



DEVELOPING CRITICAL THINKING USING THE GEOGEBRA INTEGRATED DEEP LEARNING APPROACH ON QUADRATIC EQUATIONS MATERIAL FOR ELEMENTARY SCHOOL STUDENTS

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Abstract

Critical mathematical thinking is an essential cognitive ability that significantly contributes to understanding abstract algebraic concepts, particularly quadratic equations, in elementary school education. This study aimed to evaluate the effectiveness of a GeoGebra-integrated deep learning approach in enhancing fifth grade students' critical mathematical thinking skills, focusing on quadratic equations. A quantitative pre-experimental method with a one-group pretest posttest design was used, involving 30 elementary school students. The learning activities emphasized problem orientation, dynamic visualization of quadratic graphs, exploration of coefficient-graph relationships, analytical reasoning, reflective discussion, and generalization through GeoGebra-assisted exploration. The students' critical mathematical thinking skills were assessed based on five key indicators: identifying problems, analyzing relationships between concepts, formulating solution strategies, evaluating solutions, and drawing conclusions through digital exploration. Data were analyzed using descriptive statistics and the Wilcoxon Signed Rank Test. The results showed a significant improvement in students' critical thinking skills, with post-test scores notably higher than pre-test scores. The Wilcoxon Signed Rank Test indicated a statistically significant difference ($p < 0.001$), and the effect size was very large, confirming the strong practical impact of the intervention. These findings suggest that the GeoGebra integrated deep learning approach is highly effective in fostering critical mathematical thinking in students, providing a meaningful and powerful instructional strategy for learning quadratic equations at the elementary school level.

Keywords: Critical Thinking; Deep Learning Approach; Geogebra; Quadratic Equations

Abstrak

Berpikir kritis matematis merupakan kemampuan kognitif esensial yang berkontribusi signifikan terhadap pemahaman konsep-konsep aljabar abstrak, khususnya persamaan kuadrat dalam pembelajaran matematika. Penelitian ini bertujuan untuk mengevaluasi efektivitas pendekatan deep learning terintegrasi GeoGebra dalam meningkatkan kemampuan berpikir kritis matematis siswa kelas V sekolah dasar, dengan fokus pada materi persamaan kuadrat. Penelitian ini menggunakan metode kuantitatif pra-eksperimen dengan desain one-group pretest–posttest yang melibatkan 30 siswa sekolah dasar. Kegiatan pembelajaran menekankan orientasi masalah, visualisasi dinamis grafik kuadrat, eksplorasi hubungan antara koefisien dan grafik, penalaran analitis, diskusi reflektif, serta generalisasi melalui eksplorasi berbantuan GeoGebra. Kemampuan berpikir kritis matematis siswa dinilai berdasarkan lima indikator utama, yaitu mengidentifikasi masalah, menganalisis hubungan antarkonsep, merumuskan strategi penyelesaian, mengevaluasi solusi, dan menarik kesimpulan melalui eksplorasi digital. Data dianalisis menggunakan statistik deskriptif dan uji Wilcoxon Signed Rank. Hasil penelitian menunjukkan adanya peningkatan yang signifikan dalam kemampuan berpikir kritis matematis siswa, yang ditunjukkan oleh skor posttest yang lebih tinggi dibandingkan dengan skor pretest. Hasil uji Wilcoxon Signed Rank menunjukkan perbedaan yang signifikan secara statistik ($p < 0,001$), dengan ukuran efek yang sangat besar, sehingga mengindikasikan dampak praktis yang kuat dari intervensi pembelajaran. Temuan ini menunjukkan bahwa pendekatan deep learning terintegrasi GeoGebra berpotensi menjadi strategi pembelajaran yang efektif untuk mengembangkan kemampuan berpikir kritis matematis siswa. Pendekatan ini juga menawarkan strategi pembelajaran yang bermakna untuk mempelajari persamaan kuadrat melalui visualisasi, eksplorasi, dan penalaran matematis.

Kata Kunci: Berpikir Kritis, Pendekatan Deep Learning, GeoGebra, Persamaan Kuadrat



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1. Introduction

Critical thinking skills are one of the key competencies of the 21st century that have a strategic role in learning mathematics in elementary schools. Critical thinking allows students to analyze information, recognize gaps in understanding, and design problem-solving strategies logically and reflectively (Cahyaningsih & Nahdi, 2021; Rahmawati et al., 2025; Risnanosanti et al., 2019). The development of these skills from the elementary level is very urgent because it serves as an important foundation for the formation of algebraic thinking, namely the ability to understand mathematical patterns, relationships, and generalizations that will be used in algebraic material at the next level (Godino et al., 2014; Maudy et al., 2022; Sun et al., 2023). Without reinforcement of critical thinking from an early age, students tend to have difficulty when it comes to moving from concrete arithmetic operations to more abstract symbolic reasoning. In the context of mathematics education, critical thinking is defined as the ability to think logically, systematically, and reflexively to understand the relationships between concepts and make the right decisions in solving problems (Aizikovitsh-Udi, 2011; Raj et al., 2022).

Critical thinking indicators include the ability to analyze, reason, evaluate, and make decisions (Burhanuddin et al., 2019; Utama et al., 2022). This skill plays a major role in learning algebra, including the understanding of quadratic equations, as students are required to interpret the meanings of variables, connect various representations (symbolic, graphic, and contextual), and evaluate the correctness of the solutions obtained (Marzuki et al., 2021; Rochmad et al., 2021). However, studies have shown that elementary and early secondary school students still face significant obstacles, such as misconceptions about variables, difficulties in generalization, weak mathematical representations, and limited mastery of basic concepts (Andini & Suryadi, 2017; Sidik et al., 2025). Quadratic equations, which began to be introduced at the upper level as part of the transition from arithmetic to algebra, demanded strong abstract thinking skills. Students are not only required to understand general forms, but must also be able to relate the meaning of coefficients to the behavior of graphs as well as the context of real problems $ax^2 + bx + c = 0$ (Baybayon & Lapinid, 2024; Herawaty et al., 2021). Research shows that many students have difficulty understanding the concept of variables, relating symbolic representations to parabolic graphs, as well as understanding the role of parameters in quadratic equations (Fitria et al., 2023; Wilkie, 2024; Yansa et al., 2021). This condition confirms that strengthening critical thinking needs to be carried out systematically and continuously since elementary school as a prerequisite for the success of more complex algebraic learning.

Pendekatan deep learning In mathematics learning offers a relevant pedagogical framework for developing critical thinking and higher-level thinking skills. Deep learning emphasizing meaningful learning, conceptual understanding, and knowledge transfer to new situations, in contrast to shallow learning that is oriented towards procedural memorization (Kovač et al., 2025; Mystakidis, 2021; Winje & Løndal, 2020). Stages deep learning includes acquisition, fluency, maintenance, and generalization providing space for students to reflectively analyze, evaluate, and apply mathematical concepts (Jiménez et al., 2024). Various empirical findings show that problem-based learning approaches, inquiry, hands-on experience, and the integration of critical thinking into mathematical

content have been proven to be effective in improving students' critical thinking skills (Arifin et al., 2025; Hermita et al., 2025; Luvia Raggi et al., 2021).

In line with the approach deep learning, the integration of GeoGebra as a dynamic digital media has great potential in supporting the development of critical thinking in mathematics learning. GeoGebra enables the visualization of abstract concepts, the exploration of symbolic-graphic relationships, and the interactive manipulation of mathematical objects, thus encouraging reasoning, evaluation, and evidence-based decision-making (Dahal et al., 2022; Yerizon et al., 2023). Various studies have shown the effectiveness of GeoGebra in improving the understanding of algebra and quadratic equations, particularly in associating equations with graphs and their properties (Sebsibe & Abdella, 2025; Sumartini & Maryati, 2021). However, research at the elementary school level that specifically examines the contribution of GeoGebra to the development of critical thinking is still relatively limited, thus opening up further research space to integrate digital technology. deep learning, and strengthening critical thinking in an integrated manner in basic mathematics learning (Azis & Rohaeti, 2025; Putra et al., 2022).

Based on this description, an empirical study is needed that systematically investigates the application of the deep learning approach integrated with GeoGebra in mathematics learning in elementary schools, especially in quadratic equation materials. This research is directed to analyze the extent to which the integration of GeoGebra in the deep learning syntax is able to improve the mathematical critical thinking skills of elementary school students, which includes the ability to identify problems, analyze concept relationships, formulate solution strategies, evaluate solutions, and draw conclusions based on digital exploration.

2. Research Methods

This study uses a quantitative approach with a quasi-experimental method. The quasi-experimental method was chosen because the researcher did not allow to randomize the subjects in full, but still aimed to test the effect of treatment on the bound variables systematically (Creswell, 2018; Fraenkel, Wallen, & Hyun, 2019). The research design used is One Group Pretest–Posttest Design, where one group is given an initial test (pretest), treatment, and final test (posttest). This design is effective for measuring changes in students' abilities before and after a learning intervention (Shadish, Cook, & Campbell, 2002). The research design can be described in Table 1.

Table 1. Research Design

Pretest	Treatment	Posttest
O ₁	X	O ₂

Description:

O₁ = Pretest of critical thinking skills

X = Learning using an integrated deep learning approach GeoGebra

O₂ = Posttest critical thinking skills

Through this design, the improvement of students' critical thinking skills can be analyzed quantitatively based on the difference in pretest and posttest scores.

Research Subjects and Settings

This research was carried out at SD Cibubur 04 Pagi, Cibubur District, East Jakarta, with the research subjects of grade V students in the current school year totaling around 32 students, adjusted to the real conditions of the classroom. Subject selection was conducted using purposive sampling.

Research Instruments

The research instruments used include: 1) Mathematical critical thinking ability test; 2) Observation sheet of learning activities and 3) Learning documentation. The main

instrument in this study is the mathematical critical thinking ability test, which is compiled based on critical thinking indicators from (Ennis, 1991) and (Facione, 2011), including the ability to identify problems, analyze concept relationships, evaluate solutions, and draw conclusions.

Data Collection Procedure

The data collection technique in this study is carried out in several ways. First, written tests in the form of pretests and posttests are used to measure students' mathematical critical thinking skills before and after treatment (Table 2). Second, learning observations were carried out to observe student engagement, critical thinking activities, and interaction processes during the implementation of GeoGebra's integrated deep learning approach. Third, documentation is used to complete the research data, which includes photos of learning activities, field notes, and student work results during the learning process.

Table 2. Critical Thinking Skills Grid

Critical Thinking Aspects	Indicator	Question Number
Identify issues	Identify known and inquired information	1, 2
Analyzing concept relationships	Explain the relationship of coefficients to graphs	3, 4
Strategizing solutions	Systematically determine the solution steps	5, 6
Evaluating solutions	Checking and justifying the outcome of the settlement	7, 8
Drawing conclusions	Draw conclusions based on GeoGebra's Exploration	9, 10

3. Results and Discussion

Implementation of the GeoGebra Application

The GeoGebra app is used as a digital-based math learning app to help students understand the concept of quadratic equations visually and dynamically. Through the GeoGebra app, students can manipulate the value of the coefficient, a , and use the *abcslider feature*, so that the change in the shape of the parabolic graph can be observed directly. This activity allows students to explore the relationship between algebraic forms and their graphical representations, including the position of the apex points, the axis of symmetry, the value of determinants, and the roots of equations. $y = ax^2 + bx + c$. Based on Figure 1, it can be seen that the change in the value of the coefficient, and on the quadratic equation directly affects the shape and position of the parabolic graph. The graph shows a satellite dish that opens upwards with the apex point being at the coordinates, which signifies the minimum value of the function. In addition, the graph intersects the axis- at two points, which shows that the quadratic equation has two different real roots. This is reinforced by the positive value of the determinant, which mathematically confirms the existence of two real solutions. Through this visualization, students can understand the relationship between the algebraic form of quadratic equations, determinant values, the position of the apex points, and the location of the roots of equations in an integrated manner, thus helping to strengthen conceptual understanding and critical reasoning in the learning of quadratic equations.

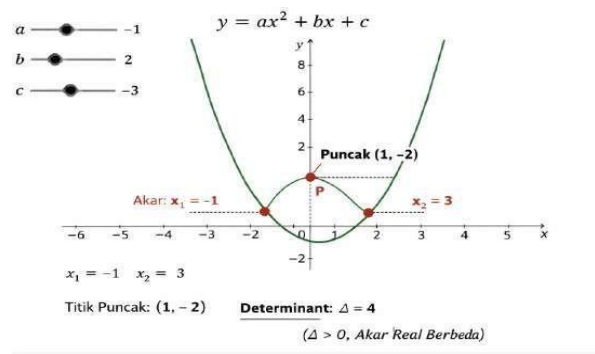


Figure 1. Geogebra Application Learning

Learning Steps (Deep Learning)	Student Activities	Teacher Activities
1. Problem Orientation	Observing the contextual problems, identifying necessary information, asking initial questions, and identifying curiosity.	Presenting relevant contextual issues, guiding students to identify necessary information, and encouraging important inquiry.
2. Explore Concepts with GeoGebra	Using GeoGebra to visualize graphs of quadratic equations, changing coefficients, and exploring.	Provide tutorials on using GeoGebra, facilitate chart changes, and monitor students.
3. Analysis and Reasoning	Analyze the relationship of coefficients with the graph, determine key points, and make hypotheses.	Guide students to analyze relationships, ask driving questions, and clarify concepts.
4. Discussion and Reflection	Present findings, discuss with classmates, evaluate solutions, and draw critical conclusions.	Facilitate discussions, provide feedback, and encourage student reflection.
5. Generalization and Application	Relate the understanding of quadratic equations to real-life situations, and create new problems.	Provide examples of applications of quadratic equations in real life and emphasize the relevance of learning.

Table 4 presents a statistical overview of students' mathematical critical thinking skills before and after the application of quadratic equation learning using a deep learning approach integrated with the GeoGebra application

Table 4. Descriptive Analysis Results

	N	Red	Median	SD	OR
Pre-Test	34	47.0	47.0	2.80	0.480
Post Test	34	80.0	80.0	3.13	0.537

Based on Table 4 of the results of the Descriptive Analysis, there is a clear improvement in students' mathematical critical thinking skills after the application of quadratic equation learning using a deep learning approach integrated with the GeoGebra application. The average score of students increased from 47.0 in the pretest to 80.0 in the posttest, which

indicates an increase in critical thinking skills after the treatment was given. The median score that also increased from 47.0 to 80.0 indicated that the increase occurred relatively evenly in most students, not just in a few specific individuals.

In addition, the standard deviation value in the posttest ($SD = 3.13$) was slightly higher than that of the pretest ($SD = 2.80$), which indicates a slightly more diverse variation in student scores after learning, but still within a controlled range. The relatively small standard error (SE) value in both measurements indicates that the average score estimate is quite stable and representative. Overall, this descriptive data provides an early indication that the application of GeoGebra's integrated deep learning approach contributes positively to improving students' mathematical critical thinking skills in quadratic equation material. Table 5 presents the results of the normality test of students' critical thinking ability data on pretest and posttest scores. The normality test is carried out as part of the analysis prerequisite test to determine the feasibility of using parametric statistical tests at a later stage.

Table 5. Test Results of Tests of Normality

			statistic	p
Pre Test	Post Test	Shapiro-Wilk	0.776	<,001
		Kolmogorov-Smirnov	0.336	<,001
		Anderson-Darling	3.77	<,001

Note. Additional results provided by *moretests*

Based on the results of the normality tests conducted using the Shapiro-Wilk, Kolmogorov Smirnov, and Anderson-Darling tests, the p-value was lower than the established significance limit ($p < 0.001$). This indicates that the pre-test and post-test data on students' critical thinking skills in mathematics did not meet the assumption of normality. Although the Shapiro-Wilk test showed a statistical value of 0.776, which is greater than 0.05, the results of the Kolmogorov-Smirnov and Anderson-Darling tests, with p-values < 0.001 , indicate that the data were not normally distributed. Therefore, although some normality tests appear to meet the assumption of normality, the overall results indicate that the data were not normally distributed. With the data unable to meet the assumption of normality, non-parametric analysis is a more appropriate approach to examine the differences between the pre-test and post-test. The analysis will then proceed with the Wilcoxon Signed-Rank Test, a non-parametric method that does not require the assumption of normal distribution. This test will be used to examine significant differences in students' critical mathematical thinking skills before and after the implementation of quadratic equation learning using a deep learning approach integrated with the GeoGebra application.

Table 6. Results of the Hohypothesis Test Analysis

Null Hypothesis		Test	Sig.	Decision
1	The median of differences between Pre_Test and Post_Test equals 0.	Related-Samples Wilcoxon Signed Rank Test	.000	Reject the null hypothesis.

Based on the Wilcoxon Signed Rank Test results (Table 6), a p-value of 0.000 was obtained, which is less than the significance level of 0.05. This indicates that we can reject the null hypothesis, which states that there is no significant difference between pre

test and post-test scores. In other words, there is a significant difference between students' pre-test and post-test scores after being given the learning treatment.

These results indicate that the intervention implemented through integrated learning with the GeoGebra application has a significant impact on improving students' critical thinking skills in mathematics. The decision to reject the null hypothesis supports the hypothesis that the changes occurred were not coincidental, but rather a result of the learning method applied, which can significantly improve students' critical thinking skills in mathematics.

Table 7. Related-Samples Wilcoxon Signed Rank Test Summary

Related-Samples Wilcoxon Signed Rank Test Summary	
Total N	34
Test Statistic	595.000
Standard Error	58.413
Standardized Test Statistic	5.093
Asymptotic Sig.(2-sided test)	.000

Based on Table 7, the Test Statistic value was 595.000, with a Standard Error of 58.413, and a Standardized Test Statistic of 5.093. The Asymptotic Sig. (2-sided test) value was 0.000, which is significantly lower than the significance limit of 0.05. This indicates a significant difference between the pre-test and post-test scores. In other words, the change between the two measurements is statistically significant. These results indicate that the intervention had a significant impact on improving the measured skills, supporting the hypothesis that the change between the pre-test and post-test was not coincidental but rather a result of the learning method used. Therefore, we can reject the null hypothesis and conclude that there was a significant change between the pre-test and post-test.

Identify known and inquired information

The results of the study showed an increase in students' ability to identify known and asked information on the problem of quadratic equations after the application of learning using the deep learning approach integrated with the GeoGebra application. In the problem orientation stage, students are faced with contextual problems visualized through parabolic graphs, so that they are encouraged to recognize variables, coefficients, and problem-solving goals more systematically. Theoretically, the ability to identify problems is an initial component of critical thinking that requires students to understand the problem situation before conducting further analysis (Ennis, 2011). The dynamic visualization provided by GeoGebra helps students connect symbolic information with graphical representations, thus clarifying what is known and what to look for. These findings are in line with research by Yerizon et al. (2023) and Dahal et al. (2022) which showed that the use of dynamic mathematics software can improve students' ability to understand and formulate mathematical problems more precisely.

Explain the relationship of coefficients to graphs

In this indicator, students show an improvement in their ability to analyze the relationship between the coefficient, a , and with the shape and position of the parabolic graph. Through exploration using *abcs* sliders on GeoGebra, students can directly observe the changes in the graph when the value of the coefficient is changed, making the cause and-effect relationship between algebra symbols and visual representations clearer.

According to Facione (2015), the ability to analyze is at the core of critical thinking because it involves logical reasoning and the recognition of relationships between concepts. GeoGebra acts as a cognitive tool that supports this process by providing a visual-based exploratory environment. The results of this study are consistent with the findings of Sumartini and Maryati (2021) and Sebsibe and Abdella (2025) who stated that GeoGebra is effective in helping students understand the relationship between quadratic equation and their graphs, especially in the context of algebra learning.

Determine the solution steps systematically

The application of GeoGebra's integrated deep learning approach also has a positive impact on students' ability to develop systematic problem-solving strategies. After understanding the relationship of concepts, students are directed to design solution steps, such as determining the culmination point, axis of symmetry, and the roots of quadratic equations based on graphical exploration. Theoretically, strategy development is part of high-level thinking skills that involve planning and decision-making (Ennis, 2011). The deep learning approach emphasizes the active involvement of students in the deep-thinking process, rather than simply following algorithmic procedures. Research by Zhang et al. (2025) and Putra et al. (2022) shows that the integration of digital technology in mathematics learning is able to improve students' ability to design more meaningful and reflective completion strategies.

Checking and justifying the outcome of the settlement

In the indicator of evaluating solutions, students become more able to check and justify the correctness of the results obtained. Through GeoGebra, students can compare the results of analytical calculations with graphical representations, so that errors can be identified and corrected immediately. According to Facione (2015), evaluation is a critical thinking skill that involves assessing the quality of arguments and solutions produced. GeoGebra's interactive environment provides visual feedback that supports this evaluation process. The findings of this study are in line with the results of Rittle-Johnson and Koedinger (2009) research which emphasized that the association between symbolic and visual representations can improve students' ability to verify and evaluate mathematical solutions more accurately.

4. Conclusion and Suggestions

Based on the Wilcoxon Signed Rank Test, the Test Statistic was 595.000, with a Standard Error of 58.413, and a Standardized Test Statistic of 5.093. The Asymptotic Sig. (2-sided test) was 0.000, which is significantly lower than the 0.05 significance level. This indicates a significant difference between the pre-test and post-test scores. In other words, the change between the two measurements is statistically significant. Based on the research results and discussion, it can be concluded that the application of the deep learning approach integrated with the GeoGebra application in learning quadratic equations has a significant effect on improving elementary school students' critical thinking skills in mathematics. This is evidenced by the results of the Wilcoxon Signed Rank Test which shows a p-value <0.001 , which means the null hypothesis (H_0) is rejected and the alternative hypothesis (H_a) is accepted. Thus, there is a significant difference between students' mathematical critical thinking skills before and after participating in learning using the deep learning approach integrated with the GeoGebra application. In addition, the analysis results show a very large effect size value, with Cohen's $d = -49.0$, indicating that the application of GeoGebra within the deep learning framework has a strong impact on improving students' mathematical critical thinking skills. This effect size value confirms that the improvements that occur are not only statistically significant but also practically meaningful in the context of mathematics

learning in elementary schools. Overall, the deep learning approach integrated with the GeoGebra application has proven effective in improving students' abilities to identify problems, analyze the relationship between coefficients and graphs of quadratic equations, formulate systematic solution strategies, evaluate the correctness of solutions, and draw conclusions based on visual and interactive exploration. Therefore, this approach can be recommended as an effective learning strategy to develop elementary school students' critical thinking skills in mathematics, especially in learning abstract algebraic concepts such as quadratic equations.

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