogeneous |
| Post-test | Experiment<br>Control | 1.226 | | 0.502 | Accept $H_0$ | The data are homogeneous |

The F-test showed p-values > 0.05 and F-Calculated < F-Critical, confirming equal variances in pre- and post-test scores, thus meeting homogeneity assumptions for parametric analysis. Accordingly, an independent two-tailed t-test was applied to compare post-test means of experimental and control groups in assessing TPS effects.

**Table 9.** Results of the Independent t-Test

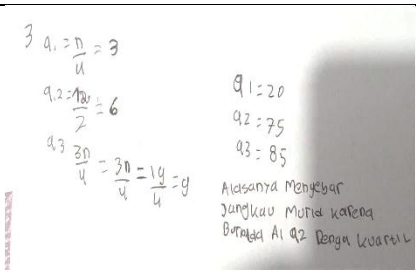
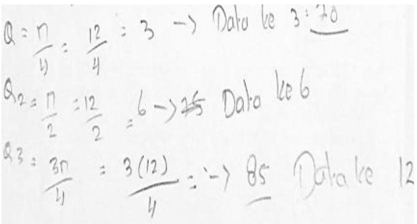
| Test Name | Statistics | Value | Decision | Conclusion |
|---|---|---|---|---|
| Independent t-Test | t calculated | 3.5785 | $\lvert\text{t calculated}\rvert > \lvert\text{t critical}\rvert$ | There is a significant difference in the mean. |
| | t critical | 2.001717 | therefore, $\mathrm{H_0}$ is rejected. | |
| | P-value | 0.000706 | P-value $< \alpha = 0.05$ | |
| | Df | 58 | therefore, $\mathrm{H_0}$ is rejected. | |

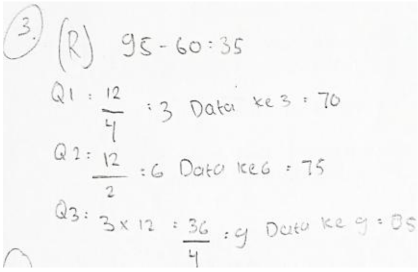
Since t-calculated (3.5785) $>$ t-critical (2.0017) and p (0.000706) $<$ 0.05, $\mathrm{H_0}$ is rejected and $\mathrm{H_a}$ accepted, indicating a significant difference in mathematical communication ability. Furthermore, with Cohen's $d$ = 0.923 (large effect, $d >$ 0.80), about 82% of experimental students outperformed the control average, highlighting the substantial impact of the Think Pair Share (TPS) cooperative learning model.

To enrich the interpretation of quantitative findings, the qualitative analysis explored students' mathematical communication through representation, drawing, and writing/explaining. The data were collected from interviews, classroom observations, and written work. Interview participants were determined by pre-test scores (M = 25.03, SD = 9.51): scores above $\bar{x} + SD$ (34.54) were high achievers (4 students), between $\bar{x} + SD$ and $\bar{x} - SD$ (15.52 – 34.54) were moderate achievers (23 students), and below $\bar{x} - SD$ (15.52) were low achievers (3 students), with two students from each category selected for interviews.

Students' written work was also analyzed by ability level. The test results showed improvement in all indicators: in representation, 25 experimental and 14 control students achieved mastery (Score $\geq 3$); in drawing, 27 experimental and 23 control students reached mastery; and in explaining/writing, 14 experimental and 9 control students organized solutions systematically. These results highlight stronger development in the experimental class. The following section examines selected test responses.

**Table 10.** Analysis of Students' Work Based on Ability Levels

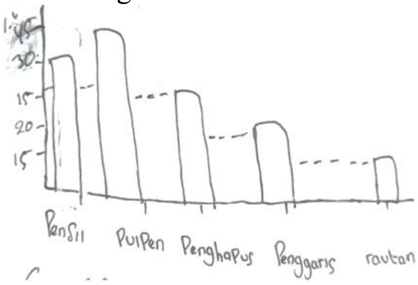
| Mathematical Communication Indicators | Students' Answers | Decription |
|---|---|---|
| Representation | <br>Low Student Answer | The student made many errors in writing mathematical symbols. The formula used was unclear, accompanied by unstructured calculations and an incorrect final result. |
| | <br>Moderate Student Answer | The student's answer was incomplete. The explanation was poorly structured and unclear, with an error in identifying the third quartile position. |




High Student Answer

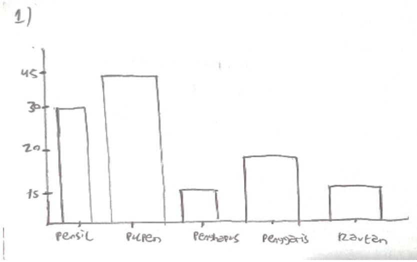
The student used mathematical symbols accurately to represent data distribution and applied arithmetic operations correctly, resulting in the correct final answer.

Drawing



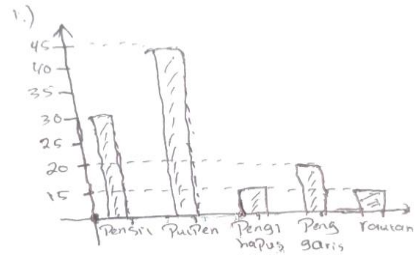

Low Student Answer

The student was inaccurate in ordering quantities on the Y-axis, making the bar chart incorrect and unclear.



Moderate Student Answer

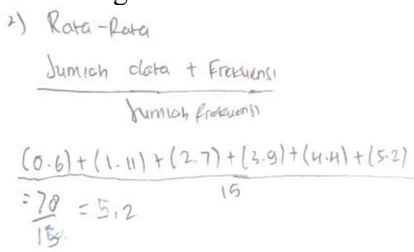
The student drew a complete graph according to the given information but did not use a scale on the Y-axis, making the visualization less clear.



High Student Answer

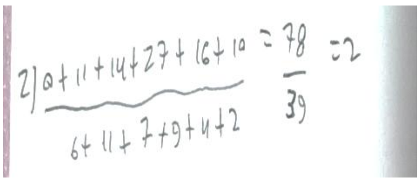
The student was able to construct a clear and complete bar chart based on the given information, demonstrating accurate visualization.

Writing/Explaining



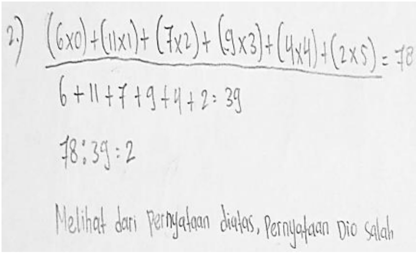

Low Student Answer

The student used incorrect mean formula, neglected important steps, and provided no interpretation, resulting in an unclear and incomplete answer.



Moderate Student Answer

The student obtained the correct result with accurate calculations, but the answer was incomplete as the known information, question, and conclusion were omitted.




The student answered correctly with a proper conclusion, but omitted the known information and the question.

High Student Answer

Based on the thematic findings from the qualitative interview data, in representation, high-ability students accurately used mathematical language, symbols, and formulas to express understanding, connecting concepts such as range, quartiles, and median with logical reasoning. Moderate-ability students showed partial proficiency, often depending on notes or peer support, while low-ability students mostly imitated others with limited grasp.

In drawing, high-ability students constructed bar charts correctly but sometimes neglected details such as scale. Moderate-ability students could produce bar charts with peer support, yet made errors in axis assignment and spacing. Meanwhile, low-ability students struggled to determine axis components and often copied peers' work. Peer discussions improved accuracy across all groups, demonstrating that TPS facilitated the revision and refinement of visualizations.

In writing/explaining, five themes emerged: (1) understanding the problem, (2) structuring problem-solving steps, (3) verifying and justifying answers, (4) peer discussion for refinement, and (5) confidence building. High-ability students demonstrated strategic reading, systematic reasoning, and logical justifications, verifying answers independently. Moderate-ability students produced partly accurate steps but lacked independence. Low-ability students tended to mimic others and struggled with justification. Across all levels, peer discussions under TPS enhanced clarity and gradually improved confidence in written communication.

Triangulation of interviews, observations, and written test responses confirmed these findings. High-ability students consistently demonstrated accurate representations, structured graphs, and logical written explanations across data sources. Moderate students showed partial understanding, requiring peer input, and their test results reflected minor errors or incomplete reasoning. Low-ability students exhibited reliance on prompts and peers, with test responses revealing conceptual gaps and disorganized explanations. Observation data highlighted active engagement in each TPS phase, including thinking individually, collaborating in pairs, and sharing in groups, supporting progress in mathematical communication.

Overall, the convergence of evidence demonstrates that TPS effectively fosters students' mathematical communication by providing structured opportunities for representation, visualization, and explanation. While high-ability students refined existing strengths, moderate- and low-ability students benefited significantly from collaborative interaction. Nevertheless, differentiated support remains necessary to ensure all learners meaningfully engage in communicating mathematical ideas.

## DISCUSSION

This section discusses the effect of the Think-Pair-Share (TPS) cooperative learning model on students' mathematical communication ability, focusing on three key indicators: representation, drawing, and writing/explaining. Following the explanatory sequential design, quantitative results are analyzed first, then elaborated with qualitative findings from interviews, classroom observations, and written tests.

Descriptive statistics show higher post-test scores in the experimental class (Mean = 75.10) than in the control class (Mean = 65.77), consistent across median and mode, with a stable standard deviation. The Shapiro-Wilk and F-tests confirmed normality and homogeneity, validating the independent t-test result (t-calculated = 3.5785, p = 0.0007), which revealed a significant difference. Cohen's $d$ = 0.92 (large) indicates strong improvement. With nearly identical pre-test scores and consistent external conditions, TPS was the key factor enhancing students' mathematical communication, aligning with findings by Anggraeni *et al*. (2023).

Building on statistical results, mastery analysis shows substantial TPS effects. This is based on the number of students reaching the threshold score $\geq 3$ (holistic rubric 0–4, aligned with KKM 75). In the experimental class, Drawing improved most (3.3% - 90%), followed by Representation (0% - 83.3%) and Explaining/Writing (0% - 46.7%). These results suggest that while TPS fostered growth in systematic problem-solving and logical reasoning, articulating complete written solutions remained more challenging than representing and drawing. Notably, compared with control, Representation showed the largest gap (83.3% vs. 46.7%), followed by Explaining/Writing (46.7% vs. 30%) and Drawing (90% vs. 76.7%). Overall, TPS significantly enhanced representation, while also benefiting drawing and writing/explaining aspects compared to direct instruction.

Thematic analysis of qualitative data enriched the quantitative results by confirming consistent improvements from the converging information sources: interview transcripts, classroom observations, and student-written work, across representation, drawing, and writing/explaining indicators. In representation, high-ability students demonstrated accurate use of symbols and terminology, moderate students showed partial fluency with reliance on peers, and low-ability students struggled but improved through collaboration. Observations revealed that the Think and Pair phases supported independent interpretation and refinement of representations through dialogue. These findings align with Putri *et al*. (2022), highlighting the role of representation in linking conceptual and procedural fluency, and with Vygotsky's Zone of Proximal Development (ZPD), where students advanced when supported by more capable peers through scaffolded interaction.

In drawing, TPS enabled students to transform abstract data into visual forms. High-ability students produced structured graphs with minor refinements, while moderate and low-ability students relied on peer support to correct scales, axes, and ordering. They showed progress but still struggled with consistency. This aligns with Purba & Rajagukguk (2024) who noted that cooperative learning fosters greater student involvement in communicating mathematical ideas visually. This also aligns with Bruner's theory, where learners transition from enactive to iconic stages. The collaborative visualization activities in TPS fostered reflection and accuracy, particularly in the Share phase, where students explain their visualizations to others.

Writing/explaining presented the most complex variation. High-ability students provided coherent reasoning; moderate students produced correct answers but lacked elaboration; and low-ability students produced disorganized responses, yet improved after peer dialogue. The structured TPS phases guided reasoning from reflection to explanation, consistent with Vygotsky's social constructivism, which emphasizes that learners internalize reasoning through interaction within their ZPD. Likewise, Piaget's concepts of assimilation and accommodation help explain how students adjusted and reorganized their thinking through reflective dialogue. Through these collaborative and reflective processes, students strengthened their ability to express mathematical ideas more clearly and coherently in written form.

Therefore, the TPS model significantly improved students' mathematical communication across indicators: representation, drawing, and explaining/writing. The three stages of TPS are interconnected to strengthen each mathematical communication indicator. In the Think stage, students independently analyze problems and select ways to represent, visualize, and explain ideas in diverse forms. This fosters free expression and multiple solutions, later refined in the Pair and Share stages. In the Pair stage, students exchange and negotiate ideas, using drawings, symbols, and written explanations to enhance clarity and accuracy. During the Share stage, groups present their results to the class, supported by verbal and written descriptions. Responding to peers' questions promotes deeper comprehension, reinforcing accuracy, logical reasoning, and appropriate mathematical language.

Overall, TPS enhances students' mathematical communication by fostering independent thinking, collaborative reasoning, and public articulation. The integration of the TPS deepens the expression of mathematical ideas. Through structured stages of TPS, students improve representation, drawing, and writing/explaining abilities, while peer interaction, reflection, and feedback refine understanding and accuracy. These results align with the view that well-structured cooperative learning supports both cognitive and social development, enabling students to construct and communicate mathematical meaning with clarity and confidence.

## CONCLUSION AND SUGGESTIONS

This study examined the effect of the Think-Pair-Share (TPS) cooperative learning model on students' mathematical communication using an explanatory sequential mixed-method. Quantitative results showed that students in the experimental group significantly outperformed the control group, with a post-test mean of 75.10 vs 65.77. The independent t-test ($t = 3.5785$, $p = 0.0007$) confirmed a significant difference, and a large effect size (Cohen's $d = 0.92$) indicated a substantial practical impact of TPS on mathematical communication abilities. Qualitative findings revealed that TPS enhanced students' abilities across three indicators: representation, drawing, and writing/explaining. Structured stages of TPS (Think, Pair, Share) enabled students to process problems independently, collaboratively construct knowledge, and publicly articulate their understanding. Representation improved through fluent use of mathematical terms and models, drawing developed via peer-refined graphs, and writing/explaining advanced through organized reasoning, problem-solving steps, answer justification, articulation of mathematical thinking, and increased confidence and clarity. This study concludes that cognitive and social-constructivist theories, highlighting reflection, collaboration, and scaffolding as key mechanisms through which TPS fosters both conceptual understanding and effective mathematical communication.

As a future development, teachers are encouraged to implement TPS consistently to enhance mathematical communication, while schools should support cooperative learning through training and curriculum integration. Students should actively engage in all TPS phases to strengthen understanding, collaboration, and confidence. Notably, future research could involve larger and more diverse samples, examine motivation and anxiety, and explore the long-term impact of TPS across different mathematical topics, with the ultimate goal of further improving students' mathematical communication abilities.

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