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DEEP DIALOGUE-CRITICAL THINKING (DDCT) LEARNING MODEL TO AFFECT STUDENTS' MATHEMATICS LEARNING OUTCOMES ON SENIOR HIGH SCHOOL

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ABSTRACT

Improving students' achievement in mathematics remains a major concern in secondary education, particularly in trigonometric ratios, where conceptual understanding and mathematical reasoning are often insufficiently developed. These challenges show the need for instructional approaches that actively engage learners in discussion and critical reflection. This study investigated the effectiveness of the Deep Dialogue-Critical Thinking (DDCT) learning model in improving students' mathematics learning outcomes on trigonometric ratios. The study employed a quantitative quasi-experimental design using a pretest-posttest control group approach. Forty-two tenth-grade students were selected through cluster random sampling and equally assigned to an experimental group and a control group. Students in the experimental group learned through the DDCT model, while those in the control group received direct instruction. Learning outcomes were measured using a validated essay test, and the data were analyzed using descriptive statistics, normalized gain (N-Gain), an independent samples t-test, and Cohen's d effect size analysis. The results showed that students exposed to the DDCT model achieved a higher mean posttest score (33.24) than those in the control group (30.13). The experimental group also obtained a higher N-Gain score (0.8213) than the control group (0.7500). Moreover, the independent samples t-test confirmed a significant difference between the two groups ($t = 2.3861$, $p < 0.05$), while Cohen's d value of 1.18 indicated a large educational effect. These findings suggest that the DDCT learning model is an effective instructional strategy for enhancing students' mathematics learning outcomes in trigonometric ratios.

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INTRODUCTION

Mathematics learning outcomes are one of the main indicators used to evaluate the quality of education because they reflect students' ability not only to master mathematical concepts but also to reason mathematically, solve real-world problems, and interpret mathematical solutions. As emphasized in the OECD PISA 2022 report, in today's world students are expected not merely to know mathematics, but to apply their knowledge effectively in various contexts. Therefore, improving students' mathematics learning outcomes has become an important priority for education systems worldwide (OECD, 2023).

Students' mathematics achievement in Indonesia remains one of the main challenges in efforts to improve the quality of education. According to the National Academic Ability Test (TKA) statistics for the 2025/2026 school year at the high school and vocational high school levels, the average mathematics score was only 36.10, with 44.71% of students falling into the "Insufficient" category and only 2.17% reaching the "Exceptional" category (Badan Kebijakan Pendidikan, Pusat Asesmen Pendidikan, 2025). This situation indicates that improving mathematics learning outcomes remains a challenge that requires serious attention through the implementation of more effective learning processes.

To improve students' mathematics learning outcomes, mathematics education plays a fundamental role in developing students' conceptual understanding, reasoning, and problem-solving skills. Through systematic mathematics instruction, learners are projected to acquire positive attitudinal shifts, refined practical competencies, and sharper analytical and critical reflection faculties (Hasan et al., 2020). Correspondingly, (Pauweni et al., 2022) emphasize that mathematics comprises numerous abstract frameworks, thereby demanding active student participation in exploring, applying, and deciphering related issues. Consequently, instructional delivery must be resourcefully crafted, leveraging models, strategies, and pedagogical methodologies tailored to specific student dynamics.

Diagnostic observations conducted on January 13, 2026, revealed several systemic hurdles in the ongoing mathematics classroom dynamics. Students consistently demonstrated hesitation in clarifying ambiguous topics, peer-to-peer interactions during collaborative tasks were scarce, and most learners resisted presenting their mathematical solutions publicly. Active engagement with instructional explanations remained minimal, with several students drifting toward off-task activities driven by classroom disinterest and boredom. This passivity primarily stems from teacher-dominated instructional methods that significantly compress the windows for student involvement. As (Abbas & Zakaria, 2018) point out, such a deficiency in active learner participation directly undermines the optimization of mathematical concept retention. This aligns with (Ismail et al., 2025), who note that conventional mathematics classrooms are habitually dominated by a highly central instructor role, controlling both the lesson trajectory and the absolute dissemination of mathematical contents. Consequently, the teacher remains the exclusive information reservoir, leaving students with restricted agency, spending most of their classroom hours passively absorbing lectures.

Within the high school mathematics curriculum, trigonometry represents a highly pivotal domain. Nonetheless, a substantial portion of students find this topic particularly daunting due to its extensive reliance on formulas and the strict necessity for robust conceptual mastery. This learning obstacle manifests not only when students try to execute algorithmic formulas but also when they attempt to link trigonometric concepts to real-world, contextual phenomena in daily activities (Nanmumpuni & Retnawati, 2021). Furthermore, (Obeng et al., 2024) identify that student errors during trigonometric problem-solving do not merely arise from deficient procedural execution, but rather root from fragile conceptual underpinnings. Students frequently resort to rote memorization without grasping the core meaning of mathematical logic, leading to erroneous choices of trigonometric identities, missteps in computational pathways, and invalid extensions of algebraic properties to trigonometric expressions. Such conditions highlight an immediate imperative for pedagogical shifts that emphasize deep comprehension and high-order cognition, thereby bridging the chronic disconnect between conceptual knowledge and procedural skills.

(Alvarez-Tinajero et al., 2026) further show that cultivating mathematical proficiency and critical reflection faces persistent challenges, including rigid curricular designs, suboptimal teacher professional development, inadequate contextual frameworks, and a reliance on unidirectional, traditional modes of teaching. These structural issues constrain the growth of multifaceted cognitive competencies, such as analytical rigor, logical argumentation, and critical evaluation. Hence, there is a profound need for innovative educational models that not only aid conceptual processing but also spark interactive dialogue, deep analysis, and active knowledge construction. To transcend the boundaries of rote learning and purely procedural routines, adopting a model that empowers students to synthesize knowledge, build critical thinking capacities, and solve complex problems meaningfully is vital. (Kobandaha et al., 2019) emphasize that mathematical problem solving requires students to relate prior knowledge, learning experiences, and newly acquired concepts in order to determine appropriate solution strategies. Therefore, students' reasoning abilities play a crucial role in supporting successful problem-solving processes.

One instructional model that has demonstrated considerable potential in addressing these challenges is the Deep Dialogue-Critical Thinking (DDCT) learning model. DDCT emphasizes meaningful dialogue, collaborative learning, and critical reflection, enabling students to construct knowledge actively rather than merely receive information passively. Previous studies have shown that the implementation of DDCT significantly improves students' mathematical conceptual understanding. (Que et al., 2022) reported that students taught using the DDCT model achieved substantially higher average scores (88.67) than those taught through conventional instruction (60.00), indicating a significant positive effect of DDCT on students' conceptual understanding. Furthermore, the study found that DDCT facilitates students in understanding mathematical concepts more easily while creating a more engaging learning environment. Similarly, (Shobirin et al., 2025) found that the DDCT model effectively enhanced students' conceptual understanding, higher-order thinking skills, and active participation during learning. These findings suggest that DDCT provides meaningful learning experiences by encouraging students to construct knowledge collaboratively through dialogue and critical thinking. This model centers on intensive dialogic exchanges and analytical reasoning by fostering peer ideation, rational justification, and collaborative problem-solving. Under the DDCT approach, students transition from passive recipients to active participants who interrogate concepts, articulate well-reasoned perspectives, and critique diverse mathematical problem-solving methodologies.

Despite its potential, empirical documentation assessing DDCT's utility in mathematics education, particularly regarding trigonometric ratios, remains sparse. Yet, as (Usman et al., 2021) underscore, achieving robust learning outcomes constitutes a cornerstone of any instructional endeavor. Driven by this gap, the current study aims to evaluate the distinct impact of the Deep Dialogue-Critical Thinking instructional model on students' mathematical outcomes within the topic of trigonometric ratios. This inquiry is anticipated to offer an innovative, communicative, and active pedagogical alternative that strengthens critical thinking in secondary mathematics environments.

METHOD

Adopting a quantitative framework, this research made use of a quasi-experimental method built around a pretest-posttest control group design, conducted with the aim of assessing the influence of the Deep Dialogue/Critical Thinking (DDCT) model on mathematics learning outcomes related to Trigonometric Ratios. The setting for this research was State Senior High School 2 North Gorontalo, with data collected across the even semester of the 2025-2026 academic year. Involving all 10th-grade students at the school distributed among four separate classes as its population, the study narrowed its sample down to two classes via Cluster Random Sampling, one functioning as the experimental group and the other as the control group. Instruction in the experimental class followed the DDCT model, whereas students in the control class were taught through a direct, conventional method. In total, the sample comprised 42 students, evenly split between the two classes at 21 each.

The study unfolded across three sequential phases preparatory, implementation, and concluding. In the preparatory phase, teaching modules and learning materials were developed alongside a research instrument, namely a 15-item essay test built around the learning indicators for Trigonometric Ratios. To confirm its suitability, the instrument was reviewed by a panel of experts four Mathematics Education lecturers and one mathematics teacher after which necessary revisions were made and the instrument was tested on a group of students not included in the actual research sample.Analysis of the trial data drew on two statistical tools: Pearson's product-moment correlation (Sugiyono, 2007), used to establish empirical validity, and Cronbach's alpha (Sugiyono, 2013), used to determine reliability. Only once these validity and reliability benchmarks were met did the instrument serve as the pretest and posttest tool. The implementation phase opened with a pretest given to both classes to establish students' baseline competence. From there, DDCT-based teaching was delivered to the experimental class over three sessions, in contrast to the control class, which received conventional direct instruction across the same number of sessions. A posttest identical to the earlier instrument was then administered to both groups once teaching concluded, capturing their resulting learning outcomes. Data processing, analysis, and the formulation of conclusions rounded out the final phase of the study.

Data analysis was conducted using descriptive and inferential statistics. Descriptive statistical analysis was used to describe student learning outcomes based on the mean, standard deviation, maximum value, and minimum value. Before hypothesis testing, prerequisite tests were conducted, consisting of a normality test and a homogeneity test. The statistical test used for the normality test was the Shapiro-Wilk test, as follows (Ahadi & Zain, 2023):

$$W = \frac{(\sum_1^n a_i x_i)^2}{\sum_1^n (x_\mathrm{i} - \bar{x})^2}$$

The homogeneity test was conducted using the Hartley test with the following formula (Usmadi, 2020: 53):

$$F = \frac{Highest\ Variance}{Lowest\ Variance}$$

Next, improvements in student learning outcomes were analyzed using Normalized Gain (N-Gain) with the following formula (Hake, 1999).

$$\mathrm{g} = \frac{(Posttest - Pretest)}{(Max\ Score - Pretest)}$$

The criteria are as follows:

Table 1. Criteria for Interpreting N-Gain Scores

Normalized Gain Value	Category
$0{,}70 \leq g \leq 1{,}00$	High
$0{,}30 \leq g < 0{,}70$	Moderate
$0{,}00 \leq g < 0{,}30$	Low

Next, a hypothesis test was conducted to determine the difference in learning outcomes between the experimental and control classes using an independent samples t-test at a 5% significance level, using the following formula (Magdalena & Angela Krisanti, 2019):

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1-1)s_1^2(n_2-1)s_2^2}{n_1+n_2-2} + \left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$$

Description :

t = calculated t-value

$\bar{x}_1$= mean score of the experimental group

$\bar{x}_2$= mean score of the control group"

s_1^2= variance of the experimental group

s_2^2 = variance of the control group

n_1= sample size of the experimental group

n_2= sample size of the control group

To determine the extent to which the implementation of the Deep Dialogue/Critical Thinking (DDCT) learning model affects student learning outcomes, Cohen's d effect size analysis was used, calculated using the following formula (Ialongo, 2016):

$$d = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{(s_1^2+s_2^2)}{2}}}$$

Description:

d = Cohen's d effect size

$\bar{x}_1$ = mean score of the experimental group

$\bar{x}_2$ = mean score of the control group

s_1^2 = variance of the experimental group

s_2^2 = variance of the control group

The criteria for interpreting the effect size are as follows:

Table 2. Criteria for Interpreting Effect Size Values

Effect Size Value	Description
0,00 – 0,20	very small effect
0,21 – 0,50	Small effect
0,51 – 1,00	Medium effect
> 1,00	Large effect

RESULTS AND DISCUSSIONS

Results

The statistical overview of the baseline and terminal testing across both tracking groups provides a clear diagnostic view of student progression. A concise breakdown of the operational data can be observed in Table 3.

Table 3. Summary of Descriptive Learning Statistics

Group	Test	N	Score Min	Score Max	Mean ($\bar{x}$)	Median (M_e)	Modus (M_o)	St.Dev (S)	Varians (S^2)
Eksperimental	Pre-test	21	12	20	15,93	15,7	14,38	2,54	6,45
	Post-test	21	29	37	33,30	33,37	33,5	2,35	5,56
Control	Pre-test	21	11	20	15,59	15,5	14,1	2,48	6,19
	Post-test	21	24	35	30,07	30,37	30,67	2,87	8,26

Based on the descriptive breakdown in Table 3, the baseline parameters (pre-test) between the two cohorts were highly comparable, with the experimental mean standing at 15.93 and the control mean at 15.59. Following the intervention phase, the experimental group achieved a post-test mean score of 33.30, while the control group reached a post-test mean of 30.07. When converted to a standard 100-point scale, the experimental group's average rose remarkably from an initial 39.88 to a final 83.09. Meanwhile, the control group exhibited a more conservative growth, moving from 38.92 to 75.35. These figures provide a preliminary indication that the classroom integration of the DDCT framework yielded a more pronounced acceleration in mastery compared to traditional direct instruction.

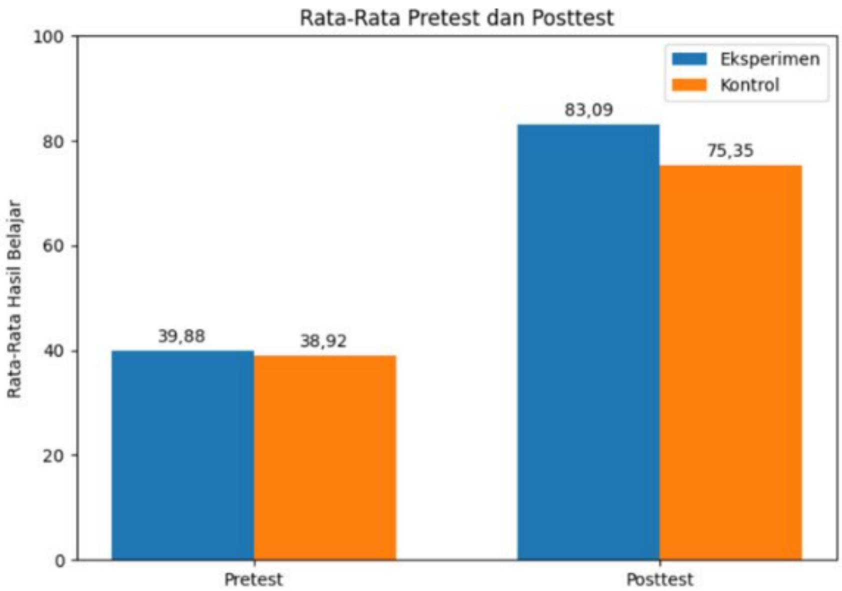

Figure 1. Average Student Academic Achievement Scores

To ensure the mathematical validity of the inferential analysis, normality and homogeneity verifications were conducted. The normality profiles extracted via the Shapiro-Wilk criteria are detailed in Table 4.

Table 4. Normality Testing Output

Group	Test Type	N	W_{count}	W_{table}	Decision
Experiment	Pre-test	21	0,9375		
	Post-test	21	0,9668	0,908	Normally Distributed
Control	Pre-test	21	0,9659		Normally Distributed
	Post-test	21	0,9464	0,908	

Because every single calculated value of $W_{\text{calculated}}$ surpassed the critical mathematical index of $W_{\text{table}} = 0.908$ at the $\alpha = 0.05$ boundary, the null hypothesis regarding non-normal distribution was rejected. Thus, the data points across all variables strictly comply with normality assumptions.

Subsequently, the Harley test was executed to confirm variance equality between the independent groups. The outcomes are structured in Table 5.

Table 5. Homogeneity of Variance Test

Group	Test Type	N	F_{count}	F_{table}	Decision
Experiment	Pre-test	21			
	Post-test	21	1,0340	2,1241	Homogeneous
Control	Pre-test	21			Homogeneous
	Post-test	21	1,8496	2,1241	

The variance analysis demonstrated that the calculated F-statistics for both the pre-test $F = 1.0340$ and post-test $F = 1.8496$ dropped below the critical distribution score $F_{\text{table}} = 2.1241$. Consequently, the tracking groups possess equal and homogeneous variances, justifying the subsequent deployment of parametric inferential testing.

To determine the effectiveness of the Deep Dialogue-Critical Thinking (DDCT) learning model in improving students' mathematics learning outcomes, an N-Gain analysis was conducted. The results of the N-Gain analysis are presented in Table 6.

Table 6. N-Gain Analysis of Student's Mathematics Learning Outcomes

Class	n	Mean Pretest Score	Mean Posttest Score	Mean N-Gain	Category
Experiment	21	15,95	33,24	0,8213	High
Control	21	15,57	30,14	0,7500	High

Based on the data presented in Table 6, the mean N-Gain scores stood at 0.8213 for the experimental class and 0.7500 for the control class both of which, per (Hake, 1999) classification system, qualify as falling into the high category. Despite this shared classification, the experimental class's advantage in N-Gain score suggests that greater improvement in mathematics learning outcomes resulted from the DDCT model compared to conventional instruction. This gap in N-Gain scores, favoring the experimental class, serves as evidence that

DDCT delivered stronger results in enhancing students' learning outcomes. The explanation for this lies in the core characteristics of the DDCT model itself: an emphasis on substantive dialogue, teamwork-based learning, and the cultivation of critical thinking skills. These features allow students to take an active part in shaping mathematical understanding, exchanging perspectives, and honing logical reasoning all factors that translate into stronger learning gains. Similar conclusions were drawn by (Que et al., 2022), whose research showed that students exposed to the DDCT model demonstrated markedly better conceptual grasp than peers taught using conventional methods.

The verification of the main research hypothesis was managed via an Independent-Sample t-test. The statistical breakdown is highlighted in Table 7.

Table 7. Independent Samples t-Test Evaluation

Group	**Test Type**	**Mean Score**	**Degrees of Freedom (dk)**	t_{count}	t_{table}	**Decision**
	Pre-test	15,95				
Experiment	Post-test	33,24	40	2,3861	1,684	H_1 Accepted
	Pre-test	15,57				
Control	Post-test	30,13	40	2,3861	1,684	H_1 Accepted

The mathematical computation produced a $t_{\text{calculated}}$ score of 2.3861, which structurally exceeds the corresponding t_{table} score of 1.684 at a 0.05 alpha level with 40 degrees of freedom $df = 40$. This critical gap confirms the rejection of the null hypothesis H_0. Therefore, a statistically significant difference in mathematical outcomes exists between the student body exposed to the Deep Dialogue-Critical Thinking (DDCT) methodology and those under direct instruction routines. Additionally, the Cohen's d framework returned an effect size value of 1.18, falling deep into the highly intensive impact category. This proves that the pedagogical shift to DDCT generates a massive practical impact on student performance.

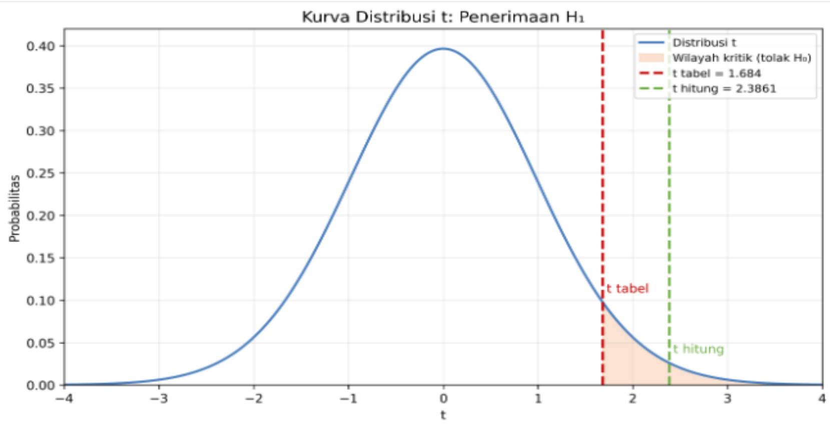

Figure 2. Acceptance and Rejection Coverage Area Curves

Discussions

Study results demonstrate that applying the Deep Dialogue-Critical Thinking (DDCT) model brought about a meaningful increase in students' mathematics achievement on the trigonometric ratios topic, surpassing the results obtained through direct instruction. Several statistical indicators reinforce this conclusion. To begin with, the mean posttest score of the experimental group (33.24) exceeded that of the control group (30.13), reflecting a stronger grasp of the material following the treatment. Next, the normalized gain obtained by the experimental group (N-Gain = 0.8213) was likewise higher than that of the control group (N-Gain = 0.7500). Even though both groups fell into the high-improvement category, this gap in N-Gain scores signals that students taught via the DDCT model attained a more substantial level of progress. Moreover, the independent samples t-test produced a statistically significant result between the two groups ($t = 2.3861$, $p < 0.05$), affirming that the observed improvement was not attributable to chance. Adding to this, a Cohen's d value of 1.18 reflects a large practical effect, pointing to the considerable educational value the DDCT model holds for enhancing mathematics learning outcomes. Taken as a whole, these findings confirm that the DDCT model surpasses conventional direct instruction in strengthening students' comprehension of trigonometric ratios.

The inferential findings validate that the deployment of the Deep Dialogue-Critical Thinking (DDCT) approach produces a substantially better grasp of mathematical ideas compared to traditional teacher-centered instruction within the specific context of trigonometric ratios. This optimization highlights that fostering active student dialogue directly enhances conceptual clarity. Through collaborative interactions and intensive reasoning exercises, learners can co-construct their cognitive understanding, making the instructional process more meaningful. The pedagogical superiority of the DDCT framework lies in its active design, which requires students to rationalize their ideas, articulate their thought processes, react to peer interpretations, and critically review problem-solving strategies. Such dialogic habits help students trace the structural relationships within trigonometric ratios, particularly when calculating the core ratios of sine, cosine, and tangent, as well as applying these ideas to authentic real-world problems.

The findings of this study are consistent with those of (Que et al., 2022), who reported that the implementation of the Deep Dialogue-Critical Thinking (DDCT) learning model significantly improved students' mathematical conceptual understanding compared with conventional instruction, as meaningful dialogue and collaborative discussion enabled students to actively construct knowledge. Similarly, (Shobirin et al., 2025) concluded that the DDCT model effectively enhances conceptual understanding, higher-order thinking skills, and students' active participation throughout the learning process. These findings are further supported by (Saifina & Tanjung, 2020), who found that dialogue-based and reflective learning activities within the DDCT model facilitate deeper conceptual understanding than teacher-centered instruction. Likewise, (Widiati et al., 2020) demonstrated that the DDCT learning model significantly improved students' critical thinking skills compared with the lecture method. The improvement in critical thinking skills consequently contributed to students' ability to understand concepts and solve problems more effectively, which ultimately enhanced their learning outcomes. However, the present findings differ from those reported by (Rianti et al., 2020), who found that the implementation of the Deep Dialogue model did not optimally improve students' critical thinking skills. They attributed this result to limited instructional time, less effective classroom management, and students' insufficient prior experience with analytical problem-solving tasks. The discrepancy may be explained by differences in research design, learning context, and the quality of model implementation. In the present study, all stages of the DDCT learning model were implemented systematically, allowing students sufficient opportunities to engage in meaningful dialogue, critical thinking, and collaborative knowledge construction. Consequently, the DDCT learning model produced greater improvements in students' mathematics learning outcomes than conventional direct instruction.

In contrast, the direct instruction model restricts students' opportunities to explore ideas independently due to its rigid, teacher-centered nature. Consequently, students under the DDCT model demonstrate a much higher level of mathematical mastery than their peers in the conventional control group.

CONCLUSION

The findings of this study point to a clear conclusion: implementing the Deep Dialogue-Critical Thinking (DDCT) model brings about a positive and statistically significant improvement in students' mathematics learning outcomes on the trigonometric ratios topic. Addressing the research question directly, the data confirm that students under the DDCT model outperformed those receiving direct instruction in terms of mathematics achievement. Backing this claim are four key indicators a higher posttest average among the experimental group, a stronger N-Gain (0.8213 versus 0.7500 for the control group), a significant difference verified by the independent t-test, and a substantial effect size reflected in a Cohen's d of 1.18. Collectively, these outcomes reveal that the emphasis on meaningful dialogue, collaborative engagement, and critical thinking within DDCT plays a considerable role in strengthening students' conceptual grasp and reasoning ability in mathematics. For this reason, DDCT stands out as a viable and effective alternative for teaching mathematics, especially the topic of trigonometric ratios.

Future research is recommended to examine the long-term effectiveness of the Deep Dialogue-Critical Thinking (DDCT) learning model and to compare its impact with that of other learning models that are similarly oriented toward active learning across various mathematics topics and different educational contexts. In addition, future research could investigate the role of other variables such as learning motivation, student engagement, self efficacy, mathematical reasoning skills, and mathematical communication skills as factors that may explain the mechanisms underlying improved learning outcomes through the application of the DDCT model.

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