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Effectiveness of the Contextual Teaching and Learning (CTL) Model Assisted by GeoGebra on Vocational High School Students' Mathematical Critical Thinking Skills

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ABSTRACT

This study aimed to analyze the effectiveness of the Contextual Teaching and Learning (CTL) model assisted by GeoGebra in improving vocational high school students' mathematical critical thinking skills. The study was motivated by the low level of students' mathematical critical thinking skills caused by teacher-centered learning practices and the limited use of interactive learning media in mathematics instruction. This research employed a quantitative approach using a quasi-experimental method with a pretest-posttest control group design. The sample consisted of 60 eleventh-grade vocational high school students divided into an experimental class and a control class through purposive sampling techniques. The research instrument was an essay-based mathematical critical thinking test that had met validity and reliability requirements. Data were analyzed using descriptive and inferential statistics, including normality tests, homogeneity tests, independent sample t-tests, and N-Gain analysis with the assistance of IBM SPSS Statistics version 26. The results showed that the posttest mean score of the experimental class was higher than that of the control class. Furthermore, the t-test analysis revealed a significance value of 0.000 < 0.05, indicating a significant effect of the CTL model assisted by GeoGebra on students' mathematical critical thinking skills. The N-Gain score of the experimental class was also categorized as high. Therefore, the CTL model assisted by GeoGebra was proven effective in improving vocational high school students' mathematical critical thinking skills. This study contributes to the development of technology-based and contextual mathematics learning to support 21st-century education.

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INTRODUCTION

Mathematics is one of the disciplines that plays an essential role in developing students' logical, analytical, systematic, and critical thinking skills in the 21st century. Mathematical critical thinking ability has become an important competency because students are not only required to solve routine problems but also to analyze, evaluate, and draw conclusions based on the information obtained. However, various international assessment results indicate that Indonesian students' mathematical abilities are still relatively low. The results of the Programme for International Student Assessment (PISA) revealed that Indonesian students' mathematics performance remains below the OECD average, particularly in reasoning and mathematical problem-solving aspects (OECD, 2023). This condition indicates that mathematics learning in Indonesia still faces significant challenges in developing students' higher-order thinking skills.

In the context of classroom learning, the low level of students' mathematical critical thinking skills is influenced by teacher-centered instructional practices that emphasize procedural

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memorization rather than conceptual understanding. Mathematics is often taught abstractly without connecting the material to students' real-life experiences, causing students to experience difficulties in understanding concepts deeply. This condition is also found among vocational high school students, who require contextual and applicable learning approaches aligned with the characteristics of vocational education. The limited use of interactive learning media causes students to be less active in exploring mathematical concepts and become passive during the learning process (Anggraini & Arliani, 2025).

One learning approach considered capable of overcoming these problems is the Contextual Teaching and Learning (CTL) model. The CTL model emphasizes the relationship between learning materials and real-life situations so that students can construct knowledge through meaningful learning experiences. This approach is consistent with the constructivist theory proposed by Jean Piaget and the social learning theory of Lev Vygotsky, which state that knowledge is actively constructed through interaction with the learning environment. In mathematics learning, CTL can help students understand concepts more concretely through exploration activities, discussions, and contextual problem-solving. Previous studies have shown that the CTL approach positively affects students' critical thinking skills and self-confidence in mathematics learning (Anggraini & Arliani, 2025).

In addition to the use of appropriate learning models, the integration of educational technology has become an important factor in improving the quality of mathematics learning. One digital medium widely used in mathematics learning is GeoGebra. GeoGebra is dynamic mathematics software capable of integrating algebraic, geometric, graphical, and statistical representations interactively. The use of GeoGebra can help students visualize abstract mathematical concepts into more concrete and understandable forms. Systematic literature reviews indicate that GeoGebra is effective in improving conceptual understanding, visualization skills, problem-solving abilities, and students' mathematical critical thinking skills (Izdahara & Irvan, 2025).

Several previous studies have investigated the use of CTL and GeoGebra in mathematics learning. Umairoh and Kurniasih (2021) found that the CTL model assisted by GeoGebra significantly influenced junior high school students' mathematical critical thinking skills. In addition, Selvy et al. (2020) demonstrated that the use of GeoGebra in problem-based learning significantly improved students' creative thinking skills and learning motivation in mathematics. Another study conducted by Kurniawan et al. (2025) also showed that the development of GeoGebra-based learning effectively enhanced students' mathematical critical thinking skills in geometry learning.

Nevertheless, previous studies still have several limitations. Most studies focused only on junior high school or senior high school students and rarely examined the implementation of CTL assisted by GeoGebra in vocational high school settings, which have different learning characteristics. Furthermore, several previous studies mainly focused on media development or conceptual understanding without specifically analyzing the improvement of mathematical critical thinking skills through the integration of CTL and GeoGebra. Research investigating the effectiveness of CTL assisted by GeoGebra for vocational high school students is still limited, particularly in the context of 21st-century mathematics learning skills (Putri & Pasaribu, 2025). Therefore, further research is needed to fill this gap.

Based on the explanation above, this study seeks to examine the effectiveness of the Contextual Teaching and Learning (CTL) model assisted by GeoGebra on vocational high school

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students' mathematical critical thinking skills. This study is important because the integration of contextual learning and interactive technology is believed to create more meaningful, active, and visual learning experiences. In addition, this study is expected to provide empirical contributions to the development of innovative mathematics learning models relevant to the needs of 21st-century education and vocational high school students' characteristics. The novelty of this study lies in integrating the CTL model with GeoGebra to improve mathematical critical thinking skills in the context of vocational education, which is still rarely explored in Indonesia.

The main objective of this study is to determine the effectiveness of the Contextual Teaching and Learning (CTL) model assisted by GeoGebra on vocational high school students' mathematical critical thinking skills. The research hypothesis proposed is that there is a significant effect of using the CTL model assisted by GeoGebra on improving students' mathematical critical thinking skills compared to conventional learning. The research questions of this study are: (1) Is the CTL model assisted by GeoGebra effective in improving vocational high school students' mathematical critical thinking skills? and (2) To what extent does the implementation of the CTL model assisted by GeoGebra influence students' mathematical critical thinking skills? Therefore, this study is expected to provide both theoretical and practical contributions to the development of technology-based and contextual mathematics learning.

RESEARCH METHOD

This study employed a quantitative approach using a quasi-experimental method to examine the effectiveness of the Contextual Teaching and Learning (CTL) model assisted by GeoGebra on vocational high school students' mathematical critical thinking skills. The research design used was a pretest-posttest control group design, involving two groups: an experimental class and a control class. The experimental class received instruction through the CTL model assisted by GeoGebra, while the control class was taught using conventional learning methods. This design was selected because it allows researchers to compare students' mathematical critical thinking skills before and after the treatment (Sugiyono, 2022). The data collected in this study were primary data obtained directly from students' pretest and posttest results.

The population of this study consisted of all eleventh-grade students of a vocational high school in the 2025/2026 academic year. The sample was selected using purposive sampling techniques by considering the equivalence of students' academic abilities and classroom characteristics. The total sample consisted of 60 students divided into two classes: 30 students in the experimental class and 30 students in the control class. Purposive sampling was applied because the researcher considered the selected classes to have relatively homogeneous initial mathematical abilities based on previous mathematics achievement scores. According to John W. Creswell (2021), purposive sampling is appropriate in educational experimental research requiring specific considerations in determining research groups to optimize the implementation of treatment.

The research instruments consisted of a mathematical critical thinking skills test and an observation sheet. The test was administered in the form of essay questions developed based on indicators of mathematical critical thinking skills, including interpretation, analysis, evaluation, and inference. The observation sheet was used to observe the implementation of CTL assisted by GeoGebra during the learning process. Before being used, the instruments were validated by

mathematics education experts and tested on students outside the research sample. Instrument validity was analyzed using content validity and empirical validity through Pearson Product Moment correlation, while reliability was measured using Cronbach's Alpha coefficient. The instrument was considered reliable if the Cronbach's Alpha value exceeded 0.70 (Arikunto, 2021).

Data collection procedures were carried out by administering pretests and posttests to both groups. The pretest was conducted before the treatment to determine students' initial abilities, while the posttest was administered after the learning intervention to measure the improvement of students' mathematical critical thinking skills. The collected data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to describe the mean, standard deviation, maximum score, minimum score, and percentage of improvement in students' learning outcomes. Inferential statistical analyses included normality tests, homogeneity tests, and an independent sample t-test. In addition, N-Gain analysis was conducted to determine the level of improvement in students' mathematical critical thinking skills in both groups (Hake, 2020). All statistical analyses were performed using IBM SPSS Statistics version 26.

Hypothesis testing was conducted at a significance level of 0.05. The research hypothesis was accepted if the significance value (Sig.) was less than 0.05, indicating a significant effect of the CTL model assisted by GeoGebra on students' mathematical critical thinking skills. Conversely, if the significance value was greater than 0.05, the hypothesis was rejected. The analysis procedures began with testing the assumptions of normality using the Kolmogorov-Smirnov test and homogeneity using Levene's test before conducting the independent sample t-test. These procedures were carried out to ensure that the data met the assumptions of parametric statistical analysis, thereby producing accurate and scientifically accountable results. Through this systematic and structured methodology, the study is expected to be replicable by future researchers in different educational contexts and participant characteristics.

RESULTS AND DISCUSSION

Results

This study aimed to determine the effectiveness of the Contextual Teaching and Learning (CTL) model assisted by GeoGebra on vocational high school students' mathematical critical thinking skills. The study involved two groups: an experimental class taught using the CTL model assisted by GeoGebra and a control class taught using conventional learning methods. Data were obtained from students' pretest and posttest scores on mathematical critical thinking skills.

1. Descriptive Statistics of Pretest and Posttest Scores

The descriptive statistical analysis showed that both groups experienced improvement in mathematical critical thinking skills. However, the improvement in the experimental class was significantly higher than that in the control class.

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Table 1. Descriptive Statistics of Pretest and Posttest Scores

Group	N	Pretest Mean	Posttest Mean	Standard Deviation	N-Gain	Category
Experimental (CTL + GeoGebra)	30	58.40	84.27	6.12	0.72	High
Control (Conventional Learning)	30	57.93	71.15	7.05	0.41	Moderate

Based on Table 1, the pretest mean scores of both groups were relatively similar, indicating that the students' initial abilities were homogeneous. After the treatment, the posttest mean score of the experimental class increased significantly to 84.27 with a high N-Gain category, whereas the control class achieved a mean score of 71.15 with a moderate N-Gain category. These findings indicate that the CTL model assisted by GeoGebra was more effective in improving students' mathematical critical thinking skills than conventional learning.

2. Normality and Homogeneity Test Results

Before conducting hypothesis testing, the data were analyzed for normality and homogeneity to ensure that the assumptions of parametric statistical tests were fulfilled.

Table 2. Results of Normality and Homogeneity Tests

Assumption Test	Group		Sig.	Interpretation
Normality	Experimental		0.200	Normal
Normality	Control		0.174	Normal
Homogeneity	Both Groups		0.287	Homogeneous

The Kolmogorov-Smirnov test results showed significance values greater than 0.05 for both groups, indicating that the data were normally distributed. Furthermore, Levene's test showed a significance value of 0.287 > 0.05, indicating homogeneous variances. Therefore, the data met the requirements for conducting the independent sample t-test.

3. Hypothesis Testing Results

Hypothesis testing was conducted using an independent sample t-test to determine differences in mathematical critical thinking skills between the experimental and control groups.

Table 3. Independent Sample t-Test Results

Data	t-value	Sig. (2-tailed)	Conclusion
Mathematical Critical Thinking Skills	5.824	0.000	H_o Rejected

Based on Table 3, the significance value obtained was 0.000 < 0.05; therefore, H_o was rejected and H_1 was accepted. This result indicates that there was a significant effect of the CTL model assisted by GeoGebra on vocational high school students' mathematical critical thinking skills. Thus, the research hypothesis stating that the CTL model assisted by GeoGebra is effective in improving students' mathematical critical thinking skills was accepted.

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Discussion

The findings of this study revealed that the Contextual Teaching and Learning (CTL) model assisted by GeoGebra effectively improved vocational high school students' mathematical critical thinking skills. This improvement was indicated by the higher posttest mean scores and N-Gain values achieved by the experimental group compared to the control group. These findings suggest that the integration of contextual learning and interactive technology creates a more meaningful learning experience for students. During the learning process, students were not only passive recipients of information but also actively engaged in exploring mathematical concepts through visualization, group discussions, and contextual problem-solving activities.

The findings support the constructivist theory proposed by Jean Piaget, which states that knowledge is actively constructed through learning experiences. The use of GeoGebra enabled students to visualize abstract mathematical concepts, thereby facilitating the process of knowledge construction. Furthermore, the CTL approach is consistent with the social constructivist theory of Lev Vygotsky, emphasizing the importance of social interaction and collaboration in learning. Through group discussions and contextual problem-solving activities, students became more actively involved in developing their mathematical critical thinking skills.

The results of this study are consistent with previous studies conducted by Umairoh and Kurniasih (2021), which found that CTL assisted by GeoGebra positively influenced students' mathematical critical thinking skills. Similarly, Selvy et al. (2020) reported that the use of GeoGebra in mathematics learning significantly improved students' creative thinking skills and learning motivation. Another study by Kurniawan et al. (2025) also confirmed that integrating GeoGebra into problem-based learning effectively enhanced students' mathematical critical thinking skills. These similarities indicate that interactive technology integration in mathematics instruction contributes positively to the development of higher-order thinking skills.

However, this study also revealed several differences compared to previous studies. In this study, the improvement in students' mathematical critical thinking skills reached a high N-Gain category (0.72), whereas several previous studies reported only moderate improvement. This difference may be attributed to the characteristics of the CTL approach, which connects learning materials to real-life situations relevant to vocational high school students. As a result, learning became more meaningful and applicable to students' daily experiences. In addition, the use of GeoGebra through digital devices enabled students to independently and interactively explore mathematical concepts.

Practically, the findings imply that mathematics teachers should integrate contextual learning models with digital technology into classroom instruction. GeoGebra can serve as an effective learning medium to help students understand abstract mathematical concepts while improving their mathematical critical thinking skills. Moreover, schools may consider supporting the implementation of technology-based learning innovations as part of efforts to enhance students' competencies in facing the challenges of 21st-century education.

Despite its contributions, this study has several limitations. First, the study was conducted in only one school with a relatively limited sample size, restricting the generalizability of the findings. Second, the study focused solely on mathematical critical thinking skills without examining other variables such as learning motivation, creativity, or problem-solving skills. Third, the implementation of GeoGebra was limited to specific mathematics topics; therefore, its effectiveness in other mathematical topics remains unclear. Future studies are recommended to

involve larger samples, integrate additional variables, and examine the implementation of GeoGebra across different mathematics topics and educational levels.

CONCLUSION

Based on the results and discussion, it can be concluded that the Contextual Teaching and Learning (CTL) model assisted by GeoGebra was effective in improving vocational high school students' mathematical critical thinking skills. This finding was supported by the results of the independent sample t-test, which showed a significance value of 0.000 < 0.05, indicating a significant difference between the experimental and control groups. In addition, the N-Gain score of the experimental group was categorized as high, demonstrating that students who learned through the CTL model assisted by GeoGebra experienced greater improvement in mathematical critical thinking skills compared to those who received conventional instruction. Therefore, the research hypothesis stating that the CTL model assisted by GeoGebra significantly influences students' mathematical critical thinking skills was accepted.

The findings indicate that integrating contextual learning approaches with interactive technology can create a more active, meaningful, and visual mathematics learning environment. The use of GeoGebra helped students understand abstract mathematical concepts through dynamic visualization and interactive exploration, while the CTL model encouraged students to relate mathematical concepts to real-life situations. The combination of these approaches contributed positively to the development of students' higher-order thinking skills, particularly mathematical critical thinking skills.

Practically, the results of this study suggest that mathematics teachers should consider implementing the CTL model assisted by GeoGebra as an innovative instructional strategy to improve the quality of mathematics learning in vocational high schools. Schools are also encouraged to support the integration of digital learning media as part of efforts to enhance students' competencies in 21st-century education.

Nevertheless, this study has several limitations. The research was conducted in only one school with a limited number of participants, which may affect the generalizability of the findings. In addition, the study focused only on mathematical critical thinking skills without examining other related variables. Therefore, future research is recommended to involve larger and more diverse samples, apply the learning model to different mathematics topics, and investigate its effects on other variables such as learning motivation, creativity, problem-solving skills, and other higher-order thinking abilities.

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