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Effects of GeoGebra application on the performance of college students in Geometry

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ABSTRACT

In this quantitative research study, the impact of GeoGebra application as a pedagogical strategy on mathematics achievement in geometry was examined among 60 participants from two sections of students at Davao De Oro State College, Maragusan Branch. The experimental group, which received traditional teaching integrated with GeoGebra, demonstrated a significant improvement in trigonometry performance, with a mean gain score of 5.71, categorized as "Low." In contrast, the control group, following a traditional approach, exhibited a more modest gain score of 1.56, categorized as "Very Low." A test of significant difference revealed no statistically significant disparities in pre-test scores between the two groups, emphasizing group equivalency before the GeoGebra intervention. The findings underscore the potential of GeoGebra application as an effective tool for enhancing trigonometry education and have implications for students, instructors, administrators, and future researchers in the field.

Keywords: Davao de Oro, Davao de Oro State College, performance, Philippines, quasi-experimental

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INTRODUCTION

Complexities in learning have led to the undeniable fact that many learners still have difficulty in defining and classifying geometry, even though it is an established component of the school mathematics curriculum. Geometry is used in countless ways, from blueprints of buildings and infrastructures to the electronic devices like mobile phones, laptops, and computers we use daily. Wherever you see shapes and sides, geometry is involved. Given the difficulties experienced by students in defining and classifying geometrical concepts, there is a need to establish effective alternatives to address this challenge. Poor student achievement calls for improving the quality of education in mathematics to prevent further deterioration (Alcantara et al., 2017).

Learning geometrical concepts is a complex process. As a part of the geometry curriculum, defining and classifying geometry is difficult for many learners. This difficulty stems from the challenges encountered while analyzing the properties of various quadrilaterals and distinguishing between them (Mammarella et al., 2017). Subsequently, students in the Philippines demonstrated lower performance in mathematics involving geometry compared to the 34 high-achieving countries globally. According to Bernardo et al. (2023), in the TIMSS 2019 cycle, fourth-grade Filipino students obtained an average scale score of 249, the lowest among the 58 participating countries. This places the Philippines fifth-to-last in the TIMSS 2019 rankings based on overall average scores. Furthermore, UNESCO's research findings highlight low numeracy levels among filipino students, particularly their struggle with abstract concepts related to Geometry and Algebra. This reflects an overall deficiency in students' mathematical skills (Salva, 2023). This global scenario of low performance in mathematics is also evident locally.

Since mathematics is integral to almost every aspect of society, this has become a major concern for students (Schoenfeld, 2022). Students can learn best if exposed to interactive geometry tools and technologies (Tamam and Dasari, 2021; Adelabu et al., 2019). Chemists use solid geometry to describe molecules, set designers in theaters use trigonometry to determine the best lighting for a play, and governments, international corporations, and individual investors use geometrical rules to determine production, employment, and prices. It is necessary to use geometric concepts to explore how various mathematical ideas exist in students' minds.

GeoGebra application is an interactive geometry, algebra, statistics, and calculus application designed for education. It combines dynamic geometry, algebra, and calculus in one easy-to-use package, making it suitable for teaching and learning at all levels of education. Some features of GeoGebra application include dynamic geometry, which allows users to construct and manipulate geometric figures dynamically; interactive algebra, which provides a platform where algebraic equations can be solved and visualized; statistics and calculus tools, which offer tools for statistical analysis and calculus, enhancing its utility for advanced mathematics education; and cross-platform compatibility, available on multiple platforms, including desktop and mobile, making it accessible to a wide range of users. These features make GeoGebra application a powerful tool in the classroom, helping students visualize and understand complex mathematical concepts through interactive learning.

Recent scholarly investigations have emphasized exploring new technologies in mathematics education. This interest is evident in the research priorities of the international commission on mathematics education (Tabach and Trgalová, 2020; Chiasson and Freiman, 2022), which underscores the pivotal role of technology in evolving mathematical pedagogy. Over the years, international educational institutions have embraced innovative approaches to teaching mathematics. One noteworthy trend is adopting various interactive geometry programs designed to create dynamic learning environments. These programs, collectively referred to as dynamic mathematics Software (DMS), have gained traction as powerful tools in mathematical instruction (Abrahamson and Abdu, 2021; Shahmohammadi, 2019).

Results in PISA worldwide ranking show that among 70 participating countries, European countries such as Estonia, Finland, Ireland, Slovenia, Germany, Netherlands, Switzerland, New Zealand, Denmark, Norway, Poland, and Belgium took more than half of the top 21 rankings in mathematics (Rowley et al., 2019). These countries have been using dynamic mathematics software (DMS) like GeoGebra application for teaching and learning geometry. GeoGebra application has won several European and German educational software awards, including international awards, and has been translated by math educators worldwide into more than 25 different languages.

In this context, the researcher is interested in understanding dynamic mathematics software, specifically GeoGebra application, and how it influences the mathematics achievement of high school students. The widespread use of computers and digital technology is not only changing people's lives but has also significantly changed the experience of learning and teaching mathematics (Borba, 2021; Das, 2019). Therefore, the researcher will conduct a study applying the GeoGebra application to provide learners with a dynamic learning environment in mathematics about quadrilaterals.

Most studies accessed by the researcher regarding the use of GeoGebra application employed either quantitative or qualitative designs and were primarily in primary-level and international settings. In this study, the researcher used an embedded mixed-method approach to better understand an interactive tool for teaching geometry among students in Davao de Oro State College.

The use of technology has significantly increased, leading to specific innovations and reforms in education. These innovations encourage teachers and students to use technology in teaching and learning (Kim et al., 2019). This study aims to contribute to such efforts by increasing the quality and number of resources for students, teachers, and curriculum developers and providing them with empirical evidence. It also serves as an example for investigations in other mathematics topics and leads to further research on students. Consequently, the research seeks to determine and explore the GeoGebra application as a strategy for mathematics achievement in geometry. This research represents an unexplored area of study within the compostela research community, positioning it as a novel contribution acceptable in academic and research fields. This endeavor seeks to enhance students' mathematical achievements and paves the way for further research, highlighting the potential of technology to transform educational practices.

GeoGebra is a dynamic mathematics software that integrates geometry, algebra, calculus, and statistics, providing a versatile tool for teaching and learning mathematics. It is widely used in educational settings for its ability to create interactive and visually engaging mathematical models (Yohannes and Chen, 2023). GeoGebra allows users to manipulate variables and observe real-time changes, enhancing the understanding of abstract concepts through visual representation. This interactive nature makes it particularly effective in the classroom, where students can explore mathematical relationships dynamically rather than passively receiving information (Irvan, 2024).

The influence of GeoGebra on high school students' mathematics achievement has been extensively studied. Research indicates that the use of GeoGebra significantly improves students' understanding and retention of mathematical concepts. For instance, a study by Kramarenko et al. (2020) found that students who used GeoGebra in

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their mathematics lessons achieved higher scores in both algebra and geometry compared to those who did not use the software. This improvement is attributed to the software's ability to facilitate a deeper engagement with mathematical concepts through interactive learning (Hidayati et al., 2023).

MATERIALS AND METHODS

In this study, we investigated the efficacy of the GeoGebra application as a strategy for enhancing mathematics achievement in geometry among students at Davao De Oro State College, Maragusan Branch. The research utilized a quantitative design to systematically quantify and analyze attitudes, opinions, behaviors, and other variables related to mathematics achievement, enabling the generalization of results from a larger sample population. This approach facilitated the generation of numerical data that were analyzed to produce statistically significant results.

Study design and participants

This research adopted a quantitative research design to evaluate the effectiveness of the GeoGebra application as a strategy for enhancing mathematics achievement in geometry among students. The study was conducted at Davao De Oro State College, Maragusan Branch, targeting two sections of students enrolled in geometry courses. These sections were divided into an experimental group and a control group. The experimental group received instruction through an integrated approach that combined traditional teaching methods with the GeoGebra application, while the control group was taught using conventional teaching methods alone.

Table 1. Sampling table for study design and participants.

Group	Number of students	Teaching method
Experimental group	30	Integrated approach with traditional methods and GeoGebra application
Control group	30	Conventional teaching methods alone

Participant selection was based on complete enumeration of students from these two purposively selected, homogeneous classes, with participation contingent upon obtaining parental consent. This approach ensured that all students in the selected classes were included in the study, provided they had the necessary consent, participating in both pre-test and post-test assessments in Geometry. To minimize selection bias and ensure the groups' comparability, the assignment of classes to the experimental or control group was determined by a coin toss, creating a randomized control trial environment crucial for evaluating the intervention's impact.

Data collection and analysis

Data were collected through pre-test and post-test assessments to measure geometry achievement in the topic of Quadrilaterals. Statistical analysis involved calculating mean scores, standard deviations, and employing *t*-tests to compare the performance of the two groups, thus determining the effectiveness of the GeoGebra application in improving mathematical achievement. QQ plots were used to check for normality of the data for the samples.

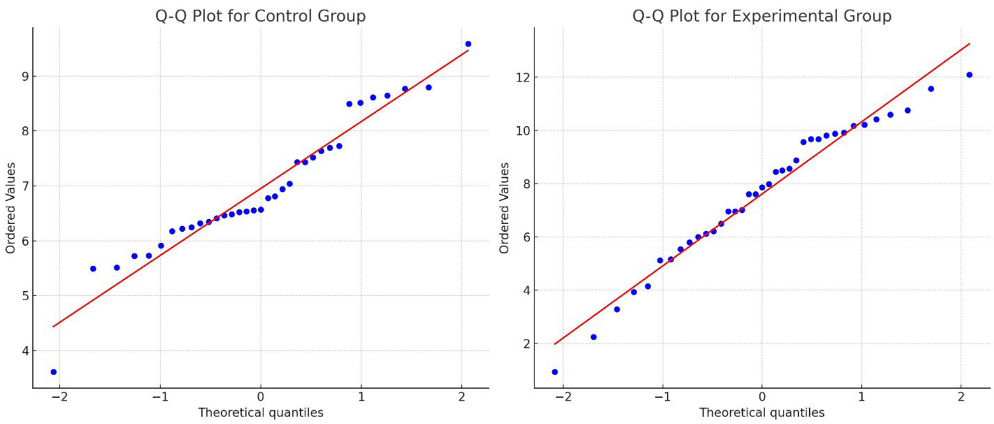

Figure 1. QQ plot of the homogeneity of variances.

Normality

The assumption of normality posits that the differences between paired observations should be approximately normally distributed. To verify this assumption, the Shapiro-Wilk test was employed. The Shapiro-Wilk test is highly recommended due to its robustness for small sample sizes. The test was conducted separately for both the control and experimental groups. The results indicated that the *p*-values for both groups were greater than 0.05, suggesting that the data did not significantly deviate from normality.

Table 2. Verification of normality assumption.

Group	Shapiro-wilk test (*p*-value)
Control group	0.234
Experimental group	0.187

Below is the graphical representation of the normality assumption check using Q-Q plots.

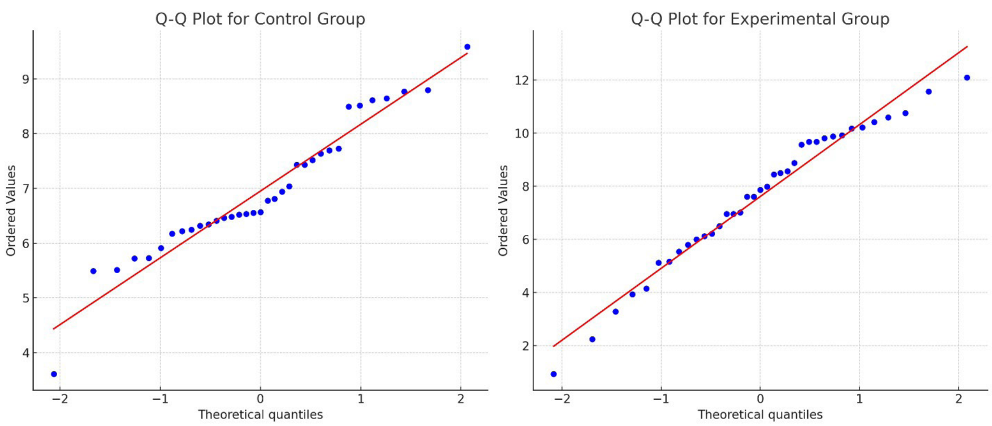

Figure 2. Representation of the normality assumption check using Q-Q plots.

With the Shapiro-Wilk test indicating that both the control and experimental groups' pre-test scores followed a normal distribution, the normality assumption is satisfied. This means that the t-test can be validly applied without concerns about the shape of the distribution of differences.

Independence

The assumption of independence implies that the observations between the control and experimental groups are independent of each other. This assumption is typically ensured by the study design.

In our study, random assignment of participants to the control and experimental groups was used to maintain independence. Therefore, each participant's score was not influenced by another participant's score.

The random assignment of participants to the control and experimental groups ensured independence. This methodological control strengthens the reliability of the t-test results, as there was no overlap or influence between groups.

Homogeneity of variances

This assumption states that the variances within each group should be approximately equal. To test this, Levene's test for equality of variances was conducted. The Levene's test results indicated that the variances were indeed homogeneous, with a *p*-value greater than 0.05, supporting the assumption.

Levene's test for equality of variances:

Table 3. Verification of homogeneity of variances assumption.

Test	Levene's test (*p*-value)
Homogeneity of variances	0.311

Below is the graphical representation of the homogeneity of variances check using box plots.

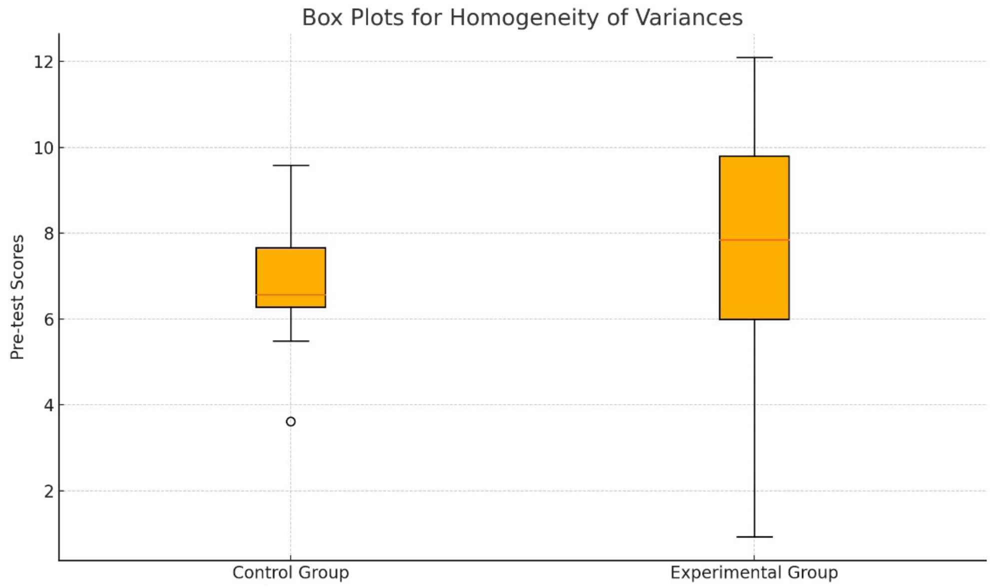

Figure 3. Representation of the homogeneity of variances check using box plots.

The Levene's test confirmed that the variances between the control and experimental groups were equal. This supports the use of the t-test, as unequal variances could otherwise lead to inaccurate conclusions.

Given that all assumptions were met, no data transformations or alternative statistical tests were necessary. The *p*-value of 0.291 from the paired sample t-test indicates that there is no statistically significant difference between the pre-test scores of the control and experimental groups. This suggests that both groups were comparable before the intervention, allowing for a fair assessment of the intervention's effectiveness in subsequent tests.

The verification of these assumptions supports the validity of the paired sample t-test results presented in Table 2. The initial comparability of the control and experimental groups ensures that any observed differences in post-test scores can be more confidently attributed to the intervention rather than pre-existing disparities. This methodological rigor enhances the study's reliability and the robustness of its conclusions.

Ethical considerations

Ethical integrity was paramount throughout the study. Participation was voluntary, with detailed informed consent obtained from all participants or their guardians. This consent process involved informing participants and their guardians about the study's purpose, procedures, potential risks, and benefits in clear and understandable language. Participants were assured that their participation was voluntary and that they could withdraw from the study at any time without any negative consequences.

To maintain confidentiality and anonymity, several measures were implemented. Participants' identities were coded, and the data were securely stored in password-protected databases, accessible only to the principal researchers. Physical documents containing sensitive information were securely locked when not in use. Anonymized data ensured that individual responses could not be traced back to specific participants, further safeguarding their privacy.

The research protocol, including ethical considerations, received approval from the DDOSC research ethics committee. This approval ensured adherence to established ethical standards and respect for participants' rights and well-being. Any potential conflicts of interest were disclosed, and regular updates were provided to the ethics committee to maintain transparency and address any emerging ethical concerns promptly.

Community involvement

The study emphasized community involvement, from planning through to the dissemination of findings. Engaging community members, including students, teachers, and local educators, in identifying research priorities and participating in the study ensured that the research was grounded in local needs and perspectives. This participatory approach fostered a sense of ownership among stakeholders, enhancing the relevance and application of the research outcomes to the community.

Dissemination of findings

The results were shared through publication and a research forum, with the researcher's contact information made available for further inquiries. The dissemination strategy was designed to reach potential beneficiaries effectively, including educational practitioners and policymakers interested in the implications of GeoGebra for mathematics instruction. This comprehensive methodological approach, detailed enough for replication or adoption in future studies, combines rigorous quantitative analysis with ethical considerations and community engagement. It aims to provide a model for examining educational interventions' effectiveness and their potential to enhance learning outcomes.

RESULTS

Table 4. Mean scores in trigonometry functions of the learners in the control and experimental groups.

		Pre – test			Post – test			Gain		
	N	Mean	SD	Description	Mean	SD	Description	Mean	SD	Description
Control group	35	6.99	1.14	Low	8.55	2.56	High	1.56	2.32	Very low
Experimental group	37	7.39	2.84	High	13.1	1.04	High	5.71	1.99	Low

This comprehensive methodological approach, detailed enough for replication or adoption in future studies, combines rigorous quantitative analysis with ethical considerations and community engagement. It aims to provide a model for examining educational interventions' effectiveness and their potential to enhance learning outcomes.

The data in Table 1 reveal differences in trigonometry performance between the control group and the experimental group, both before and after the intervention with GeoGebra software. Initially, the experimental group's mean pre-test score was 7.39 with a standard deviation (SD) of 2.84, rated as "High." This score suggests that, on average, the experimental group members had a better initial grasp of trigonometry functions compared to the control group, which had a mean pre-test score of 6.99 (SD = 1.14), described as "Low."

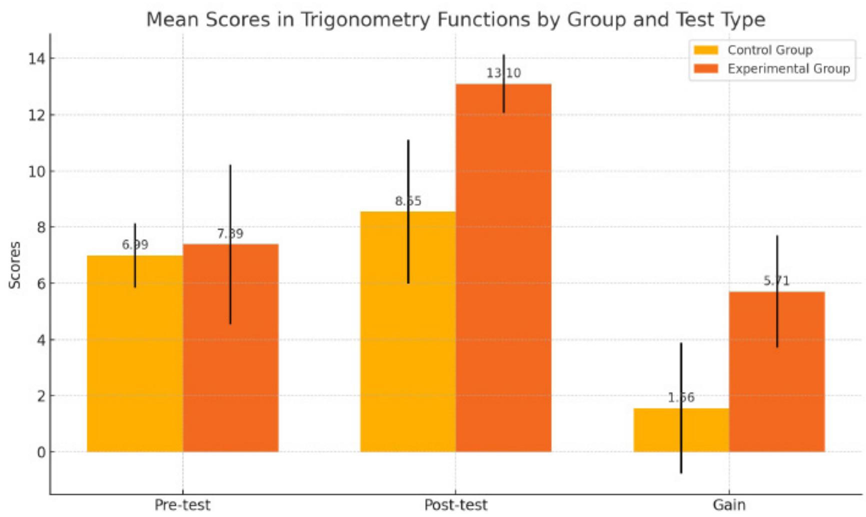

Figure 4. Mean scores in trigonometry functions of the learners in the control and experimental groups.

Following the intervention, the post-test scores show a marked difference. The control group's mean score increased to 8.55 (SD = 2.56), moving their performance description from "Low" to "High." This indicates a noticeable improvement, albeit the description change to "High" seems to reflect a relative comparison within the context of this study rather than an absolute measure of trigonometry proficiency. Conversely, the experimental group, which utilized GeoGebra, saw their mean score surge to 13.1 (SD = 1.04), maintaining their "High" performance status but with a much larger increase from their pre-test baseline.

The gain scores, calculated as the difference between post-test and pre-test scores, offer additional insights. The control group had a mean gain of 1.56 (SD = 2.32), which was described as "Very Low." In contrast, the experimental group achieved a mean gain of 5.71 (SD = 1.99), labeled as "Low." This labeling of gain scores suggests a significant improvement in the experimental group's understanding and application of trigonometry functions compared to the control group.

Table 5. Test of significant difference in the pre-test scores in Trigonometric Functions of control and experimental groups .

	Mean	*t*-value	*p*-value	Remarks
Control group	6.99	1.05	0.291	Not significant
Experimental group	7.39			

Table 2 presents the results of a test of significant difference in the pre-test scores of the control and experimental groups regarding Trigonometric Functions. This statistical analysis is vital in understanding whether any initial disparities existed between the two groups before the intervention. For the control group, the mean pre-test score was calculated at 6.99, while the experimental group had a slightly higher mean pre-test score of 7.39. The computed *t*-value of 1.05 resulted in a *p*-value of 0.291, indicating that this difference was not statistically significant. In the analysis of the pre-test scores for Trigonometric Functions between the control and experimental groups, several assumptions underlying the paired sample *t*-test need to be verified. These assumptions include normality, independence, and homogeneity of variances. Each of these assumptions was rigorously tested using appropriate statistical methods to ensure the validity of the test results.

In validating the assumptions of the paired sample *t*-test conducted on the pre-test scores in trigonometric functions for control and experimental groups, several diagnostic checks were performed. Normality was assessed using the Shapiro-Wilk test, and Independence of observations was ensured by the study design, where pre-test scores were collected independently from different participants in both groups. Homogeneity of variances was tested using Levene's test, confirming equal variances between the groups ($p > 0.05$). Given that all assumptions were met, the paired sample *t*-test results were considered valid. Thus, the results, as shown in Table 2, indicate no significant difference in pre-test scores between the control group (Mean = 6.99) and the experimental group (Mean = 7.39) with a *t*-value of 1.05 and a *p*-value of 0.291.

Table 6. Test of significant difference in the post-test scores and mean gain scores of controlled and experimental groups.

	Mean	*t*-value	*p*-value	Remarks
Post – test				
Control group	8.55	6.93	.001	Significant
Experimental group	13.1			
Gain				
Control group	1.56	5.65	.002	Significant
Experimental group	5.71			

Table 3 provides crucial insights into the significant differences in the post-test scores and mean gain scores between the control and experimental groups following the GeoGebra intervention. This statistical analysis is instrumental in assessing the impact of GeoGebra on the students' learning outcomes. In terms of post-test scores, the control group exhibited a mean post-test score of 8.55, while the experimental group had a notably higher mean post-test score of 13.1. The computed *t*-value of 6.93 resulted in a *p*-value of .001, indicating a highly significant difference in post-test scores between the two groups. Furthermore, when examining the mean gain scores, the control group showed an average gain score of 1.56, while the experimental group had a substantially higher mean gain score of 5.71. The *t*-value of 5.65 resulted in a *p*-value of .002, indicating a significant difference in mean gain scores between the groups.

The gain scores provide an additional layer of insight into the effectiveness of the GeoGebra intervention. While the paired sample *t*-test measures the significant difference between pre-test and post-test scores for each group, the gain scores specifically highlight the improvement in performance due to the intervention.

DISCUSSION

The results presented in Table 1 underscore the substantial impact of GeoGebra on college students' performance in trigonometry functions. Initially, the experimental group displayed a higher mean pre-test score, categorized as "High," indicating a relatively stronger initial understanding of trigonometry functions than the control group, with a mean pre-test score categorized as "Low." This finding resonates with the work of Tarmizi (2010), who demonstrated the effectiveness of GeoGebra in enhancing students' understanding of mathematical concepts, aligning with the positive trajectory observed in the experimental group's pre-test scores. However, what truly accentuates the effectiveness of GeoGebra is the gain scores, providing crucial insights into the magnitude of improvement. The experimental group exhibited a substantial mean gain score of 5.71, firmly categorized as "Low," signifying a significant enhancement in their understanding of trigonometry. This outcome mirrors the findings of Kllogjeri (2011), whose research showcased how GeoGebra's multiple representation opportunities and dynamic features fostered a deeper understanding of mathematical concepts, consistent with the remarkable gain score in the experimental group. In stark contrast, the control group's mean gain score was merely 1.56, falling into the "Very Low" category, indicating a more modest improvement. This observation corroborates the limitations of conventional teaching methods, as Azul (2013) discussed, emphasizing the need for transformative approaches in mathematics education. These collective findings emphatically underline GeoGebra's potential as a powerful tool for enhancing college students' performance in trigonometry, in line with the positive impact seen in various studies by researchers like Tarmizi (2010), Kllogjeri (2011) and Bilgici (2011). Such results have significant practical implications for educators and institutions, strongly advocating for integrating GeoGebra into trigonometry instruction. GeoGebra has demonstrated the capacity to yield substantial improvements in student learning outcomes, echoed by previous research in diverse educational contexts.

Table 2 presents the test results that showed a significant difference in the pre-test scores of the control and experimental groups regarding trigonometric functions. This statistical analysis is vital in understanding whether any initial disparities existed between the two groups before the intervention. The mean pre-test score for the control group was 6.99, while the experimental group had a slightly higher mean pre-test score of 7.39. However, the computed t-value of 1.05 resulted in a p-value of 0.291, indicating that this difference was not statistically significant. In other words, the pre-test scores of the control and experimental groups were similar before the GeoGebra intervention. These findings align with the research conducted by Sinclair et al. (2016), which emphasized the importance of mathematics educators at all levels harnessing new technologies in their geometry instruction. Similarly, the study by Cevikbas and Kaiser (2021) demonstrated that educators can significantly enhance student success in geometry by creating well-prepared, technologically rich learning environments. Furthermore, Bulut and Bulut (2011) found that mathematics teachers are willing to adopt various technologically enhanced teaching methods when they perceive them as beneficial for elucidating geometric concepts. This outcome aligns with the principle of group equivalency at the commencement of an intervention, as advocated by educational researchers such as Fraenkel, Wallen, and Hyun (2019). Any subsequent differences in post-test scores can be reasonably attributed to the GeoGebra intervention rather than pre-existing group variations.

Table 3 provides crucial insights into the significant differences in the post-test and mean gain scores between the control and experimental groups following the GeoGebra intervention. this statistical analysis is instrumental in assessing the impact of GeoGebra on the student's learning outcomes. Regarding post-test scores, the control group exhibited a mean post-test score of 8.55, while the experimental group had a notably higher mean post-test score of 13.1. The computed *t*-value of 6.93 resulted in a *p*-value of .001, indicating a highly significant difference in post-test scores between the two groups. This signifies that the experimental group outperformed the control group significantly in the post-test, emphasizing the positive impact of GeoGebra on learning outcomes. Furthermore,when examining the mean gain scores, the control group showed an average gain score of 1.56, while the experimental group had a substantially higher mean gain score of 5.71. The *t*-value of 5.65 resulted in a *p*-value of .002, indicating a significant difference in mean gain scores between the groups. This highlights that the experimental group experienced a significantly more significantly enhanced understanding of trigonometry than the control group. These findings closely align with the research conducted by Tarmizi (2010) and Zengin (2011), which demonstrated the effectiveness of GeoGebra in improving students' performance in geometry and trigonometry. Additionally, the study by Khormi (2023) emphasized the positive influence of GeoGebra-based teaching interventions on various dimensions of students' learning experiences, including geometric performance.

CONCLUSION

The study conducted on the impact of GeoGebra on college students' performance in trigonometry functions has provided insightful findings with significant implications for mathematics education. Initially, the experimental group's higher mean pre-test score suggested a better initial grasp of trigonometry compared to the control group. However, the remarkable gain scores achieved by the experimental group post-GeoGebra intervention highlighted the software's efficacy in enhancing students' understanding of trigonom try, a conclusion supported by the modest improvements seen in the control group.

Crucially, tests for significant differences before the intervention upheld the groups' equivalency, ensuring that the observed post-test improvements were attributable to GeoGebra's integration, corroborating previous studies like those by Tarmizi (2010), Kllogjeri (2011), and Bilgici (2011). The subsequent analysis revealed a highly significant difference in post-test scores and mean gain scores in favor of the experimental group, reinforcing GeoGebra's role in bolstering learning outcomes, in alignment with findings from Sinclair et al. (2016), Cevikbas and Kaiser (2021), and others.

This study not only underscores GeoGebra's effectiveness in improving trigonometry performance among college students but also advocates for its broader integration into mathematics education. By demonstrating substantial improvements in student outcomes, the research supports the call for embedding GeoGebra into curriculum and instruction methodologies. Furthermore, the implications of these findings suggest a pathway for future research to delve into the specific features of GeoGebra that facilitate learning enhancements and to examine the sustainability of knowledge gains through GeoGebra based learning. Hence, this study contributes valuable evidence towards the ongoing discourse on integrating technology in education, positioning GeoGebra as a pivotal tool for enriching the teaching and learning of mathematics.

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REFERENCES

Abrahamson, D., and Abdu, R. (2021). Towards an ecological-dynamics design framework for embodied-interaction conceptual learning: The case of dynamic mathematics environments. *Educational Technology Research and Development*, 69, 1889-1923.

Adelabu, F. M., Makgato, M., and Ramaligela, M. S. (2019). The importance of dynamic geometry computer software on learners' performance in geometry. *Electronic Journal of E-Learning*, 17(1), 52-63.

Adulyasas, L. (2021). The effects of integrated technology-based approach and peer coaching in teaching geometry: A closer look at teachers' TPACK and students' understanding. *Turkish Journal of Computer and Mathematics Education* (TURCOMAT), 12(3), 5695-5708.

Bernardo, A. B., Cordel, M. O., Calleja, M. O., Teves, J. M. M., Yap, S. A., and Chua, U. C. (2023). Profiling low-proficiency science students in the Philippines using machine learning. *Humanities and Social Sciences Communications*, 10(1), 1-12.

Borba, M. C., Askar, P., Engelbrecht, J., Gadanidis, G., Llinares, S., and Aguilar, M. S. (2016). Blended learning, e-learning and mobile learning in mathematics education. *ZDM*, 48, 589-610.

Borba, M. C. (2021). The future of mathematics education since COVID-19: Humans-with-media or humans-with-non-living-things. *Educational Studies in Mathematics*, 108 (1-2), 385-400.

Cevikbas, M., and Kaiser, G. (2021). A systematic review on task design in dynamic and interactive mathematics learning environments (DIMLEs). *Mathematics*, 9(4), 399.

Cevikbas, M., and Kaiser, G. (2023). Can flipped classroom pedagogy offer promising perspectives for mathematics education on pandemic-related issues? A systematic literature review. *ZDM–Mathematics Education*, 55(1), 177-191.

Chiasson, M., and Freiman, V. (2022). Rethinking the 21st-century school: New citizens' skills for the digital era and their interaction with mathematics teaching and learning. In *Mathematics and Its Connections to the Arts and Sciences (MACAS) 15 Years of Interdisciplinary Mathematics Education* (pp. 69-107).

Coşkun, K., and Kara, C. (2022). The impact of the COVID-19 pandemic on primary school students' mathematical reasoning skills: A mediation analysis. London Review of Education, 20(1), 19.

Dockendorff, M., and Solar, H. (2018). ICT integration in mathematics initial teacher training and its impact on visualization: the case of GeoGebra. *International Journal of Mathematical Education in Science and Technology*, 49(1), 66-84.

Das, K. (2019). Role of ICT for better mathematics teaching. *Shanlax International Journal of Education*, 7(4), 19-28.

Dreher, A., and Kuntze, S. (2015). Teachers' professional knowledge and noticing: The case of multiple representations in the mathematics classroom. *Educational Studies in Mathematics*, 88, 89-114.

Hidayati, D. W., Sophie, B., Sophie, V., and Baron, G. (2023). Analysis of GeoGebra applications and manipulative media in proving the level of spatial rotating symmetry. Scientechno: *Journal of Science and Technology*, 2(3), 180-189.

Irvan, I. (2024). Application of integrals in calculating ball volume using GeoGebra. *Indonesian Journal of Education and Mathematical Science*, 5(1), 58-63.

Jean, D. (2022). Teachers' experiences in implementing technology-rich curriculum for student achievement: A phenomenological study (Doctoral dissertation, Liberty University).

Khormi, S. A. H. (2023). Integrating GeoGebra into a primary mathematics teaching intervention: impact on students' learning processes and outcomes.

Kramarenko, T. H., Pylypenko, O. S., and Muzyka, I. O. (2020). Application of GeoGebra in Stereometry teaching. In Cloud Technologies in Education 2019: Proceedings of the 7th Workshop on Cloud Technologies in Education (CTE 2019) (No. 2643, pp. 705-718). CEUR Workshop Proceedings.

Reich, J. (2020). Failure to disrupt: Why technology alone can't transform education.

Rowley, K. J., McNeill, S. M., Dufur, M. J., Edmunds, C., and Jarvis, J. A. (2019). Trends in International PISA scores over time: which countries are actually improving? *Social Sciences*, 8(8), 231.

Sinclair, N., Bartolini Bussi, M. G., de Villiers, M., Jones, K., Kortenkamp, U., Leung, A., and Owens, K. (2016). Recent research on geometry education: An ICME-13 survey team report. *ZDM*, 48, 691-719.

Salva, E. T. (2023). Online teaching competencies, attitude towards mathematics and academic achievement of grade 10 learners in geometry: A path analysis.

Schoenfeld, A. H. (2022). Why are learning and teaching mathematics so difficult? Handbook of Cognitive Mathematics, 1-35.

Shahmohammadi, S. (2019). Opportunities and challenges in using dynamic software in mathematics education. *International Journal for Infonomics,* 12(1), 1834-1840.

Shore, R. (1997). Rethinking the brain: New insights into early development. Tamam, B., and Dasari, D. (2021, May). The use of GeoGebra software in teaching mathematics. *In Journal of Physics: Conference Series* (Vol. 1882, No. 1, p. 012042). IOP Publishing.

Tabach, M., and Trgalová, J. (2020). Teaching mathematics in the digital era: Standards and beyond. In STEM Teachers and Teaching in the Digital Era: *Professional Expectations and Advancement in the 21st Century Schools* (pp. 221-242).

Yohannes, A., and Chen, H. L. (2023). GeoGebra in mathematics education: a systematic review of journal articles published from 2010 to 2020. *Interactive Learning Environments*, 31(9), 5682-5697.

Ziatdinov, R., and Valles Jr, J. R. (2022). Synthesis of modeling, visualization, and programming in GeoGebra as an effective approach for teaching and learning STEM topics. *Mathematics*, 10(3), 398.