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ORIGINAL

Effectiveness of Geogebra-Based Learning on Students' Cognitive and Affective Participation in Mathematics

Eficacia Del Aprendizaje Basado en GeoGebra en la Participación Cognitiva y Afectiva de los Alumnos en Matemáticas

Maria Magdalena Zagoto[1], Edwin Musdi[2], I Made Arnawa[2], Ahmad Fauzan[2], Alwen Bentri[3], Oskah Dakhi[4]

[1]Universitas Negeri Padang, Doctoral Program of Educational Sciences. Padang, Indonesia.
[2]Universitas Negeri Padang, Department of Mathematics. Padang, Indonesia.
[3]Universitas Negeri Padang, Department of Educational Technology Curriculum. Padang, Indonesia.
[4]Universitas Negeri Padang, Department of Technology and Vocational Education. Padang, Indonesia.

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Corresponding Author: Edwin Musdi

ABSTRACT

Mathematics learning often poses significant challenges, particularly in sustaining student engagement and promoting deep conceptual understanding. To address these issues, this study explored the integration of interactive digital tools, specifically GeoGebra, into mathematics instruction. The primary objective was to evaluate the effectiveness of GeoGebra-based learning in enhancing students' cognitive and affective engagement, focusing on the visualization of trigonometric function graphs. A quasi-experimental approach was employed, using a single-group pre-test and post-test design involving 20 students from SMA Negeri 1 Telukdalam. Data were gathered through classroom observations and structured questionnaires, assessing students' cognitive, affective, and conative responses, as well as indicators of emotional engagement and curiosity. The results revealed that the use of GeoGebra significantly improved student enthusiasm and involvement, with an average effectiveness rate of 82 %, categorized as "very effective." The visually engaging and interactive features of GeoGebra contributed to increased comprehension and motivation among students. These findings align with constructivist learning theory and reinforce previous research highlighting the positive role of technology in enhancing mathematics education.

Keywords: GeoGebra; Mathematics Learning; Student Response; Learning Interest.

RESUMEN

El aprendizaje de las matemáticas a menudo presenta desafíos significativos, especialmente en lo que respecta a mantener la participación de los estudiantes y promover una comprensión conceptual profunda. Para abordar estos problemas, este estudio exploró la integración de herramientas digitales interactivas, específicamente GeoGebra, en la enseñanza de las matemáticas. El objetivo principal fue evaluar la eficacia del aprendizaje basado en GeoGebra para mejorar la participación cognitiva y afectiva de los estudiantes, centrándose en la visualización de las gráficas de funciones trigonométricas. Se empleó un enfoque cuasi-experimental con un diseño de pretest y postest en un solo grupo, que involucró a 20 estudiantes del SMA Negeri 1 Telukdalam. Los datos se recopilaron mediante observaciones en el aula y cuestionarios estructurados, evaluando las respuestas cognitivas, afectivas y conativas de los estudiantes, así como indicadores de compromiso emocional y curiosidad. Los resultados revelaron que el uso de GeoGebra mejoró significativamente el entusiasmo y la participación de los estudiantes, con una tasa de efectividad promedio del 82 %, clasificada como "muy efectiva". Las características visuales e interactivas de GeoGebra contribuyeron a una mayor comprensión y motivación entre los estudiantes. Estos hallazgos están en consonancia con la teoría del aprendizaje constructivista y refuerzan investigaciones previas que destacan el papel positivo de la tecnología en la mejora de la educación matemática.

Palabras Clave: GeoGebra; Aprendizaje de las Matemáticas; Respuesta de los Estudiantes; Interés por el Aprendizaje.

INTRODUCTION

Mathematics instructional media play a crucial role in enhancing the teaching and learning process, particularly in secondary education where learners often find abstract concepts challenging to comprehend. The effectiveness of such media is underscored by their ability to facilitate the manipulation of concrete objects, such as dynamic sliders to change coefficients in linear equations, interactive geometric constructions to explore angle relationships, or draggable points on a coordinate plane to observe transformations. These features allow students to visualize abstract mathematical concepts in a tangible way, encouraging experimentation, hypothesis testing, and deeper understanding.[1,2,3] According to Jitendra[4,5], using tangible resources in classrooms can transform abstract concepts into observable phenomena, enhancing students' understanding. This assertion aligns with recent findings that emphasize visual and interactive media in stimulating engagement and interest among students.[1,6,7]

In addressing the challenge of student engagement, it is imperative that educators employ specialized teaching tools capable of capturing and sustaining attention. Research by Iwani[8] highlights that innovative instructional materials can significantly boost student interest, a sentiment echoed by [1,9,10], who argue that the right tools can invigorate the learning environment. Research consistently shows that learners who find classes engaging are more likely to demonstrate positive responses to instructional activities.[11,12] Thus, teachers must be mindful of their pedagogical choices, ensuring that they incorporate strategies that maintain enthusiasm and foster a love for mathematics.

At SMA Negeri 1 Telukdalam, the observed decline in student interest and performance in mathematics can be attributed to various factors. Primary among these is students' difficulty in accurately interpreting graphical representations, compounded by a general lack of intrinsic motivation or enthusiasm toward the subject.[10,13] The lack of ICT-based instructional media exacerbates this situation, as students are increasingly exposed to technology-rich environments outside the classroom.[14,15] Moreover, contemporary curriculum requirements mandate precise graphing and modeling skills, further highlighting the necessity for technological integration in teaching practices.[16,17]

Addressing these issues calls for innovative solutions, particularly the implementation of computer-based learning media as effective instructional resources. Zulkardi[17] draws attention to the proclivity of today's youth for visually stimulating content, frequently encountered through digital platforms such as social media, which suggests that similar educational tools may enhance students' receptiveness to learning. The incorporation of multimedia elements, including animations and interactive platforms, could transform students' experiences in mathematics, making them more relatable and engaging.[18,19]

Moreover, enhancing the classroom environment involves adopting diverse teaching methodologies that resonate with students' individual learning preferences. As demonstrated by Anupan[20], tailoring instruction to meet diverse learner needs can significantly influence student interest and participation. The integration of varied pedagogical approaches, such as collaborative learning and technology-aided instruction, fosters a more dynamic classroom climate conducive to learning.[8,19]

The interrelationship between instructional media and student performance is well-supported in the literature, illustrating how effective teaching practices not only improve student understanding but also their overall academic success. Implementation of innovative methodologies results in more favorable student evaluations, which in turn reflect positively on teaching effectiveness.[12] Teachers must ensure that their instructional approaches are adaptable, catering to various learning styles while maintaining high engagement levels.[2,10]

There exists a compelling need for educators at SMA Negeri 1 Telukdalam to reassess their pedagogical strategies concerning mathematics instruction. By embracing modern instructional media and varied teaching methodologies, educators can address student disinterest and improve academic performance. Effective integration of technology, combined with a focus on creating an engaging learning environment, will likely yield improved student outcomes, thereby fulfilling educational objectives in mathematics.[2,11]

GeoGebra presents a robust solution to the challenges faced in mathematics education, particularly in comprehending geometry and algebra. This dynamic mathematics application is tailored to enhance classroom instruction by allowing students to actively engage with mathematical concepts through technology.[21,22,23] Utilizing GeoGebra as both a teaching and learning tool provides students with the necessary resources to comprehend complex concepts and tackle mathematical problems more effectively.[23,24,25] The interactive features of GeoGebra foster an environment conducive to exploration and experimentation, which are critical elements in the learning of mathematics.

In evaluating the effectiveness of GeoGebra, three response dimensions are employed: cognitive, affective, and conative responses.[26] This multi-faceted approach allows researchers to gauge not only how well students understand mathematical concepts but also how they feel about and engage with the learning process. These responses highlight the importance of measuring student engagement through metrics like enjoyment, curiosity, acceptance, and active participation.[27] Employing these indicators elucidates the comprehensive impact of GeoGebra on students' learning experiences in mathematics.

The effectiveness of GeoGebra is further operationalized through students' participation in workshops alongside evaluations of their responses and levels of interest.[28,29] Significant research findings suggest that students using GeoGebra demonstrate an increase in their interest in mathematics and their problem-solving abilities.[21] The interactive and visual nature of the software appears to enhance students' understanding, making abstract concepts more tangible and accessible.[20,23]

A systematic review of GeoGebra's application in educational settings illustrates its positive impact on student learning outcomes. Studies confirm that GeoGebra encourages active problem-solving and facilitates interactive exploration, which leads to a deeper understanding of mathematical relationships.[4,19] Researchers emphasize that the software not only aids in visualization but also fosters essential skills such as conceptual understanding and mathematical reasoning.[23,25,26]

Moreover, the advantages of GeoGebra extend beyond simply enhancing mathematical skills; the software has been shown to promote positive attitudes toward learning mathematics. According to studies, utilizing GeoGebra can develop a more favorable self-efficacy in students, which is critical for sustaining long-term engagement and interest in mathematics.[20,26] This is particularly important in addressing varying levels of motivation and interest among diverse student populations.

The integration of comprehensive approaches such as GeoGebra in mathematics education aligns with contemporary pedagogical strategies that emphasize student-centered learning.[27,28,29] By incorporating technology into traditional teaching methods, educators can create a dynamic learning environment that effectively addresses the diverse needs and interests of their students. Thus, the potential of GeoGebra effective by educators and researchers, as it provides teachers and students with innovative tools for teaching and learning.[22,25]

The application of GeoGebra in mathematics education shows considerable promise in enhancing student engagement, comprehension, and problem-solving skills. The evidence suggests that not only does GeoGebra facilitate a better understanding of mathematical concepts, but it also cultivates a positive learning environment that encourages curiosity and active participation.[30,31,32] Continued research and integration of GeoGebra into mathematics instruction will likely lead to improved educational outcomes, making math learning more accessible and enjoyable for students across various educational settings.[33,34]

The primary objective of this study is to evaluate the effectiveness of GeoGebra-based learning in enhancing students' cognitive and affective participation in mathematics. This research aims to assess how the interactive, visual nature of GeoGebra can improve students' understanding of mathematical concepts, specifically in areas like geometry and algebra. Additionally, the study seeks to examine the impact of GeoGebra on students' engagement, motivation, and emotional responses to learning mathematics, including factors like enjoyment, curiosity, and confidence in problem-solving. By measuring both cognitive and affective participation, the study will provide a comprehensive analysis of how GeoGebra contributes to fostering a positive learning environment that enhances students' overall learning experience in mathematics.

METHOD

The research was carried out at SMA Negeri 1 Telukdalam, involving 20 students from class XI Kalabubu as the study participants. This study employed a non-experimental, quantitative descriptive design using frequency and percentage analysis to assess students' cognitive and affective responses when utilizing the GeoGebra application in mathematics learning. Data collection techniques included both observation and the distribution of questionnaires. To complement the self-report questionnaires, pre- and post-tests were administered to assess students' actual cognitive performance. This dual approach allows for more reliable conclusions about learning outcomes by combining subjective perceptions with objective evidence of knowledge gains.

Prior to administering the questionnaires, a data quality assessment was conducted by evaluating the validity and reliability of the instruments. Content validity was established through expert judgment, while reliability was tested using Cronbach's alpha coefficient in SPSS (version 12.0), confirming acceptable internal consistency ($\alpha > 0{,}05$). The internal consistency reliability of the instruments used in this study was assessed

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using Cronbach's alpha. The student response questionnaire demonstrated a Cronbach's α value of 0,86, while the student interest questionnaire yielded a value of 0,89. These results indicate high internal consistency for both instruments, suggesting that the questionnaire items reliably measure students' responses and interest. The high reliability values strengthen the validity of the data collected through self-report measures, ensuring consistency across items within each scale. The use of a 4-point Likert scale in this study was a deliberate choice to eliminate the neutral midpoint and reduce central tendency bias, which often occurs when respondents choose the middle option to avoid making a clear judgment. By using a forced-choice format, participants are encouraged to express a more decisive opinion, leading to more accurate and meaningful data. This approach is supported by prior research, which shows that removing the midpoint enhances the discriminative power of the instrument and promotes deeper cognitive engagement with survey items.[35,36] The questionnaire uses a four-point scale as described in table 1 below.

Table 1. Student Learning Interest Scale in Mathematics Using GeoGebra

Score	Category	Description
4	Strongly Agree (SA)	The student shows strong enthusiasm, clear understanding, and enjoys using GeoGebra.
3	Agree (A)	The student gives a positive response and feels helped in understanding mathematical concepts.
2	Disagree (D)	The student feels less comfortable or not interested in using GeoGebra.
1	Strongly Disagree (SD)	The student rejects or feels disturbed by the use of GeoGebra in learning.

Source: Arikunto[37]

Table 1 presents the Student Learning Interest Scale in Mathematics using GeoGebra, comprising four response categories: Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD), scored from 4 to 1. The scale assesses students' affective responses, ranging from strong enthusiasm and clear understanding to discomfort or rejection of GeoGebra in learning. This instrument serves to measure students' emotional engagement and perceived effectiveness of GeoGebra in supporting mathematical understanding. Next is determining the percentage of students' responses and learning interest based on the questionnaire results, which is calculated using the following formula.

$$Percentage = \frac{\text{Student Score on Each Indicator}}{\text{Maximum Score for Each Indicator}} \times 100\ \%$$

The formula shown calculates the percentage score for each indicator by dividing a student's actual score on a specific indicator by the maximum possible score for that indicator, then multiplying by 100 %. This method provides a standardized value that reflects how well a student performed on each learning indicator, making it easier to interpret and compare levels of achievement across individuals or groups. The resulting percentage can then be converted into assessment scale criteria. According to Arikunto[37], the percentage data is categorized using the following classification.

Table 2. Assessment Scale Criteria

Percentage Range	Category	Interpretation
81 - 100	Very Good	The response or interest is very high
61 - 80	Good	The response or interest is high
41 - 60	Fair	The response or interest is moderate
21 - 40	Poor	The response or interest is low
0 - 20	Very Poor	The response or interest is very low

Source: Arikunto[37]

Table 2 presents the assessment scale criteria used to interpret student response percentages. The scores are categorized into five levels—Very Good, Good, Fair, Poor, and Very Poor—based on percentage ranges. This classification facilitates a clearer understanding of students' interest or response levels, allowing for a standardized interpretation of the data gathered from learning assessments.

RESULTS

Data Analysis and Findings

Data collection was carried out through a combination of classroom observation and structured questionnaires aimed at evaluating two primary aspects: students' responses to the implementation of GeoGebra and their intrinsic interest in mathematics learning when supported by the application. This dual approach provided a comprehensive view of both behavioral engagement and cognitive-affective reactions to the learning process. Classroom observations allowed researchers to capture real-time student interaction, participation, and engagement with the digital tool, while the questionnaires offered structured insights into learners' subjective experiences and perceptions.

To ensure the reliability and validity of the measurement process, two specific instruments were utilized. The first instrument focused on measuring students' cognitive, affective, and conative responses toward the use of GeoGebra in mathematics instruction. This included students' understanding of concepts (cognitive), their attitudes and feelings (affective), and their willingness to engage and persevere in problem-solving tasks (conative). The second instrument was developed to assess students' interest in learning mathematics, with emphasis on indicators such as emotional involvement, sustained attention, curiosity, and participation during the learning activities. Each item in both instruments was scored using a Likert-type scale, and the results were converted into percentages to facilitate interpretation and comparison.

The implementation process began with an introductory session designed to familiarize students with the GeoGebra interface and its core functionalities. During this phase, students were guided through a structured orientation that included: (1) a detailed explanation of the menus and features available in the application, and (2) a demonstration of key operations, particularly those relevant to the day's topic—graphing trigonometric functions. These introductory activities served as the foundation for the subsequent instructional sessions and were aimed at ensuring students could independently navigate and utilize GeoGebra as a learning tool. These activities are illustrated in the following figures.

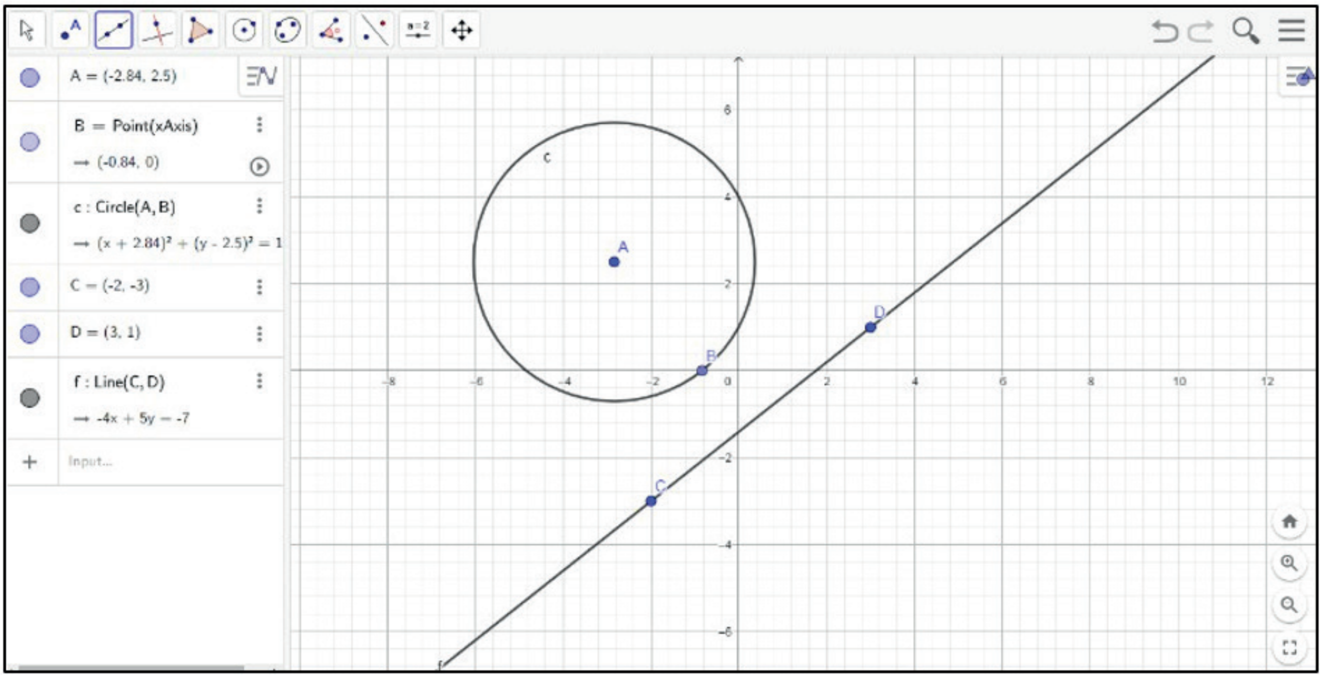

Figure 1. Menus in the GeoGebra Application and Their Functions

Figure 1 illustrates the interface of the GeoGebra application, highlighting the primary menu tools and their respective functions. The figure displays various mathematical objects, including points, lines, and a circle, constructed using the input and toolbar features provided by GeoGebra. This visual representation serves to demonstrate how students can utilize the application to manipulate and visualize geometric elements dynamically. Through such interactive features, GeoGebra facilitates the development of conceptual understanding by allowing real-time exploration and modification of mathematical constructs.

Figure 2 presents the graphical representation of a trigonometric function, generated using the GeoGebra application. The graph clearly illustrates the periodic nature of the cosine function, displaying its amplitude, frequency, and phase shift across the x-axis. This visual aid enables students to observe the characteristics and behavior of trigonometric functions dynamically, thereby supporting a deeper understanding of abstract mathematical concepts through direct interaction and real-time visualization. After completing the instructional

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session, the researcher distributed questionnaires to the students. The collected data were then calculated and analyzed, resulting in percentage scores, which are presented in table 3.

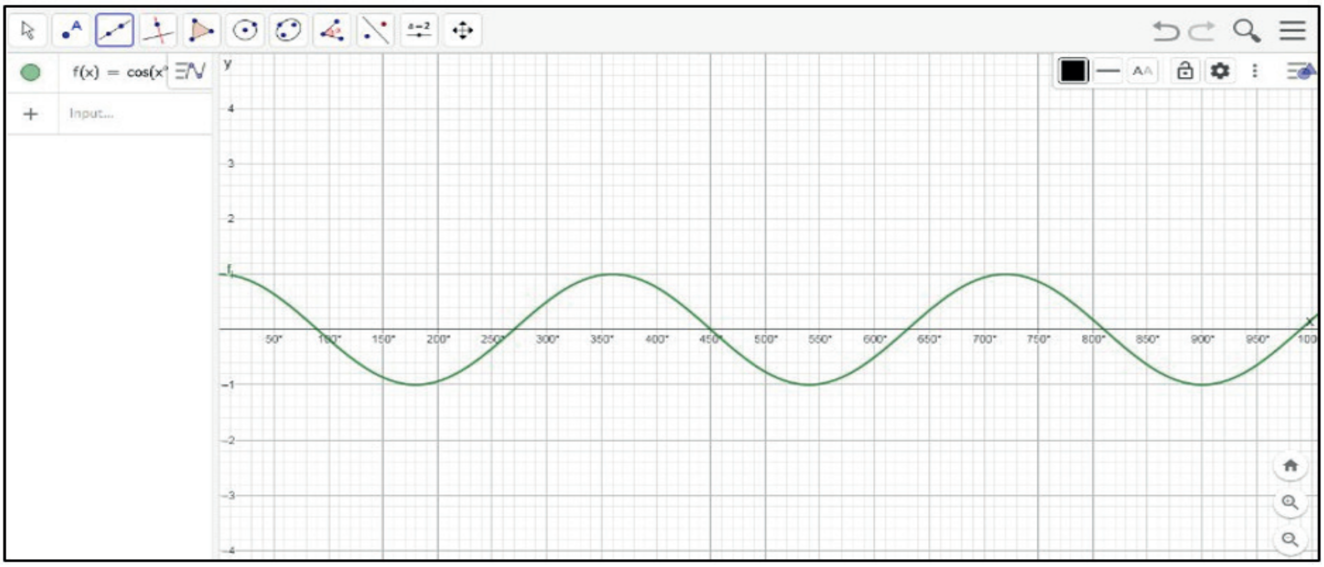

Figure 2. Graph of a Trigonometric Function

Table 3. Percentage of Student Responses in Using the GeoGebra Application

No.	Indicator	Percentage (%)	Category
1	Cognitive	86	Very Effective
2	Affective	84	Very Effective
3	Conative	77	Effective
Average		82	Very Effective

The effectiveness of using the GeoGebra application can be seen from the student responses presented in table 3 above. The average result was 82 %, which falls under the "Very Effective" category. This high average indicates that the integration of GeoGebra in mathematics instruction is not only well-received but also enhances students' engagement and learning experiences. Specifically, the cognitive indicator received the highest score at 86 %, demonstrating that students experienced improved understanding and clarity when interacting with mathematical content through GeoGebra. Similarly, the affective response, which measures emotional engagement such as enjoyment and interest, also showed a high percentage of 84 %, further affirming the application's impact on students' positive attitudes toward learning mathematics.

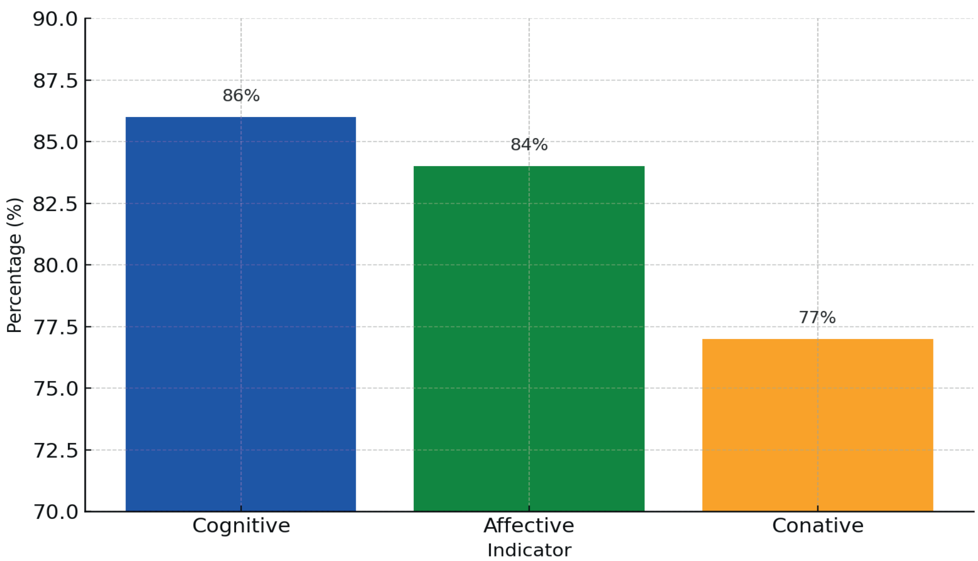

Figure 3. Bar Chart of Student Response Percentages

Meanwhile, the conative response, referring to students' behavioral intentions and participation levels, was slightly lower at 77 % but still categorized as "Effective." This suggests that while most students were cognitively and emotionally engaged, there is still room to further encourage active involvement and participation during the learning process. Overall, the data supports the conclusion that GeoGebra serves as a highly effective instructional tool, particularly in fostering cognitive understanding and affective interest, which are critical components for successful mathematics learning.

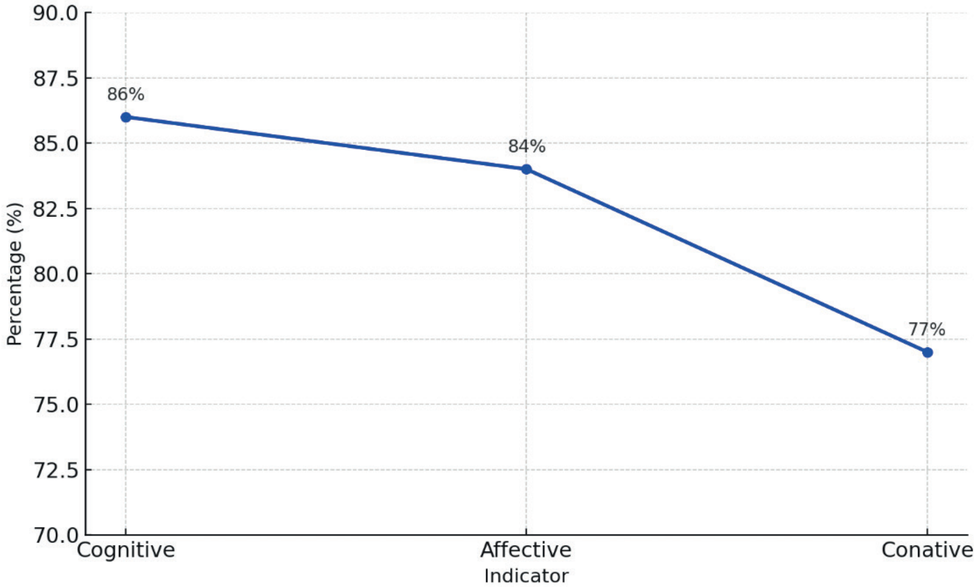

Figure 4. Line Chart of a Trigonometric Function

The next analysis focuses on the percentage of students learning interest in using GeoGebra, as shown in table 4 below.

Table 4. Student Learning Interest Percentage

No.	Indicator	Percentage (%)	Category
1	Enjoyment	84	Very Effective
2	Attention	77	Effective
3	Curiosity/Interest	77,5	Effective
4	Student Engagement	82,5	Very Effective
Average		80	Effective

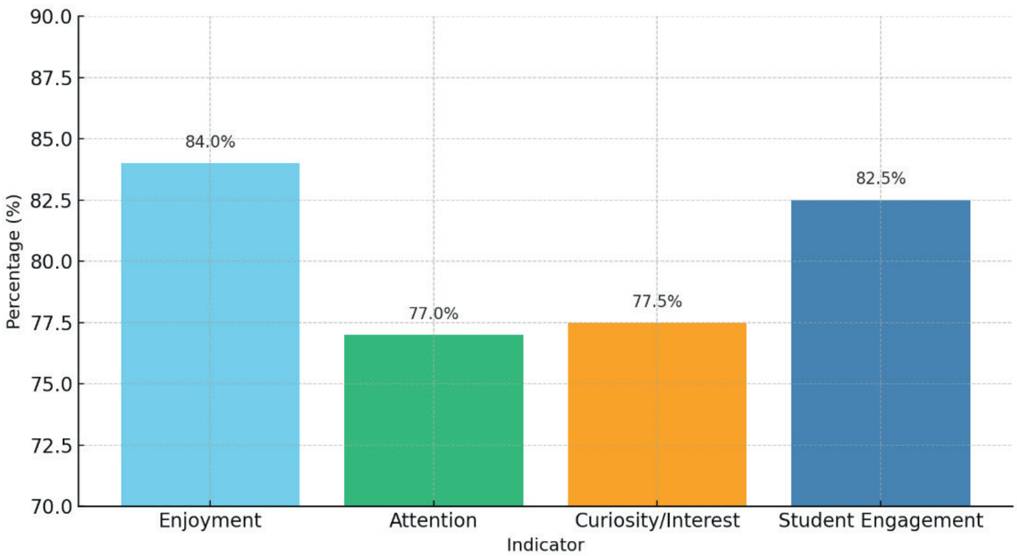

Figure 5. Bar Chart of Student Learning Interest Percentage

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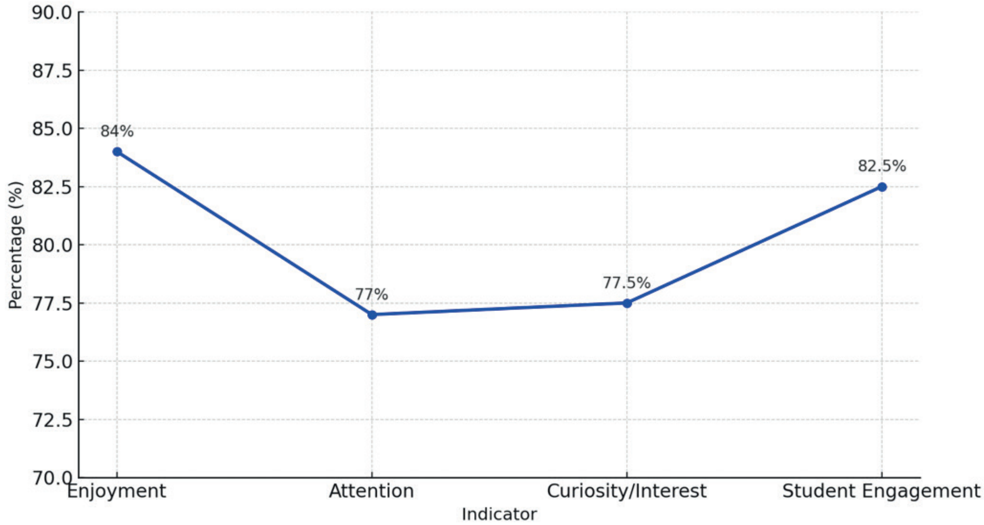

Figure 6. Line Chart of Student Learning Interest Percentage

Table 4 presents the percentage distribution of student learning interest across four indicators: enjoyment, attention, curiosity/interest, and student engagement. The results indicate that students demonstrated high levels of enjoyment and engagement when learning mathematics using the GeoGebra application, with respective percentages of 84 % and 82,5 %, both categorized as "Very Effective." These results suggest that the integration of GeoGebra significantly enhances students' emotional connection and active participation in learning activities, which are critical elements in fostering meaningful and sustained interest in mathematics education.

On the other hand, the attention and curiosity/interest indicators received slightly lower percentages—77 % and 77,5 % respectively—both categorized as "Effective." These figures still reflect a generally positive response, implying that the use of GeoGebra effectively captures students' focus and stimulates their intrinsic motivation to explore mathematical concepts. The average percentage across all indicators was 80 %, placing the overall learning interest in the "Effective" category. This suggests that while GeoGebra is a valuable tool for increasing student interest, further refinement in instructional strategies may help maximize its potential to maintain student attention and curiosity consistently throughout the learning process.

DISCUSSION

This study aimed to examine the effectiveness of GeoGebra-based learning on students' cognitive and affective participation in mathematics. The findings demonstrate that the integration of GeoGebra significantly enhanced students' engagement and understanding of mathematical concepts, particularly in graphing trigonometric functions. These outcomes are consistent with the objectives of the research and align with the growing emphasis on digital learning tools in secondary mathematics education.

When compared to prior studies, the results corroborate the work of Hidayat[22], who emphasized GeoGebra's role in improving student comprehension through interactive visualization. Similar to the present study, they found that the software's dynamic features fostered a more intuitive grasp of abstract mathematical content. This supports the argument that digital media, especially those incorporating visual and interactive elements, contribute meaningfully to student participation and motivation.[38,39]

From a cognitive perspective, the improvement in students' ability to construct and interpret trigonometric graphs reflects an increased depth of understanding facilitated by the GeoGebra platform. This aligns with findings Arbain et al.[40,41], who assert that GeoGebra enhances mathematical reasoning by enabling students to explore mathematical properties through manipulation and experimentation. The immediate feedback provided by the software likely played a pivotal role in reinforcing learning and correcting misconceptions.[42,43] Research has shown that immediate feedback significantly enhances learning outcomes by helping students quickly identify and correct errors, thereby promoting deeper conceptual understanding and retention.[44,45]

In terms of affective response, the study recorded high levels of student interest and emotional engagement, echoing previous research by Imani Muslim et al.[5,21], which found that technology-mediated instruction positively influences students' attitudes toward mathematics. The present results suggest that GeoGebra not only increases enjoyment and curiosity but also fosters a more confident and positive disposition toward learning mathematics.

Despite the strengths of these findings, several limitations must be acknowledged. First, the study was conducted in a single educational institution with a relatively small sample size (n=20), which may limit statistical generalizability and external validity. Second, the focus was restricted to one specific mathematical topic—trigonometric functions—thereby not accounting for the potential variability of effectiveness across different mathematical domains.

Moreover, the data collection relied predominantly on self-reported measures through questionnaires and observation, which may introduce subjectivity and response bias. Although triangulated with classroom observations, future studies should consider integrating more objective assessment tools, such as performance analytics or longitudinal achievement data, to enhance validity.

Nonetheless, the findings contribute important insights into the evolving landscape of mathematics education and the potential of technology-enhanced learning. By connecting theoretical frameworks with practical application, this study offers a replicable instructional model that can be adapted across various educational contexts. The use of GeoGebra supports a shift toward student-centered learning, which is vital for developing 21st-century skills such as critical thinking and technological literacy.

Overall, this study contributes valuable insight to both theory and practice. Theoretically, it reinforces the value of technology-enhanced learning aligned with constructivist principles. Practically, it offers a compelling case for incorporating GeoGebra into mathematics curricula to support interactive, student-centered learning environments. Future research should involve a larger and more diverse sample, include long-term observations, and investigate the impact of GeoGebra across different topics and educational levels. Mixed-method approaches that combine quantitative data with qualitative insights, such as interviews or focus groups, could provide a more comprehensive understanding of students' experiences. Moreover, professional development for teachers on the effective use of GeoGebra could help maximize its instructional potential.

CONCLUSIONS

The integration of GeoGebra into mathematics instruction demonstrates strong pedagogical value, particularly in fostering student-centered learning environments. The application's intuitive interface, dynamic visualizations, and interactive tools significantly enhanced students' engagement, comprehension, and interest, particularly in learning trigonometric functions. Rather than merely serving as a supplementary resource, GeoGebra functioned as a central instructional medium that encouraged exploration and conceptual understanding. This aligns with the goals of modern mathematics education, which emphasize digital literacy, personalized learning, and the development of higher-order thinking skills. Therefore, educators and researchers are encouraged to leverage GeoGebra not only to enrich mathematical instruction but also to bridge the gap between abstract content and meaningful student experiences across various mathematical domains.

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AUTHORSHIP CONTRIBUTION
Conceptualization: Maria Magdalena Zagoto, I Made Arnawa.

Data curation: Edwin Musdi, Ahmad Fauzan.
Formal analysis: Maria Magdalena Zagoto, Oskah Dakhi.
Research: Maria Magdalena Zagoto.
Methodology: I Made Arnawa, Edwin Musdi, Ahmad Fauzan.
Project management: Alwen Bentri, Oskah Dakhi.
Resources: Maria Magdalena Zagoto, I Made Arnawa, Edwin Musdi.
Software: Maria Magdalena Zagoto, Ahmad Fauzan.
Supervision: : I Made Arnawa, Alwen Bentri.
Validation: Edwin Musdi, Ahmad Fauzan.
Display: Oskah Dakhi, Alwen Bentri.
Drafting - original draft: Maria Magdalena Zagoto, I Made Arnawa, Edwin Musdi.
Writing - proofreading and editing: Oskah Dakhi, Edwin Musdi.