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The Effectiveness of the Quantum Learning Model with a Deep Learning Approach on Students' Critical Thinking Skills in Solving Mathematical Problems

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ABSTRACT

The problem of students' low critical thinking skills has prompted innovation in learning strategies, one of which is the use of the Quantum Learning model with a Deep Learning approach. This study aims to determine the effectiveness of the Quantum Learning model based on the Deep Learning approach on students' critical thinking skills in solving mathematical problems. This study used a combinational research approach, applying an exploratory sequential mixed methods approach. The sampling technique used was purposive sampling. The sample consisted of classes X-7 as the experimental class and X-8 as the control class, with six students serving as subjects for the qualitative analysis. Data collection techniques used included tests, documentation, and interviews. While paired t-tests were used to examine the data in the quantitative section, three phases of analysis were used to assess the data in the qualitative section: data reduction, data presentation, and conclusions. Triangulation methods, including interviews and documentation, were used in this study. Students' critical thinking skills improved significantly, according to the results of the paired t-test. The results of the hypothesis test showed a sig value (2-tailed) of 0.000. Based on the decision-making criteria, since the sig value (2-tailed) <0.05, H_0 is rejected and H_1 is accepted, so it can be concluded that there is a significant difference between the critical thinking abilities of the experimental class and the control class after the Quantum Learning model with the Deep Learning approach was implemented. In addition, according to the qualitative analysis: There was a shift in the achievement of students' critical thinking ability indicators: (1) students with high critical thinking abilities changed from two indicators in the pretest to four indicators in the posttest; (2) students with moderate critical thinking abilities changed to three indicators in the posttest; (3) students with low critical thinking abilities did not change, only meeting one indicator in the posttest.

Keywords: Effectiveness; Quantum Learning; Deep Learning; Critical Thinking Ability

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1. INTRODUCTION

Mathematics is one field of study that plays a crucial role in education, helping to address everyday life challenges. While not all problems are mathematical, it plays a crucial role in addressing everyday challenges. Therefore, mathematics is a subject taught at all levels, starting with elementary school, to equip students with logical, analytical, systematic, critical, and creative thinking skills, as well as the ability to collaborate. (Sholihah & Mahmudi, 2015)

In mathematics learning, students are faced with problems to solve, such as solving math problems. Students who understand the concepts and methods of solving these problems will find it easier to solve them. When students are able to build an understanding of mathematics, they can connect their existing knowledge and determine effective solutions. Therefore, students need to be trained in higher-order thinking skills, one of which is critical thinking. (Siti Munira, 2020)

One of the root causes of students' low critical thinking skills is the continued dominance of memorization- and procedural-oriented learning. This is due to learning models and systems that emphasize solely the mastery of intellectual (cognitive) abilities and teacher-centered learning in the classroom (Ma'mur, 2013). Therefore, a more interactive and innovative learning approach is needed so that students are not merely passive listeners but actively engaged in the learning process (Annisa Putri et al., 2025).

One relevant learning model is the Quantum Learning model. This model, developed by DePorter (2010), is rooted in the concept of Quantum Learning, which combines cognitive, emotional, and social aspects to create positive learning interactions. This model integrates the creative learning strategy TANDUR (Grow, Experience, Name, Demonstrate, Repeat, and Celebrate) to create a fun and meaningful learning experience (Ummy Azizah Harahap, 2023). This model has several principles in learning, namely: Everything speaks, Everything has a purpose, Experience before naming, Acknowledge every effort, if it is worth learning then it is also worth celebrating. Thus, in the learning process, teachers make students more active in learning, making students brave in expressing opinions which will make many students achieve the desired achievements (Deporter, 2010).

Furthermore, a learning approach is needed that combines cognitive, affective, and psychomotor components to create a consistent and meaningful learning experience (Selfia Zainur et al., 2026). One approach that has received considerable attention is the Deep Learning strategy in mathematics instruction. This strategy emphasizes deeper and more meaningful learning, where students not only memorize formulas and procedures but also understand the meaning behind mathematical concepts and how they are interconnected and applicable in real-life contexts. (Elvi Mailani et al., 2025)

Haryanti (2024) provides a more specific definition of Deep Learning as a learning approach that emphasizes in-depth mastery of concepts, going beyond simply memorizing or quickly recognizing facts. The primary goal of this approach is to ensure that students not only gain cognitive enhancement through a deep understanding of the core concepts or theories but also relate them to relevant practical contexts in real life. Therefore, teachers need to facilitate a learning environment rich in interaction, support exploration, and provide scaffolding as needed. Thus, deep learning is an effective approach to creating meaningful learning that not only increases knowledge but also fosters critical, creative, and reflective thinking. (Fatmawaty, 2024)

Several studies have shown that Quantum Learning and Deep Learning contribute positively to students' critical thinking skills, one of which is the study by Dichi Akbar Wahyudi (2026) which shows that the Deep Learning approach has a significant effect on students' mathematical critical thinking skills. Then in the study by Fitriani H, Muhammad Yunus and Burhan (2023) which in their research found a significant difference in the use of the Quantum Teaching model and the direct learning model on students' critical thinking skills and the potential of the Quantum Teaching model in improving critical thinking skills so that it has an impact on academic achievement. In the study of Katmini, et al. (2025) also showed that the Quantum Teaching model significantly improves the critical thinking skills of elementary school students. These findings confirm that learning that involves emotions, real contexts, and social interactions can create a deeper and more reflective learning experience than conventional approaches.

Based on the explanation above, it is clear that many previous studies have examined the influence of Deep Learning and Quantum Learning on students' critical thinking skills. However, so far, no research has been found that links the Quantum Learning learning model with the Deep Learning approach to students' mathematical critical thinking skills. Therefore, researchers are interested in determining how effective the Quantum Learning learning model with the Deep Learning approach is on students' mathematical critical thinking skills. It is hoped that the results of this study can serve as a reference for teachers in developing innovative learning models that focus on student activity and involvement in the teaching and learning process in the classroom.

2. RESEARCH METHOD

The type of research used was mixed methods. Mixed methods research combines two methods: quantitative and qualitative (Creswell, 2012). The combined research design used was an explanatory sequential design. The exploratory sequential design method involves the initial collection and evaluation of quantitative data, followed by the collection and evaluation of qualitative data (Sutama et al., 2022). In this study, the quantitative data used were mathematics scores before and after Quantum Learning with a Deep Learning approach, while the qualitative data used were documentation of student work results and interviews.

This research was conducted in one of the senior high schools in Medan City, North Sumatra, Indonesia. Learning focused on statistical material (measures of central tendency and location of data). Learning was carried out in accordance with the teaching module and LKPD compiled based on the Quantum Learning model based on the Deep Learning approach. The sampling technique was a

purposive sample from the population of class X students. In this design, there were two classes, namely the experimental class, namely class X-7 using the Quantum Learning learning model, while the control class, namely class X-8 using the conventional model. Before being given treatment, the learning outcomes of the two classes were compared first, namely a pretest was given to determine the initial conditions, whether there were differences in the two classes. Furthermore, after being given treatment, a posttest was given to see the differences in students' critical thinking abilities after being given treatment. Six students participated in the qualitative data analysis for this study, namely 3 students from the experimental class and 3 students from the control class. The three selected students represented the group of students with high critical thinking abilities, medium critical thinking abilities, and low critical thinking abilities. The indicators of critical thinking abilities used in this study were critical thinking indicators according to Facione's theory (2015).

The data collection techniques used were tests, documentation, and interviews. The research instruments included learning tools, interview guidelines, and test questions. Data analysis in quantitative research used an independent sample t-test to determine the difference in average scores between different groups, namely the control and experimental classes. This test was used to measure the effectiveness of the Quantum Learning model based on the Deep Learning approach. Meanwhile, data analysis techniques in qualitative research included data reduction, data presentation, and conclusion drawing.

To get the test score for students' critical thinking skills, the following is used:

$$y = \frac{Total\ Scores\ Obtained}{Total\ Scores} \times 100$$

Description: y = Critical thinking ability test score

Then, students' critical thinking abilities were grouped based on the results of the students' critical thinking ability test. To determine the category of each student's critical thinking ability, such as high, medium, and low, this study used the level of students' critical thinking ability (x) based on Anggraini et al. (2022), as presented in Table 1.

Table 1. Critical Thinking Ability Value Categories

Value Range	Critical Thinking Skills Category
$\mathbf{75 < x \leq 100}$	High
$\mathbf{60 < x \leq 75}$	Medium
$\mathbf{0 \leq x \leq 60}$	Low

Next, researchers verify the validity of the collected and analyzed data. This data validation will be conducted through observation and triangulation. Researchers use triangulation to test the credibility of the data by cross-checking it with the same source using different techniques, including tests, interviews, and documentation.

3. RESULTS AND DISCUSSION

Based on the results of the descriptive analysis, comparative data were obtained from the results of the pretest and posttest measurements of students' critical thinking abilities, which are presented in Table 2.

Table 2. Comparison of Results of Measurement of Students' Critical Thinking Skills

Value	Mean		Difference
	Control	Experiment	
Pretest	46,49	50,17	3,68
Posttest	53,64	73,02	19,38

Table 1 shows improvements in both the experimental and control groups. However, the changes in the experimental group were higher than in the control group because the experimental group received treatment using a Deep Learning-based Quantum Learning model.

Table 3. Data on Students' Critical Thinking Ability Categories

Category	Control		Experiment	
	Pretest	*Posttest*	*Pretest*	*Posttest*
Low	30	25	23	1
Medium	6	11	13	24
High	0	0	0	11

Based on the data obtained, the research conducted normality and homogeneity tests as requirements. The results of the normality test can be seen in Table 4, while the results of the

homogeneity test are in Table 5.

Table 4. Results of Normality Test for Control and Experimental Groups

	Class	Shapiro-Wilk		
		statistic	df	**Sig.**
Critical Thinking Skills	*Pretest* A (Control)	.955	36	**.148**
	Posttest A (Control)	.945	36	**.074**
	Pretest B (Experiment)	.943	36	**.062**
	Posttest B (Experiment)	.942	36	**.060**

Using IBM SPSS statistics 24, the normality test was carried out using the Shapiro-Wilk Test because the number of data was less than 50. The data was said to be normally distributed if the Sig value was > 0.05. Based on the data above, it was found that the pretest and posttest results were significant > 0.05, so it was concluded that the data was normally distributed.

Table 5. Results of the Homogeneity Test for the Control and Experimental Groups

		Levene Statistic	df1	df2	Sig.
Value	**Based on Mean**	2.632	1	70	**.109**
	Based on Median	1.783	1	70	**.186**

In the homogeneity test results, if the sig. value > 0.05, then H_0 is accepted, meaning the variance of the data obtained is homogeneous. In Table 5, the results of the homogeneity test obtained a sig. value = 0.109 > 0.05, so the data in the pretest and posttest are homogeneous.

After conducting the prerequisite test, it was determined that the data were normally distributed and homogeneous. A T-test analysis was then conducted using an independent sample T-test. The T-test aimed to determine whether there was a difference in effectiveness between the control and experimental groups on students' critical thinking skills.

In the paired t-test, the hypothesis used is H_0 which states that the Deep Learning-based Quantum Learning model has no significant effect on students' critical thinking skills. At the same time, H_1 states that the Deep Learning-based Quantum Learning model has a significant effect on students' level of critical thinking skills. This value test was conducted using SPSS 24 software with the testing criteria being rejected if Sig. (p-value) <0.05, whereas otherwise H_0 is accepted.

Table 6. Results of T-Test Analysis with Independent Sample T-Test

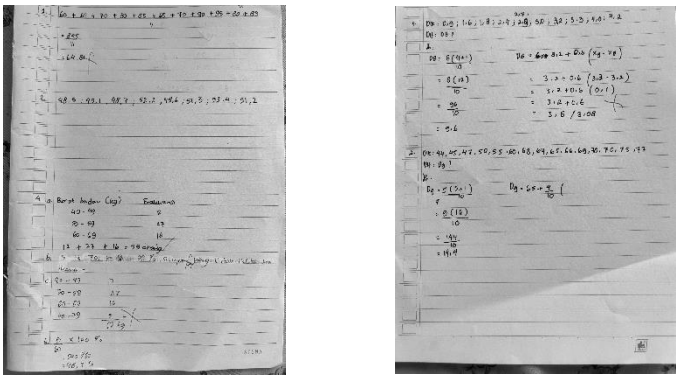
		Levene's Test for Equality of Variances		T-test for Equality of Means						
		F	Sig.	t	df	**Sig. (2-tailed)**	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Value	Equal variances assumed	10.224	.002	-7.423	70	**.000**	-19.37500	2.61005	-24.58059	-14.16941
	Equal variances not assumed			-7.423	60.507	**.000**	-19.37500	2.61005	-24.59498	-14.15502

Based on the results of the paired sample t-test, the obtained Sig. (p-value) = 0.000 < 0.05 so that H_0 is rejected. The decision taken is H_1 which states that the Quantum Learning model based on Deep Learning has a significant effect on the level of students' critical thinking skills. This shows that learning statistics with the application of the Quantum Learning model based on Deep Learning is effective in improving students' critical thinking skills.

To provide a more comprehensive understanding of the effectiveness of the Deep Learning-based Quantum Learning model on students' critical thinking skills, a post-test was conducted. Three students were then selected from the control and experimental classes to represent students with high, medium, and low critical thinking skills.

Students with Low Critical Thinking Skills

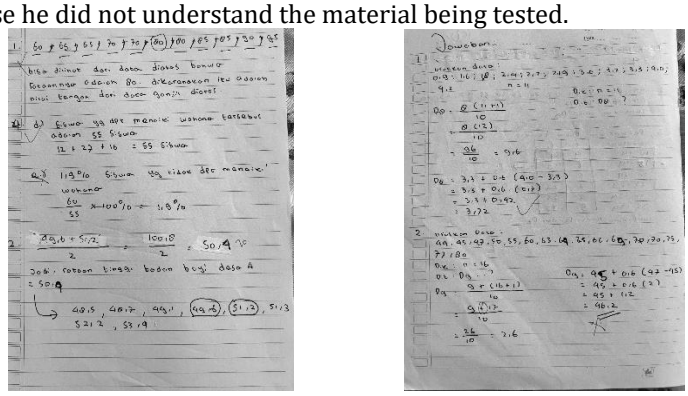
Based on the results of the student work examination, one student from the control and experimental classes was selected as a representative of students with low critical thinking skills. The subjects selected by the researcher were students with the lowest scores in answering the critical thinking skills test, namely SR-1 from the control class and SR-2 from the experimental class. The results of SR-1's work during the pretest and posttest are shown in Figure 1. Meanwhile, Figure 2 displays the results of SR-2's work during the pretest and posttest.



(a) **(b)**

Figure 1. SR-1 Answer Sheet on pretest (a) and posttest (b)

Based on the results of the SR-1 test, it can be seen that students' critical thinking skills for the interpretation indicator are low, this can be seen from students who do not write what is known and asked from the questions. Furthermore, for the analysis indicator, of the 5 questions given, there are 3 questions for which SR-1 students did not make mathematical models, in addition to that for the other 2 questions, SR-1 students made mathematical models from the questions given but they were not correct. Then for the evaluation indicator, of the 5 questions given, there are 3 questions that do not use any strategy, in addition to that for the other 2 questions, SR-1 students use inappropriate strategies in solving the questions. As well as on the inference indicator, SR-1 did not write anything for the 5 questions given. When interviewed, the subject admitted to having difficulty solving the questions given because he did not understand the material being tested.



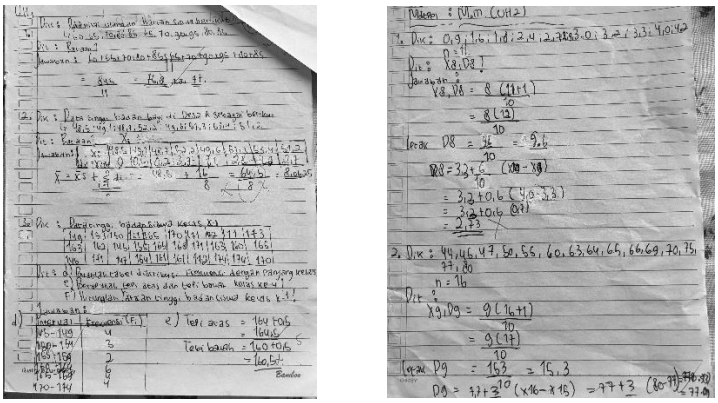
(a) **(b)**

Figure 2. SR-2 Answer Sheet on pretest (a) and posttest (b)

Based on the results of the SR-2 test, it can be seen that students' critical thinking skills for the interpretation indicator are still low, this can be seen from students who do not write what is known and asked from the questions and are less precise and complete. Furthermore, for the analysis indicator, of the 5 questions given, there are 3 questions for which SR-2 students did not make a mathematical model, in addition to that for the other 2 questions, SR-2 students made a mathematical model from the questions given but were not precise. Then for the evaluation indicator, of the 5 questions given, there are 2 questions that do not use any strategy, in addition to that for the other 3 questions, SR-2 students use less precise strategies in solving the questions. And on the inference indicator, SR-2 did not write anything for the 5 questions given. When interviewed, the subject admitted to having difficulty solving the questions given and sometimes he forgot the interpretation and inference stages so that the subject immediately solved the questions to achieve the final goal.

Students with Moderate Level of Critical Thinking Ability

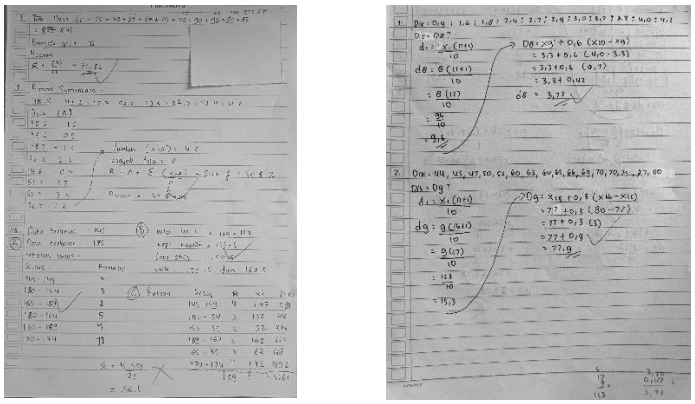
Based on the results of the student work examination, one student from the control and experimental classes was selected as a representative of students with moderate critical thinking abilities. The subjects selected by the researcher were students with the lowest scores in answering the critical thinking ability test, namely SS-1 from the control class and SS-2 from the experimental class. The results of SS-1's work during the pretest and posttest are shown in Figure 3. Meanwhile, Figure 4 displays the results of SS-2's work during the pretest and posttest.



(a) **(b)**

Figure 3. SS-1 Answer Sheet on pretest (a) and posttest (b)

Based on the results of the SS-1 test, it can be seen that students' critical thinking skills in the interpretation indicator are good, students have written what is known and asked from the questions correctly even though there are some questions that are not written what is known and asked from the questions, for the analysis indicator they are quite capable of identifying the relationships between statements, questions, and concepts given in the questions but SS-1 students are less able to explain the concepts or statements that students use in solving the questions. For the evaluation indicator, SS-1 students use appropriate and complete strategies in solving questions, complete and correct in doing calculations except for numbers 3, 4 and 5. Furthermore, for the inference stage, students are quite capable of concluding the results of their answers correctly and completely even though there are questions that do not have conclusions or conclusions that are less precise. When interviewed, the subject admitted to having difficulty solving some of the questions given and sometimes forgetting the formula that must be used and at the inference stage the subject forgot to write the conclusion of each question.



(a) **(b)**

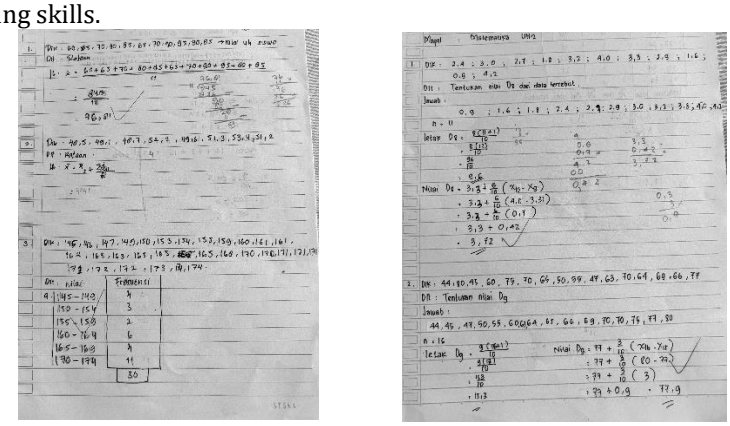
Figure 4. SS-2 Answer Sheet on pretest (a) and posttest (b)

Based on the results of the SS-2 test, it can be seen that students' critical thinking skills in the interpretation indicator are good, students have written what is known and asked from the questions correctly even though there are some questions that are not written what is known and asked from the questions. Then for the analysis indicator, SS-2 is quite capable of identifying the relationships between statements, questions, and concepts given in the questions. For the evaluation indicator, SS-2 students use appropriate and complete strategies in solving questions, complete and correct in doing calculations except for numbers 4 and 5. Furthermore, for the inference stage, students are quite capable of concluding the results of their answers correctly and completely even though there are questions that do not have conclusions or conclusions that are less precise. When interviewed, the subject admitted to having difficulty in solving some of the questions given and sometimes forgetting the formula that must be used and at the inference stage the subject forgot to write the conclusion of each question.

Students with High Levels of Critical Thinking Ability

Based on the results of the student work examination, one student from the control and

experimental classes was selected as a representative of students with high critical thinking skills. However, in the control class there were no students with high critical thinking skills. Therefore, the researcher only interviewed a representative student from the experimental class. The subject chosen by the researcher was ST-1. The following is the answer sheet for the experimental class student who has high critical thinking skills.



(a) (b)

Figure 5. ST-1 Answer Sheet on pretest (a) and posttest (b)

Based on the results of the ST-1 test, it can be seen that students' critical thinking skills in the interpretation indicator are good, students have written what is known and asked from the questions correctly. Then for the analysis indicator, ST-1 is quite capable of identifying the relationships between statements, questions, and concepts given in the questions. For the evaluation indicator, ST-1 students use appropriate and complete strategies in solving questions, complete and correct in performing calculations. However, there are still parts of the answer that are not quite right, but the final result of the question is correct so it can be concluded that ST-1 students are able to use the right strategy in solving questions. Furthermore, for the inference stage, students are quite capable of concluding the results of their answers correctly and completely even though there are questions that have inaccurate conclusions. When interviewed, the subject admitted to having difficulty in solving some of the questions given and sometimes he forgot the formula that should be used. At the inference stage, the subject chose not to write a conclusion due to limited time.

Based on the results of data analysis, it was found that there was an increase in students' critical thinking skills after being treated using the Deep Learning-based Quantum Learning model. This is evident in the increase in students' average grades from before to after treatment, as well as an increase in students' ability to solve problems according to critical thinking indicators. The results of this study align with research by Anjeli et al. (2024) which stated that the Quantum Teaching Model is proven effective because it structures learning based on the TANDUR stages designed to foster interest, strengthen understanding, and encourage students' reflective actions. This structure positions students as the main actors in learning and gets them used to developing solutions logically. The effectiveness of the Quantum Teaching model is also supported by various previous studies, such as that by Reflina et al. (2021) which showed that students who learned using the literacy-based Quantum Teaching approach achieved higher critical thinking outcomes. These findings confirm that an interactive and meaningful classroom atmosphere is key to developing critical thinking skills.

From the results of the analysis of the test sheets and interviews with two students each in the high, medium and low critical thinking ability categories from the control and experimental classes, it can be seen that: (1) Students with high critical thinking ability fulfilled all four indicators of critical thinking ability, up from two indicators in the pretest; (2) Students with medium critical thinking ability were able to fulfill the interpretation and analysis indicators but were less able to fulfill the evaluation and inference indicators; and (3) Students with low critical thinking ability were less able to interpret problems and were unable to fulfill the analysis, evaluation and inference indicators.

Based on the description above, it can be concluded that critical thinking skills are seen when students analyze problems before determining the solution steps. Students do not immediately perform calculations, but first identify relevant information in the problem, connect data with concepts, and evaluate the calculation results logically. This process aligns with the critical thinking indicators according to Facione (2015), particularly in the aspects of interpretation, analysis, evaluation, and inference. Deep Learning provides space for students to actively construct knowledge

through exploration and reflection, so that the understanding gained becomes deeper and more lasting. These findings are supported by research (Dahroni., 2025) which concluded that Deep Learning-based learning is more effective in encouraging students' higher-order thinking skills. This approach allows students to engage deeply in understanding mathematical concepts, practice critical and analytical thinking skills, and build meaningful understanding.

Overall, this study confirms a significant difference in the application of the Deep Learning-based Quantum Learning model to students' critical thinking skills. This learning model is able to address the challenges of 21st-century learning by emphasizing strengthening critical thinking skills, improving learning outcomes, and internalizing character values, thus potentially improving the quality of learning sustainably.

This study has several limitations that should be considered when interpreting the results. The learning scope only covered one topic, so the results do not reflect the overall effectiveness of the model across various materials. External factors such as classroom atmosphere, student readiness, and environmental conditions can also influence the results, and therefore should be considered in future research. The implementation of Quantum Learning clearly answers the research question by showing that all aspects of student engagement experienced significant improvements. This study recommends that teachers consistently implement the TANDUR steps and that schools provide training related to the active learning model. Limitations of the study related to class coverage and duration of the intervention can be addressed in future research involving a larger number of subjects.

4. CONCLUSION

Based on the data analysis, it was concluded that there was an increase in students' critical thinking skills after being treated using the Deep Learning-based Quantum Learning model. This was evident in the increase in students' average scores from before and after treatment, as well as an increase in students' ability to solve problems according to critical thinking indicators. These results also align with the hypothesis test using the independent sample t-test, which obtained a significance value (2-tailed) of 0.000, or less than the 0.05 level of significance. Based on the decision-making criteria, because the sig value (2-tailed) <0.05, H_0 was rejected and H_1 for the experimental class was accepted. Therefore, the data obtained proves a significant difference between the experimental class implementing the Deep Learning-based Quantum Learning model and the control class, which implemented a conventional learning model.

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