

The Effect of the Thinking Aloud Pair Problem-Solving Model-Integrated Open-Ended Approach on Students' Critical Thinking, Mathematical Communication, and Self-Confidence

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ABSTRACT

This study aims to examine the effect of the Thinking Aloud Pair Problem-Solving integrated with an Open-Ended Approach (TAPPS-OE) on students' critical thinking (CT), mathematical communication (MC), and self-confidence (SC) compared to direct instruction. The study employed a quasi-experimental method using a pretest-posttest non-equivalent control group design. The participants consisted of 56 junior high school students in Indonesia, with 28 students in the experimental group and 28 students in the control group. The instruments included tests of critical thinking and mathematical communication, as well as a self-confidence questionnaire. Data analysis involved descriptive and inferential statistics. Descriptive statistics were used to summarize students' performance, while inferential analysis was conducted using the Mann-Whitney U test. The results showed that there were no significant differences between the experimental and control groups at the pretest stage, indicating comparable initial abilities. At the posttest stage, there were significant differences in critical thinking and mathematical communication between the two groups, favoring the experimental group, while no significant difference was found in self-confidence. These findings indicate that the TAPPS-OE model has an impact on students' critical thinking and mathematical communication, but has no impact on self-confidence. In conclusion, the integration of structured verbal interaction and open-ended problem-solving provides a meaningful learning experience that supports the development of students' higher-order thinking and communication skills. This study suggests that TAPPS-OE can be considered as an alternative approach to support more active and student-centered mathematics learning.



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A. INTRODUCTION

The demands of 21st-century education require students to develop critical thinking (CT), communication skills, and positive learning attitudes. In mathematics, these competencies help students analyze problems, explain ideas, and engage actively in learning (Danao et al., 2025; Zou et al., 2025). However, many students still exhibit weak CT, particularly in evaluating arguments and generating alternative solutions (Dhayanti et al., 2018; Indriani et al., 2024; Nugroho et al., 2024). Mathematical communication (MC) also remains limited, as students often struggle to explain reasoning clearly (Kurniawan & Darmono, 2021; Nuraida & Amam, 2019). In addition, low self-confidence (SC) makes students hesitant to share opinions or participate in discussions (Nugroho et al., 2026; Nugroho, Sugiman, et al., 2025; Wahyuni et al., 2024). These three aspects are closely

related, as critical thinking supports communication, while confidence encourages active engagement. Therefore, improving mathematics achievement requires instructional strategies that support both cognitive and affective development.

Thinking Aloud Pair Problem-Solving (TAPPS) is a collaborative learning model that encourages students to verbalize their reasoning while solving problems in pairs (Pratiwi et al., 2018). In this model, one student explains the steps and reasoning involved in solving a problem, while the partner listens, asks questions, and provides feedback. This structured interaction may support CT development by encouraging students to analyze problems, evaluate their reasoning, identify errors, and justify conclusions (Anggraeni et al., 2019). At the same time, verbalizing mathematical ideas and responding to a partner's questions can provide opportunities to improve MC (Rohmah & Wahyuni, 2024). The collaborative nature of TAPPS may also help students become more comfortable expressing their ideas and participating in mathematical discussions, potentially supporting the development of SC (Rifa'i & Lestari, 2018). However, the opportunities this model provides to explore diverse mathematical strategies may depend on the characteristics of the problems presented. Therefore, incorporating tasks that encourage flexible thinking and multiple solution strategies may further enhance the learning opportunities offered by TAPPS.

An Open-Ended Approach (OE) can complement TAPPS by presenting mathematical problems that allow multiple solution strategies, answers, or representations. When integrated with TAPPS, open-ended tasks provide students with opportunities to explore alternative approaches, compare solutions, and justify their reasoning through structured dialogue with their partners (Monrat et al., 2022; Purwoko et al., 2023). These activities may strengthen CT by encouraging students to evaluate different strategies and consider the validity of alternative solutions. They may also enhance MC as students explain their approaches, interpret their partners' reasoning, and express mathematical ideas using appropriate representations. Furthermore, discussing different solutions in a collaborative setting may provide students with opportunities to express their opinions and become more comfortable sharing their mathematical thinking, which may support SC. Nevertheless, empirical research is needed to determine the extent to which integrating TAPPS and OE contributes to these cognitive and affective outcomes compared with direct instruction.

Previous studies have examined TAPPS and the Open-Ended Approach in mathematics education. Anggraeni et al. (2019) investigated TAPPS combined with audiovisual media to develop students' critical thinking, while Kurniawan & Darmono (2021) and Jehadus et al. (2021) examined open-ended learning to improve mathematical communication. Furthermore, Rohmah & Wahyuni (2024) and Sari & Safaatullah (2024) investigated students' mathematical CT in relation to SC in CORE learning with an Open-Ended Approach. Although these studies provide evidence that these approaches can support mathematics learning, research integrating TAPPS and an Open-Ended Approach to examine CT, MC, and SC simultaneously remains limited.

These gaps matter because students need instructional approaches that develop cognitive skills and affective dispositions at the same time. Integrating TAPPS with an Open-Ended Approach may give students opportunities to strengthen critical thinking by exploring multiple solutions, improve mathematical communication through structured dialogue, and build self-confidence by expressing and defending their ideas.

Therefore, the novelty of this study lies in integrating the Open-Ended Approach into the Thinking Aloud Pair Problem-Solving model (TAPPS-OE) to examine its effect on students' critical thinking (CT), mathematical communication (MC), and self-confidence

(SC) simultaneously. This study comprehensively examines these three learning outcomes compared with direct instruction, extending previous research that has primarily investigated them separately. The findings may help teachers design collaborative learning that supports reasoning, communication, and confidence. Theoretically, the study contributes to understanding how verbal interaction and open-ended tasks work together in mathematics education. Therefore, this study aims to examine the effect of TAPPS-OE on students' CT, MC, and SC.

Accordingly, this study addresses the following research questions: (1) Does TAPPS-OE have a significant effect on students' CT compared with direct instruction? (2) Does TAPPS-OE have a significant effect on students' MC compared with direct instruction? and (3) Does TAPPS-OE have a significant effect on students' SC compared with direct instruction? Therefore, this study aims to examine the effect of TAPPS-OE on students' CT, MC, and SC compared with direct instruction.

B. METHODS

1. Research Design

This study employed a quasi-experimental method using a pretest-posttest non-equivalent control group design. Two intact classes were involved: an experimental class receiving the Thinking Aloud Pair Problem-Solving (TAPPS) model integrated with an Open-Ended Approach (TAPPS-OE), and a control class receiving Direct Instruction (DI).

2. Participants

The study was conducted at a public junior high school in Indonesia during the 2025/2026 academic year. The school was selected because students' mathematical abilities, particularly in critical thinking, mathematical communication, and self-confidence, were still relatively low based on classroom observations and teacher reports. This condition made the school an appropriate setting to examine the effect of the TAPPS-OE model in improving these learning outcomes. A total of 56 students participated in this study, consisting of 28 students in the experimental class (TAPPS-OE) and 28 students in the control class (Direct Instruction). The two classes were selected based on comparable previous mathematics achievement, similar academic characteristics, and teacher recommendations. Their participation was voluntary, and informed consent was obtained prior to data collection.

3. Research Instrument

Three instruments were used in this study: tests of critical thinking (CT), mathematical communication (MC), and a self-confidence (SC) questionnaire. The CT test consisted of 2 essay problems designed to assess four indicators: (1) problem formulation, (2) data analysis, (3) argument construction, and (4) alternative solution determination. Each item required students to explain reasoning and justify solutions. The MC test consisted of 3 open-ended questions that assessed students' ability to express mathematical ideas through representations, symbols, formulas, and written conclusions. The SC was measured using a Likert-scale questionnaire comprising 20 items, including both positive and negative statements. The questionnaire covered six dimensions: (1) belief in one's ability, (2) independent decision-making, (3) positive self-concept, (4) courage to express opinions, (5) willingness to face challenges, and (6) appreciation of effort. Responses ranged from strongly disagree to strongly agree, with reverse scoring applied to negative statements.

Instrument validity was confirmed through Aiken's V and Confirmatory Factor Analysis (CFA). Aiken's V values ranged from 0.84 to 0.92, indicating strong content validity, while CFA showed factor loadings above 0.30 for all retained items. Reliability analysis using Cronbach's Alpha demonstrated high internal consistency, with coefficients of 0.8718 for the CT test, 0.874 for the MC test, and 0.8814 for the SC questionnaire.

4. Data Analysis Techniques

Data analysis included descriptive and inferential statistics. Descriptive statistics were used to summarize pretest and posttest scores (mean and standard deviation). Since the data did not meet parametric assumptions, a nonparametric test, namely the Mann-Whitney U test, was employed to examine differences between the experimental (TAPPS-OE) and control groups. All analyses were conducted using Jamovi and R with a significance level of 0.05.

C. RESULT AND DISCUSSION

1. Results of Data Pretest

This section presents the results of the pretest analysis, including both descriptive and inferential statistics. The purpose of this analysis is to examine the initial equivalence between the experimental (TAPPS) and control groups before the implementation of the treatment.

Table 1. Descriptive Statistics of Pretest Data

Variable	Group	Mean	SD
Pretest CT	TAPPS	35.0	22.4
	Control	32.5	20.5
Pretest MC	TAPPS	7.14	9.59
	Control	5.95	10.9
Pretest SC	TAPPS	73.9	8.66
	Control	73.1	7.52

Table 1 presents the descriptive statistics of the pretest scores for both the TAPPS and control groups. Overall, the mean scores between the two groups are relatively similar across all variables. In critical thinking (Pretest CT), the TAPPS group obtained a mean score of 35.0 (SD = 22.4), while the control group scored 32.5 (SD = 20.5). For conceptual mastery (Pretest MC), the TAPPS group achieved a mean of 7.14 (SD = 9.59), slightly higher than the control group (M = 5.95, SD = 10.9). Similarly, in self-confidence (Pretest SC), both groups showed nearly identical results, with mean scores of 73.9 (SD = 8.66) for the TAPPS group and 73.1 (SD = 7.52) for the control group. These results indicate that both groups had comparable initial abilities before the intervention.

Table 2. Mann-Whitney Test Results for Pretest

Variable	W	p-value	Interpretation
Pretest CT	417.5	0.6796	Not significant
Pretest MC	446.0	0.3386	Not significant
Pretest SC	414.5	0.7182	Not significant

Table 2 presents the results of the Mann-Whitney U test for the pretest data. The results indicate that there are no statistically significant differences between the TAPPS and control groups across all variables. Specifically, the p-values for CT (0.6796), MC (0.3386), and SC (0.7182) are all greater than 0.05. These findings confirm that both

groups were statistically equivalent prior to the intervention. Therefore, any differences observed in the posttest can be more confidently attributed to the treatment rather than initial group differences.

2. Results of Data Posttest

This section presents the results of the posttest analysis, including both descriptive and inferential statistics, to examine the effect of the treatment on the experimental (TAPPS) and control groups.

Table 3. Descriptive Statistics of Posttest Data

Variable	Group	Mean	SD
Posttest CT	TAPPS	80.5	13.6
	Control	69.8	17.3
Posttest MC	TAPPS	70.5	17.1
	Control	49.3	28.0
Posttest SC	TAPPS	77.8	7.89
	Control	76.2	7.47

Based on the descriptive statistics in Table 3, the TAPPS group consistently achieved higher mean scores than the control group across all variables. In CT, the TAPPS group obtained a mean score of 80.5 (SD = 13.6), while the control group scored 69.8 (SD = 17.3). Similarly, in MC, the TAPPS group reached a mean score of 70.5 (SD = 17.1), compared to 49.3 (SD = 28.0) in the control group. For SC, the TAPPS group achieved a mean score of 77.8 (SD = 7.89), slightly higher than the control group's 76.2 (SD = 7.47), indicating only a small difference between groups.

Table 4. Mann-Whitney Test Results for Posttest

Variable	W	p-value	Interpretation
Posttest CT	537.5	0.0169	Significant
Posttest MC	569.0	0.0037	Significant
Posttest SC	437.5	0.4599	Not significant

The results of the Mann-Whitney U test in Table 4 further confirm these findings. There were statistically significant differences between the two groups in CT ($p = 0.0169$) and MC ($p = 0.0037$), indicating that the TAPPS group performed significantly better than the control group in these cognitive domains. However, no significant difference was found in SC ($p = 0.4599$), suggesting that both groups had comparable levels of self-confidence after the intervention. Overall, these results indicate that the TAPPS model has a significant positive effect on students' CT and MC, while its impact on SC is not statistically significant.

This study aimed to examine the effect of the TAPPS-OE model on students' CT, MC, and SC compared to a direct learning approach. The results showed that both groups were equivalent at the baseline, as indicated by the non-significant differences in all pretest variables. However, after the intervention, significant differences emerged in CT and MC, favoring the TAPPS-OE group. In contrast, no significant difference was found in SC. These findings suggest that the TAPPS-OE model is particularly effective in improving cognitive outcomes, while its influence on affective aspects appears to be more limited.

In terms of CT, the findings indicate that students in the experimental group significantly outperformed those in the control group. This result can be attributed to the characteristics of the TAPPS-OE model, which combines structured verbal interaction with open-ended problem-solving. Through the “thinking aloud” process, students are required to articulate their reasoning step by step, while their peers actively listen, question, and provide feedback. At the same time, open-ended tasks encourage students to explore multiple solution strategies rather than relying on a single correct answer (Nugroho, Desti, et al., 2025; Sachdeva & Eggen, 2021; Septiani et al., 2022). This combination fosters deeper analysis, evaluation, and flexibility in thinking. In contrast, students in the control group, who experienced more direct instruction, had fewer opportunities to engage in such reflective and interactive processes. This finding is consistent with previous studies suggesting that collaborative and open-ended learning environments can significantly enhance students’ higher-order thinking skills (Kurniawan & Darmono, 2021; Ngurah et al., 2024; Nugroho & Sugiman, 2026; Sole, 2016).

Regarding MC, the results also show a significant advantage for the TAPPS-OE group. The integration of open-ended problems into the TAPPS structure provides students with more opportunities to express ideas, justify reasoning, and compare different solution approaches. When students explain their thinking aloud and respond to peer feedback, they not only solve problems but also actively construct and communicate mathematical meaning. This process helps students organize their thoughts more clearly and use appropriate mathematical representations, symbols, and language (Nugroho & Septianisha, 2025). In contrast, the control group may have experienced more teacher-centered instruction, limiting opportunities for active communication. These findings align with prior research emphasizing that interactive and open-ended learning approaches play a crucial role in developing students’ mathematical communication skills (Johar et al., 2025; Kurniawan & Darmono, 2021; Rachmawati et al., 2021; Tinungki, 2015; Tupamahu et al., 2023).

For SC, although the TAPPS-OE group showed slightly higher mean scores, the difference was not statistically significant. This suggests that while the TAPPS-OE model creates a more interactive and supportive learning environment, its impact on students’ confidence may not be immediate. Self-confidence is a complex affective construct influenced by various factors, such as prior learning experiences, individual personality, and classroom climate (Ertmer & Ottenbreit-Leftwich, 2010; Smith et al., 2025). Although open-ended discussions and peer collaboration can encourage participation, some students may still feel hesitant to express their ideas, especially if they are not yet accustomed to such learning environments. This finding is in line with previous studies indicating that affective outcomes, such as self-confidence, tend to develop more gradually and may require longer intervention periods or additional supportive strategies (Kosim et al., 2020; Kung, 2009; Putra et al., 2025; Sari & Safaatullah, 2024).

Despite the positive findings, this study has several limitations. First, the duration of the intervention was relatively short, which may have limited its impact on affective variables such as self-confidence. Second, the sample size was relatively small and limited to one school context, which may affect the generalizability of the results. Future research is recommended to involve larger and more diverse samples, as well as longer implementation periods, to better capture the development of both cognitive and affective outcomes. Additionally, incorporating qualitative data, such as classroom observations or student interviews, could provide deeper insights into how the TAPPS-OE model influences students’ thinking, communication, and confidence. Further studies

may also explore combining TAPPS-OE with other pedagogical strategies to enhance its effectiveness, particularly in fostering students' self-confidence.

D. CONCLUSION AND SUGGESTIONS

The results indicate that the TAPPS-OE model significantly improves students' CT and MC compared with direct instruction. The experimental group achieves higher mean scores in CT (80.5) and MC (70.5) than the control group (69.8 and 49.3, respectively), with statistically significant differences ($p = 0.0169$ and $p = 0.0037$). However, the difference in SC between the experimental and control groups is not statistically significant ($p = 0.4599$), despite the slightly higher mean score in the experimental group (77.8 compared with 76.2). These findings suggest that TAPPS-OE supports students' critical thinking and mathematical communication, while its effect on self-confidence remains inconclusive. Future research should consider longer intervention periods and additional strategies to support students' self-confidence.

Based on these findings, several recommendations can be proposed. For teachers, it is suggested to implement the TAPPS-OE model to create more interactive and student-centered classrooms, while providing sufficient time for discussion, reflection, and exploration of multiple solution strategies. For academics and researchers, further studies should investigate the long-term effects of TAPPS-OE, use larger and more diverse samples, and incorporate qualitative methods to better understand students' learning processes. For curriculum policymakers, it is recommended to support the integration of collaborative and open-ended learning approaches into the curriculum, as these strategies have been shown to enhance students' critical thinking and communication skills. Additionally, professional development programs should be provided to help teachers effectively implement innovative models such as TAPPS-OE in classroom practice.

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