



The Effectiveness of a Geogebra-Assisted Calculus Teaching Module in Enhancing Learning Outcomes to Support Quality Education (SDG 4)

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Abstract: This study aimed to examine the effectiveness of a GeoGebra-assisted calculus teaching module in improving students' mathematical learning outcomes. The research employed a One-Group Pretest-Posttest design using a mixed-methods approach. The participants were 17 Informatics Engineering students enrolled in a calculus course at Universitas Putra Indonesia YPTK Padang during the 2025/2026 academic year. Quantitative data were obtained from pretest and posttest scores, while qualitative data were collected through student response questionnaires regarding the use of the teaching module. The quantitative data were analyzed using the Wilcoxon Signed-Rank Test. The results showed a significant improvement in students' mathematical abilities, with the average score increasing from 58.33 (pretest) to 93.11 (posttest), and the statistical test confirming a significant difference ($p = 0.001$). Furthermore, the N-Gain analysis indicated an improvement of 83%, which falls into the very effective category based on Hake's criteria. These findings conclude that the GeoGebra-assisted calculus teaching module is significantly effective in enhancing students' mathematical abilities and learning outcomes, supporting the implementation of technology-enhanced learning in higher education to promote quality education.

Keywords: Calculus teaching modules; GeoGebra; Higher education; Learning outcomes; N-Gain

Introduction

Teaching modules are essential learning tools in modern education, as they support structured and independent learning while serving as comprehensive guides for both lecturers and students. Well-designed teaching modules contribute significantly to effective learning and are closely linked to improvements in educational quality (Awalinda et al., 2024; Risnawati et al., 2025). In higher education, teaching modules are developed based on curriculum requirements to facilitate the achievement of predetermined competencies (Alamin et al., 2024; Islamiati et al., 2024; Maulida, 2022). Their use enables lecturers to systematically organize learning activities, align learning objectives with assessments, and clearly

communicate expected competencies. Previous studies have shown that the quality of learning tools, including teaching modules, has a strong correlation with students' learning outcomes at the elementary school and the university level (Agustin et al., 2025; Doyan et al., 2020; Elfira et al., 2025; Halimah et al., 2023; Jannah et al., 2025; Lovisia et al., 2025; Putra et al., 2025).

Empirical studies have demonstrated that teaching modules integrated with appropriate pedagogical approaches and digital technologies can enhance students' motivation and learning outcomes. Modules based on independent learning frameworks, generative learning models, gamification, contextual teaching and learning (CTL), and flipped classroom approaches have been reported to improve student engagement, learning independence, and academic performance (Dewi et al.,

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2024; Gea, 2025; Izzati et al., 2025; Nisa et al., 2020; Rizaldi et al., 2022; Sari et al., 2021; Yunita et al., 2025), (Rizaldi et al., 2022). These findings indicate that technology-enhanced teaching modules play an important role in supporting meaningful learning processes in higher education.

Calculus is a fundamental course that underpins students' understanding of advanced mathematical concepts and their applications in science and engineering disciplines. However, calculus is widely perceived as a difficult subject due to its abstract concepts, symbolic representations, and the need for strong visualization skills. Topics such as limits, derivatives, integrals, and multivariable functions often require students to interpret relationships between algebraic expressions, graphical representations, and geometric meanings simultaneously (Idayani et al., 2024; Ventura et al., 2024). Without adequate visualization support, students tend to rely on procedural calculations rather than conceptual understanding, which negatively affects their learning outcomes.

Geometry and algebra are mathematical areas that can benefit from technological advancements (Saralar-Aras et al., 2024). Reasoning activities in geometry typically involve verifying or proving geometric statements (Alexander et al., 2014; Kovács et al., 2021). One technological advancement that facilitates the visualization of geometric statements is the use of GeoGebra Software (Prieto-González et al., 2024). GeoGebra can be applied in learning activities from secondary to higher education (Belva et al., 2023; Zabidi et al., 2024). According to Muhammad (2023) the GeoGebra digital application can be used to facilitate the study of geometric topics. Malik et al. (2025) stated that the GeoGebra Graphing Calculator application is an interactive and user-friendly digital learning tool.

GeoGebra is one of the digital platforms used as an interactive learning medium. This platform has been proven to visualize abstract mathematical concepts. Another study conducted by Gusteti et al. (2025) showed that applying GeoGebra Augmented Reality in mathematics learning can be an effective innovation to improve students' problem-solving skills. Similarly, Munyaruhengeri et al. (2025) demonstrated that GeoGebra use can improve mathematics learning outcomes. Through its dynamic graphic display, GeoGebra was used to solve a number of abstract and applied problems by engineering students enrolled in a Numerical Methods course (Arceo-Díaz et al., 2020).

Globally, post-calculus instructors often complain about students' abilities in calculus (Czoher et al., 2013). Students' performance in calculus across various parts of the world also tends to be low (Dawkins et al., 2014; Weinberg et al., 2024). This challenge is also experienced by most Informatics Engineering students at Universitas

Putra Indonesia YPTK Padang who take the Calculus course. Based on last year's Midterm and Final Examination scores, many students received low grades. The open educational resources currently used by lecturers do not adequately support an engaging calculus learning experience in the classroom. Open educational resources for calculus are crucial for students (Habre et al., 2006).

The integration of digital visualization tools is therefore crucial in addressing the abstract nature of calculus. One such tool is GeoGebra, which provides dynamic plotting, slider-based parameter manipulation, and two- and three-dimensional graphing features. These features enable students to visually explore the behavior of functions, understand the meaning of derivatives as rates of change and tangents, interpret integrals as areas under curves, and analyze three-dimensional surfaces in multivariable calculus. By linking symbolic expressions with dynamic visual representations, GeoGebra supports deeper conceptual understanding and interactive learning experiences in calculus.

Although GeoGebra has been widely reported to improve mathematical understanding and problem-solving skills, most previous studies have focused on specific topics or skills, such as derivatives or creative thinking abilities, and were conducted in different educational contexts (Nurjannah et al., 2020). Moreover, in the context of Informatics Engineering students at Universitas Putra Indonesia YPTK Padang, existing calculus learning materials are predominantly conventional and do not systematically integrate GeoGebra features into a structured teaching module. As a result, students still experience difficulties in visualizing and understanding abstract calculus concepts, which is reflected in their low achievement scores.

Therefore, the novelty of this research lies in the development and effectiveness testing of a structured GeoGebra-assisted calculus teaching module that systematically integrates GeoGebra's dynamic visualization features across core calculus topics studied by Informatics Engineering students. Unlike previous studies that primarily focused on module development or limited calculus topics, this study emphasizes empirical effectiveness testing using pretest-posttest analysis in a real classroom setting at Universitas Putra Indonesia YPTK Padang. Accordingly, this study aims to analyze the effectiveness of a GeoGebra-assisted calculus teaching module in improving the mathematical abilities and learning outcomes of Informatics Engineering students, thereby supporting the implementation of technology-enhanced learning in higher education and contributing to the achievement of Sustainable Development Goal 4 (Quality Education).

Method

Research Design

This study employed a One-Group Pretest-Posttest Pre-Experimental Design combined with qualitative methods. The quantitative approach served as the primary method to examine the effectiveness of a GeoGebra-assisted calculus teaching module, while qualitative data were used to support and deepen the interpretation of students' learning processes and conceptual understanding.

To clarify the research procedure, the study followed a systematic flow consisting of pretesting, learning intervention, posttesting, and qualitative performance assessment, as illustrated in the research flowchart (Figure 1).

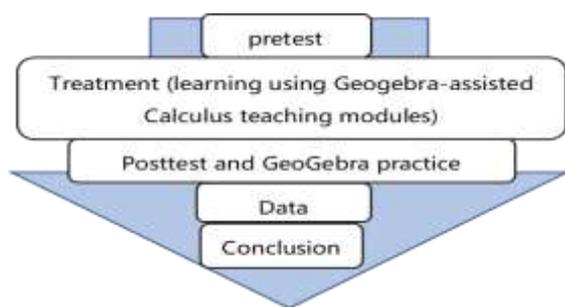


Figure 1. The research flow

Participants and Research Context

The research was conducted at Universitas Putra Indonesia YPTK Padang and involved 17 Informatics Engineering students enrolled in a Calculus course during the 2025/2026 academic year. All students in the class participated in the study using a total sampling technique.

Learning Intervention

Prior to the intervention, students completed a pretest to measure their initial mathematical abilities related to derivative concepts. The intervention consisted of learning activities using a GeoGebra-assisted calculus teaching module focused on derivatives. During the learning process, students solved problems manually and used GeoGebra to visualize functions, explore tangent lines, and analyze changes in graphs through dynamic plotting and slider-based parameter manipulation.

After completing the learning activities, students were given a posttest to measure changes in their mathematical abilities. In addition, students completed an individual GeoGebra performance task, which required them to solve derivative problems manually, verify their solutions using GeoGebra, and explain the graphical meaning of derivatives.

Instruments and Data Collection

Quantitative data were collected using pretest and posttest instruments designed to assess students' mathematical abilities in derivative topics. The GeoGebra-assisted teaching module was validated by experts prior to implementation and achieved a validity score of 91%, indicating a very valid category.

Qualitative data were obtained through an individual GeoGebra performance assessment measured using a structured performance assessment rubric. The rubric evaluated students' accuracy in solving derivative problems, correctness in using GeoGebra commands, and clarity in explaining graphical representations. Classroom observations were also conducted to support qualitative data collection.

Data Analysis Techniques

Before hypothesis testing, the Shapiro-Wilk normality test was conducted due to the small sample size ($n < 50$). The results showed that the Pretest data were not normally distributed ($\text{Sig.} < 0.05$). Therefore, a non-parametric Wilcoxon Signed-Rank Test was used to compare the pretest and posttest scores and determine whether there was a significant difference in students' mathematical abilities before and after the intervention.

To measure the level of learning improvement, an N-Gain analysis was conducted using the following formula (Sugiyono, 2012):

$$N - Gain = \frac{Posttest - pretest}{maximum\ score - pretest} \tag{1}$$

With the criteria

Table 1. N-Gain Criteria

N-Gain	Interpretation
$0.70 < g < 1.00$	effective
$0.30 < g < 0.70$	Quite effective
$0.00 < g < 0.30$	ineffective

Qualitative Analysis

Qualitative data were analyzed using thematic analysis, involving coding of students' performance rubric results and observation notes to identify patterns related to conceptual understanding, visualization ability, and effective use of GeoGebra. The integration of quantitative and qualitative findings was used to strengthen the validity of the study through triangulation.

Result and Discussion

Descriptive Statistics

Hypothesis testing began with an examination of descriptive statistics for the pretest and posttest scores. As shown in Table 2, the average pretest score was 58.33,

indicating relatively low initial mathematical ability. After the implementation of the GeoGebra-assisted calculus teaching module, the average posttest score

increased substantially to 93.11, suggesting a notable improvement in students' learning outcomes.

Table 2. Descriptive Statistics Results

	N	Range	Minimum	Maximum	Sum	Mean	Std Deviatoin	Variance
Pretest	18	90	10	100	1050	58.33	25.495	650.000
Posttest	18	20	80	100	1676	93.11	5.624	31.634
Valid N	17							

Normality Test

Prior to inferential analysis, a normality test was conducted using the Shapiro-Wilk test, as the sample size was fewer than 50 students. The results presented in Table 3 show that the pretest data were not normally

distributed (Sig. < 0.05), while the posttest data were normally distributed (Sig. > 0.05). Because at least one of the paired datasets did not meet the normality assumption, a non-parametric statistical test was required.

Table 3. Results of Normality Tests

	Statistic	Kolmogorov-Smirnov		Shapiro-Wilk		
		df	Sig.	Statistic	df	Sig.
Pretest	.251	17	.005	.891	17	.049
Posttest	.165	17	.200*	.925	17	.180

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Wilcoxon test-Rank Test

To determine whether there was a significant difference between students' pretest and posttest scores, the Wilcoxon Signed-Rank Test was applied. The results, presented in Table 4, indicate a statistically significant difference between pretest and posttest scores ($p = 0.001 < 0.05$). This finding confirms that students' mathematical abilities after learning with the GeoGebra-assisted calculus teaching module were significantly higher than before the intervention.

Table 5. Wilcoxon Test Results

Test Statistics ^a	
	Posttest-pretest
Z	-3.444 ^b
Asympg. Sig.(2-tailed)	.001

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks

Interpretation of Wilcoxon Output:

1. Test Statistic: Z-value = -3.444. The negative sign indicates the direction of the difference. Based on "negative ranks" → Posttest is higher than Pretest.
2. Significance Level: p-value (Asymp. Sig. 2-tailed) = 0.001. Statistical Conclusion: There is a statistically significant difference between the pretest and posttest scores, because: $p = 0.001 < 0.05$

Direction of difference: Posttest scores are significantly HIGHER than Pretest scores (based on negative ranks and negative Z-value)

N - Gain Test

$$\begin{aligned}
 N - Gain &= \frac{\text{Posttest} - \text{pretest}}{\text{maximum score} - \text{pretest}} \\
 &= \frac{\text{Posttest} - \text{pretest}}{\text{maximum score} - \text{pretest}} \\
 &= 0.83
 \end{aligned}$$

From the calculation results, the average increase (N-Gain) = 0.83

Based on the N-Gain criteria, this is considered effective. Therefore, it can be concluded that the use of the Geogebra-assisted calculus teaching module is effective in improving students' mathematical abilities.

Qualitative Results from GeoGebra Performance Task



Figure 2. Students practicing the use of geogebra individually

We administered this quiz to directly assess students' ability to use GeoGebra to solve problems.

Students were called one by one to meet with the instructor and demonstrate their use of GeoGebra, namely by proving the answers to derivative problems that they had previously solved manually. This is shown in Figure 2.

In the qualitative phase, students were individually asked to: (1) Solve derivative problems manually. (2) Verify. In the qualitative phase, students were individually asked to: (1) Solve derivative problems manually. (2) Verify their solutions using GeoGebra. (3) Explain graphs representing derivative behaviors. The qualitative findings revealed four dominant themes:

1) *Mastery of GeoGebra Commands*

Approximately 90% of students successfully used essential GeoGebra tools such as: (a) derivative command, (b) tangent tool, (c) point tracing, (d) function graphing.

2) *Improved Visual Interpretation*

Students demonstrated an improved ability to interpret: (a) slope changes, (b) instantaneous rate of change, (c) tangent line behavior, (d) relationships between algebraic derivatives and their graphs.

3) *Conceptual Justification*

Most students were able to verbally justify: (a) why the derivative was positive or negative at specific intervals, (b) how changes in the graph reflected rule-based differentiation.

4) *Increased Confidence and Accuracy*

Students reported greater confidence in checking their work and understanding why derivative rules work as they do. These qualitative insights strengthen the quantitative findings by showing how students achieved learning gains, not merely that gains occurred.

The study was conducted on 17 computer science students at Padang State University who were taking calculus courses. The study used a combination of quantitative and qualitative methods. The weakness of this study was the absence of a control class for comparison. However, we used qualitative methods to describe the students' abilities after the treatment.

Differences in Pretest and Posttest Results and N-Gain Results

The facts obtained in this study show that the average pretest score of students was 58.33, and the average posttest score was 93.11. This difference proves that learning using the GeoGebra-assisted calculus teaching module produces a significant improvement.

The Wilcoxon test shows that students' mathematical abilities have increased significantly. The N-Gain test results show an average increase of 0.83 or

83%, which falls into the "Effective" category. This study is supported by previous studies conducted by several researchers, which found that the use of GeoGebra-assisted modules had a positive impact on student learning outcomes. For example, Erawati et al. (2020) found that GeoGebra-assisted calculus modules based on APOS theory were valid, practical, and effective in improving student achievement and learning activities. Research conducted by Annajmi et al. (2020) revealed that the multi-variable calculus module with GeoGebra is very suitable for students' needs because it helps them learn at their own pace without reducing the quality of understanding.

Thus, learning using GeoGebra-assisted calculus teaching modules has been proven to improve learning outcomes.

Insights from the Qualitative Phase

The qualitative results provided deeper insights into how students used GeoGebra to support their learning. The majority of students (90%) were able to correctly execute GeoGebra commands and explain their meaning, demonstrating procedural fluency with the software as well as conceptual competency.

The ability to correctly interpret graphical representations indicates that students were not simply memorizing differentiation rules but understanding the relationship between algebraic and graphical forms. This aligns with Habre et al. (2006) argument that students' conceptual understanding deepens when they can connect symbolic operations to visual interpretations.

The qualitative findings also revealed increased student confidence, aligning with previous research showing that technology-supported learning environments improve self-efficacy in mathematics (Gusteti et al., 2025).

Conclusion

This study concludes that the GeoGebra-assisted Calculus teaching module is significantly effective in improving the mathematical abilities of Informatics Engineering students. The quantitative analysis confirms a significant improvement in learning outcomes after the implementation of the module, with a high level of learning effectiveness as indicated by the N-Gain analysis. These results are reinforced by qualitative findings, which show that GeoGebra supports students in visualizing abstract calculus concepts, particularly derivatives, and in linking symbolic procedures with graphical representations. Therefore, the GeoGebra-assisted calculus teaching module can be regarded as an effective learning strategy for enhancing both conceptual understanding and

procedural fluency in calculus learning at the higher education level.

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Author Contributions

DD.: Conceptualization, original draft writing, editing, and visualization; DE.: Writing (revision and editing), formal analysis, and methodology; LM.: Validation and supervision.

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Conflicts of Interest

The authors declare no conflict of interest.

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