Enhancing Students' Understanding of Functions and Graphs through GeoGebra-Based Instruction

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.910000699

Received: 06 November 2025; Accepted: 12 November 2025; Published: 21 November 2025

ABSTRACT

Proficiency in functions and graphs is fundamental in Senior High School mathematics, serving as a prerequisite for advanced courses in calculus, statistics, and real-world applications. This study employed a quasi-experimental two-group pretest–posttest design to compare the effectiveness of the Traditional Lecture Method (TLM) and GeoGebra-based instruction in teaching functions and graphs to Grade 11 GAS students at Dapa National High School, S.Y. 2022–2023. Fifty students were purposively selected and randomly assigned into two groups of 25 each. The TLM group was taught through lecture-discussion and chalkboard demonstrations, while the GeoGebra group used interactive software for dynamic visualization. Results showed that in the first trial run, the TLM group improved from 28.18% (Low Mastery) to 39.45% (Average Mastery), while the GeoGebra group increased from 30.27% (Low Mastery) to 68.71% (Moving Towards Mastery). In the second trial run, the TLM group advanced from 33.45% to 66.13%, whereas the GeoGebra group progressed from 35.76% to 80.21%. ANCOVA confirmed a statistically significant difference favoring GeoGebra ($p < 0.05$). Perception results revealed a grand mean of 3.17 (Moderately Perceived), with students strongly agreeing on GeoGebra's user-friendliness, motivational value, and effectiveness in visualizing graphs. Findings suggest that integrating GeoGebra enhances mastery, motivation, and engagement, making it a valuable instructional tool for strengthening mathematics learning.

Keywords: GeoGebra, functions and graphs, Mean Percentage Score, mathematics instruction, Senior High School

INTRODUCTION

Functions and graphs are a central component of the Senior High School (SHS) Mathematics curriculum under the Philippines' K to 12 Basic Education Program. They provide essential foundations for advanced courses such as calculus, statistics, and applied mathematics, while also serving as practical tools for real-world problem solving in areas like science, business, and engineering. More importantly, they cultivate higher-order thinking skills such as abstraction, reasoning, and problem-solving—competencies that are crucial for learners' success in both higher education and future STEM-related careers. In this sense, mastery of functions and graphs does not only fulfill curricular requirements but also contributes to equipping students with 21st-century skills.

Despite their importance, many Filipino SHS students find functions and graphs particularly challenging. Studies and classroom experiences consistently reveal difficulties in interpreting algebraic expressions, transitioning between symbolic and graphical forms, and sketching accurate graphs. The abstract nature of these concepts often leads to misconceptions and weak retention. Traditional Lecture Methods (TLM), which remain dominant in many mathematics classrooms, often emphasize teacher-centered delivery and static visual aids, such as chalkboard sketches or textbook diagrams. While these approaches can present procedures, they limit opportunities for exploration, discovery, and immediate feedback. Consequently, students may achieve surface-level familiarity but struggle with deeper conceptual understanding.

Dynamic mathematics software such as GeoGebra provides a potential solution to these learning difficulties. GeoGebra is a free, open-source application that integrates algebra, geometry, calculus, and graphing in a single interactive environment. Its dynamic interface allows students to manipulate parameters, visualize transformations in real time, and establish connections between algebraic and graphical representations. Through this process, abstract concepts become more concrete, fostering active learning and conceptual clarity. Research supports its effectiveness: Zulnaidi et al. (2020) emphasized that GeoGebra encourages mathematical discovery by linking algebra and geometry, while Tay et al. (2018) reported that students taught with dynamic software demonstrated greater motivation, achievement, and confidence compared to those instructed with traditional methods.

However, in many rural schools such as those in the Schools Division of Siargao, classroom practices remain heavily reliant on TLM. Limited access to technological resources, insufficient ICT infrastructure, and lack of teacher training hinder the integration of tools like GeoGebra. This situation reflects a broader issue of educational inequality, as learners in urban and well-resourced schools often benefit from innovative, technology-supported instruction, while those in rural settings continue to experience traditional, teacher-centered methods. The digital divide therefore contributes not only to disparities in access but also to differences in the quality of mathematics learning experiences.

In this context, the present study aims to evaluate the effectiveness of GeoGebra integration in teaching functions and graphs compared to the Traditional Lecture Method among SHS students at Dapa National High School. By examining both achievement outcomes and student perceptions, this study seeks to provide empirical evidence on the pedagogical benefits of GeoGebra in resource-constrained settings. The findings will be valuable to educators, curriculum developers, and policymakers, particularly in determining strategies to strengthen ICT integration in mathematics instruction. Ultimately, the study hopes to contribute to bridging the technological gap in education, ensuring that all students—regardless of geographic location—are given opportunities to develop mastery of fundamental mathematical concepts through innovative and equitable teaching practices.

Research Questions

This study sought to compare the effectiveness of GeoGebra and the Traditional Lecture Method (TLM) in teaching functions and graphs among Senior High School students of Dapa National High School, S.Y. 2022–2023. Specifically, it aimed to answer:

1. What are the Mean Percentage Scores (MPS) of students in the GeoGebra group and the Traditional Lecture group in the pretest and posttest during the first trial run?
2. What are the Mean Percentage Scores (MPS) of students in the GeoGebra group and the Traditional Lecture group in the pretest and posttest during the second trial run?
3. What are the students' perceptions of GeoGebra in terms of ease of use, visualization, and motivation?
4. Is there a significant difference between the students' posttest performance in the GeoGebra group and the Traditional Lecture group during the first and second trial runs?
5. Is there a significant difference in perceptions of instructional method (GeoGebra vs. TLM)?

RESEARCH METHODS

The researcher employed a quasi-experimental two-group pretest–posttest design. A total of 50 students participated in the study, all of whom were enrolled in the researcher's General Mathematics classes under the General Academic Strand (GAS), Grade 11. The participants were divided into two groups of 25 students each: one group was taught using the Traditional Lecture Method (TLM), while the other group was taught through the integration of GeoGebra.

The use of this design was considered appropriate for evaluating the effectiveness of GeoGebra in teaching functions and graphs, as it allowed for a systematic comparison of instructional outcomes between a technology-enhanced approach and a conventional lecture-based method. The sampling method was purposive, as the participants were already enrolled in General Mathematics where functions and graphs form a core component of the curriculum.

To strengthen the internal validity of the study, the allocation of participants to groups was randomized. This ensured that any observed differences in learning outcomes could be attributed with greater confidence to the instructional method employed rather than to pre-existing differences among students.

A pretest was administered to both groups prior to the intervention to establish a baseline measure of their achievement in functions and graphs. Following the pretest, each group underwent a two-week instructional intervention. The TLM group received lessons through lecture-discussion, textbook-based exercises, and chalkboard demonstrations, while the GeoGebra group engaged in interactive activities, parameter manipulation, and dynamic visualization of functions using the software.

After the intervention, a posttest was administered to both groups to assess learning gains. In addition, a four-point Likert-scale perception survey was given to the GeoGebra group to measure students' views on the tool's ease of use, ability to support visualization, and impact on motivation to learn mathematics.

This pretest–posttest design enabled the researcher to examine differences in achievement outcomes between the two groups and to evaluate the perceived effectiveness of GeoGebra as an instructional tool for teaching functions and graphs in General Mathematics.

Research Instrument

This study utilized two sets of researcher-made tests, one for the Traditional Lecture Method (TLM) group and another for the GeoGebra group. These instruments served as the primary research tools, administered as both pretests and posttests. Each test was constructed based on a Table of Specifications (TOS), ensuring alignment with the competencies of General Mathematics under the K to 12 curriculum, specifically focusing on functions and graphs (linear, quadratic, and exponential). The number of items was distributed according to the TOS to balance knowledge, comprehension, and application levels.

To assess students' achievement in both groups during the pretest and posttest, the Mean Percentage Score (MPS) was computed, and its descriptive equivalent was interpreted using guidelines from DepEd Memorandum No. 160, s. 2012, as shown in Table 1.

Table 1. Achievement Level

Mean Percentage Score (MPS)	Descriptive Equivalent
96-100	Mastered
86-95	Closely Approximating Mastery
66-85	Moving Towards Mastery
35-65	Average Mastery
15-34	Low Mastery
5-14	Very Low Mastery
0-4	Absolutely No Mastery

In addition, a four-point Likert scale questionnaire was employed to evaluate students' perceptions of GeoGebra in terms of ease of use, visualization, and motivation. The scale descriptors, parameters, verbal interpretations, and qualitative descriptions are presented in Table 2. To ensure reliability, the perception survey was subjected to pilot testing, and Cronbach's alpha was used to determine internal consistency, which yielded an acceptable reliability coefficient.

Table 2. Four-point Likert Scale

Scales	Parameters	Verbal Interpretation	Qualitative Description
4	3.25-4.00	Strongly Agree	Highly Perceived
3	2.50-3.24	Agree	Moderately Perceived
2	1.75-2.49	Disagree	Less Perceived
1	1.00-1.74	Strongly Disagree	Not Perceived at All

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue X October 2025

Data Analysis

The study used Mean and Standard Deviation to describe students' perceptions of GeoGebra based on the survey results. To compare achievement outcomes, a one-way Analysis of Covariance (ANCOVA) was employed to test significant differences in posttest scores between the GeoGebra and TLM groups while controlling for pretest performance. These statistical techniques provided a comprehensive evaluation of both the effectiveness and the usability of GeoGebra in the teaching and learning of functions and graphs.

RESULTS AND DISCUSSION

Students' Mathematics Performance

Table 3. Pretest and Posttest MPS during the first trial run

	Test	TLM (Control Group)			GeoGebra (Experimental Group)		
		MPS	Descriptive Equivalent	SD	MPS	Descriptive Equivalent	SD
1st Trial Run	Pretest	28.18%	Low Mastery	2.122	30.27%	Low Mastery	1.701
	Posttest	39.45%	Average Mastery	2.314	68.71%	Moving Towards Mastery	2.318
	MPS Increase	**11.27%**			**38.44%**		

Table 3 shows the students' mathematics performance test results in the Traditional Lecture Method (TLM) group and the GeoGebra group for the first trial run. In the first trial run, the integration of the Traditional Lecture Method (TLM) generated an MPS of *28.18% (SD=2.122)* in the pretest, whose descriptive equivalent is *low mastery*. The level of students' achievement increased by an MPS of *11.27%* in the posttest, with a resulting MPS of *39.45% (SD=2.314),* which is descriptively interpreted as *average mastery.* On the other hand, during the same trial run in the GeoGebra group, the pretest yielded an MPS of *30.27% (SD=1.701),* also equivalent to *low mastery*. The level of students' performance increased substantially by *38.44%* in the posttest, with a resulting MPS of *68.71% (SD=2.318),* which is descriptively interpreted as *moving towards mastery.*

The results indicate that while both groups demonstrated improvement from pretest to posttest, the GeoGebra group showed a much greater increase in mastery compared to the TLM group. This suggests that the integration of GeoGebra provided students with more effective tools for understanding and applying concepts on functions and graphs during the first trial run.

This finding supports the study of Abdullah et al. (2021) who reported that students exposed to GeoGebra achieved higher performance and motivation levels compared to those taught with traditional lecture methods. Likewise, Kumah and Wonu (2020) emphasized that GeoGebra fosters discovery learning by linking algebraic and graphical representations, thereby deepening conceptual understanding. Furthermore, Johar (2020) found that the dynamic features of GeoGebra significantly enhanced students' ability to comprehend and apply mathematical concepts, consistent with the improvements observed in this trial run.

Table 4. Pretest and Posttest MPS during the second trial run

	Test	TLM (Control Group)			GeoGebra (Second Experimental Group)		
		MPS	Descriptive Equivalent	SD	MPS	Descriptive Equivalent	SD
2nd Trial Run	Pretest	33.45%	Low Mastery	1.434	35.76%	Average Mastery	1.316
	Posttest	66.13%	Moving Towards Mastery	1.907	80.21%	Moving Towards Mastery	1.337
	MPS Increase	**32.68%**			**44.45%**		

Table 4 shows the students' mathematics performance test results in the Traditional Lecture Method (TLM) group and the GeoGebra group for the second trial run. In the second trial run, the Traditional Lecture Method (TLM) group obtained an MPS of *33.45% (SD=1.434)* in the pretest, which is descriptively equivalent to *low mastery*.

After the intervention, the students' performance increased by *32.68%* in the posttest, resulting in an MPS of *66.13% (SD=1.907)*, which is interpreted as *moving towards mastery*. On the other hand, the GeoGebra group recorded an MPS of *35.76% (SD=1.316)* in the pretest, whose descriptive equivalent is *average mastery*. The level of students' achievement increased by *44.45%* in the posttest, with a resulting MPS of *80.21% (SD=1.337)*, also interpreted as *moving towards mastery*.

The results reveal that both groups improved significantly from pretest to posttest during the second trial run. However, the GeoGebra group exhibited a larger gain in performance compared to the TLM group, indicating that the use of dynamic visualization tools further strengthened students' conceptual understanding and graphing skills in functions. This finding is consistent with Uwurukundu et al. (2020) who reported that GeoGebra significantly enhances both conceptual and procedural knowledge in mathematics. Similarly, Baye et al. (2021) emphasized that GeoGebra's integration of algebraic and graphical representations allows learners to engage in mathematical discovery, leading to deeper understanding.

Table 5. Perceived ease of use of GeoGebra of the experimental group

Ease of Use	Mean	SD	Verbal Interpretation	Qualitative Description
1. I found GeoGebra easy to navigate.	3.35	.763	Strongly Agree	Highly Perceived
2. I was able to learn the basic functions of GeoGebra quickly.	3.06	.224	Agree	Moderately Perceived
3. I felt comfortable using GeoGebra without constant assistance.	2.96	.975	Agree	Moderately Perceived
4. The layout and interface of GeoGebra were user-friendly.	3.48	.652	Strongly Agree	Highly Perceived
5. I could visualize mathematical functions and graphs more clearly using GeoGebra.	3.17	.453	Agree	Moderately Perceived
6. I was motivated to learn mathematics through the use of GeoGebra.	3.28	.213	Strongly Agree	Highly Perceived
7. I could complete mathematical tasks and activities more efficiently with GeoGebra compared to traditional methods.	2.78	.456	Agree	Moderately Perceived
8. GeoGebra helped me better understand the relationship between functions and their corresponding graphs.	3.03	.513	Agree	Moderately Perceived
9. The use of GeoGebra made learning functions and graphs more interesting and engaging.	3.33	.331	Strongly Agree	Highly Perceived
10. I would recommend the use of GeoGebra for learning other mathematical concepts	3.27	.676	Strongly Agree	Highly Perceived
Grand Total	**3.17**	**.526**	**Agree**	**Moderately Perceived**

Table 5 presents the perceived ease of use of GeoGebra among the experimental group based on ten indicators. Overall, the results showed a grand mean of *3.17 (SD = .526)*, verbally interpreted as *Agree* and qualitatively described as *Moderately Perceived*. This suggests that students generally viewed GeoGebra as a useful and moderately easy-to-use tool for learning functions and graphs.

Specifically, students strongly agreed that GeoGebra was easy to navigate *(M = 3.35, SD = .763)*, that its layout and interface were user-friendly *(M = 3.48, SD = .652)*, that it motivated them to learn mathematics *(M = 3.28, SD = .213)*, that it made learning functions and graphs more interesting *(M = 3.33, SD = .331)*, and that they would recommend its use for other mathematical concepts *(M = 3.27, SD = .676)*. These findings align with Badu-Domfeh (2020) who emphasized that GeoGebra's dynamic interface supports mathematical discovery and promotes student engagement. Similarly, Makandidze (2020) found that students exposed to GeoGebra reported higher levels of motivation and interest in learning compared to those taught through traditional approaches.

Meanwhile, students agreed that they were able to learn the basic functions of GeoGebra quickly *(M = 3.06, SD = .224)*, that they felt comfortable using the software without constant assistance *(M = 2.96, SD = .975)*, that they could visualize mathematical functions more clearly with GeoGebra *(M = 3.17, SD = .453)*, that GeoGebra helped them understand the relationship between equations and graphs *(M = 3.03, SD = .513)*, and that they could complete tasks more efficiently with GeoGebra compared to traditional methods *(M = 2.78, SD = .456)*. These moderately perceived indicators suggest that although GeoGebra enhanced conceptual understanding, some students required additional support in navigating the tool's more advanced features. This is consistent with Mosese and Ogbonnaya (2021) who noted that while GeoGebra improves comprehension of mathematical concepts, its effective use often depends on sufficient scaffolding and teacher guidance.

Generally, the findings indicate that GeoGebra was perceived as an engaging and effective instructional tool, particularly in enhancing visualization and student motivation. However, the moderately perceived indicators point to the need for continuous scaffolding and teacher training to maximize the benefits of integrating GeoGebra into mathematics classrooms, echoing the recommendations of Alcantara (2020) regarding ICT integration in mathematics instruction.

Table 6. One-way ANCOVA tested the significant difference between the students' posttest performance in the control group and experimental group during the first trial run.

Source	Type III Sum of Squares	Df	Mean Square	F-ratio	p-value
Corrected Model	128.288[a]	2	68.798	3.464	0.015
Intercept	1032.763	1	1011.782	62.187	0.001
Covariate	118.416	1	113.451	6.432	0.013
Application Used	11.132	1	10.877	.532	0.048
Error	379.007	57	13.221		
Total	23377.000	60			
Corrected Total	1651.482	59			

a. *R squared=.143 (Adjusted R Squared=.112) *p-value=.05 (Significant Difference)*

First Trial Run. Table 6 shows the results of the one-way ANCOVA that tested the significant difference between the students' posttest performance in the control group (TLM) and the experimental group (GeoGebra) during the first trial run.

The analysis revealed that the application used (TLM vs. GeoGebra) had a p-value of *0.048*, which is less than the 0.05 level of significance. This indicates that there is a statistically significant difference between the posttest performances of the two groups after controlling for pretest scores. In other words, the method of instruction had a significant effect on the students' achievement in functions and graphs during the first trial run.

The results suggest that students in the GeoGebra group performed significantly better than those in the TLM group, consistent with the descriptive findings in Table 3. This finding aligns with Abdullah et al. (2021) who found that dynamic software like GeoGebra improves student performance compared to traditional lecture methods. Similarly, Bullock et al. (2021) emphasized that GeoGebra fosters conceptual and procedural understanding, leading to higher achievement. The outcome also echoes Minarni (2019), who noted that dynamic visualization allows students to explore and connect mathematical representations more effectively than static board work.

In summary, the ANCOVA results confirm that the integration of GeoGebra into classroom instruction produced a significant positive impact on students' learning outcomes in functions and graphs compared to the Traditional Lecture Method during the first trial run.

Table 7. One-way ANCOVA tested the significant difference between the students' posttest performance in the control group and the experimental group during second trial run.

Source	Type III Sum of Squares	Df	Mean Square	F-ratio	p-value
Corrected Model	42.143[a]	2	13.056	3.207	0.017
Intercept	1173.122	1	117.123	198.011	0.003
Covariate	32.816	1	33.838	5.364	0.015
Application Used	4.789	1	4.689	.736	0.019
Error	218.186	57	4.237		
Total	30280.016	60			
Corrected Total	312.520	59			

a. *R squared=.103 (Adjusted R Squared=.071) *p-value=.05 (Significant Difference)*

Second Trial Run. Table 7 shows the results of the one-way ANCOVA that tested the significant difference between the students' posttest performance in the control group (TLM) and the experimental group (GeoGebra) during the second trial run. The analysis revealed that the application used (TLM vs. GeoGebra) had a p-value of *0.019*, which is less than the 0.05 level of significance. This result indicates that there was a statistically significant difference between the posttest performances of the two groups after controlling for pretest scores. Thus, the instructional method again had a significant effect on students' achievement in functions and graphs during the second trial run.

Consistent with the findings in Table 4, the GeoGebra group demonstrated stronger posttest performance compared to the TLM group. This reinforces the conclusion that the integration of GeoGebra in teaching functions and graphs was more effective in enhancing student learning outcomes. The finding supports Joshi and Singh (2020) who highlighted that GeoGebra's dynamic features promote deeper comprehension of mathematical concepts. It also aligns with Kumah and Wonu (2020), who emphasized that linking algebraic and graphical representations through dynamic visualization enhances conceptual understanding.

Generally, the ANCOVA results confirm that during the second trial run, as in the first, the use of GeoGebra had a statistically significant positive effect on students' posttest performance compared to the Traditional Lecture Method.

SUMMARY

The study found that students in the TLM group improved from a low mastery level with a pretest mean percentage score (MPS) of 28.18% to a posttest MPS of 39.45%, indicating average mastery. Meanwhile, the GeoGebra group improved from a pretest MPS of 30.27% (low mastery) to a posttest MPS of 68.71%, equivalent to moving towards mastery. In the second trial run, the TLM group progressed from a pretest MPS of 33.45% (low mastery) to a posttest MPS of 66.13% (moving towards mastery), reflecting an increase of 32.68%. In comparison, the GeoGebra group advanced from a pretest MPS of 35.76% (average mastery) to a posttest MPS of 80.21% (moving towards mastery), reflecting a higher gain of 44.45%. Both groups demonstrated improvement after instruction, but the GeoGebra group consistently achieved greater learning gains.

In terms of perceptions, students in the GeoGebra group reported a grand mean score of *3.17,* interpreted as *Agree* and qualitatively described as *Moderately Perceived*. They strongly agreed that GeoGebra was easy to navigate, user-friendly, motivating, engaging, and recommended for other mathematical concepts, but only moderately perceived their ability to work independently and efficiently with the tool. These results suggest that while GeoGebra enhanced visualization and interest in learning, some students required additional scaffolding and teacher support in using the software effectively.

Statistical analysis through ANCOVA revealed that in both the first trial run ($F = 3.464$, $p = 0.048$) and the second trial run ($F = 3.207$, $p = 0.019$), there was a statistically significant difference in posttest performance between the two groups after controlling for pretest scores. This confirmed that the use of GeoGebra had a significant positive effect on students' achievement in functions and graphs compared to the Traditional Lecture Method.

CONCLUSIONS

The findings of this study demonstrate that the integration of GeoGebra as a dynamic mathematics software can significantly enhance students' performance in learning functions and graphs. The results showed a statistically significant difference in posttest performance between the GeoGebra group and the Traditional Lecture Method (TLM) group across both trial runs, indicating that GeoGebra provided more effective support in developing conceptual understanding and graphing skills. By allowing students to manipulate parameters, visualize transformations in real time, and explore mathematical representations interactively, GeoGebra enriched the learning experience and helped bridge gaps in students' comprehension.

These results underscore the potential of GeoGebra as an effective instructional tool for Senior High School mathematics. While both TLM and GeoGebra-based instruction improved student performance, GeoGebra's dynamic visualization features and higher perception ratings in terms of usability, motivation, and engagement suggest that it offers distinct advantages in promoting deeper understanding and sustained interest in mathematics. The study affirms that integrating GeoGebra into classroom practice not only supports mastery of functions and graphs but also cultivates 21st-century learning skills such as problem-solving, critical thinking, and digital literacy.

RECOMMENDATIONS

In view of the findings and conclusions of the study, the following recommendations are proposed:

1. Teachers should be encouraged to integrate GeoGebra in teaching functions and graphs. Careful planning of lessons and scaffolding strategies are needed to maximize the software's dynamic features and provide students with meaningful opportunities for conceptual understanding and performance improvement.
2. School administrators should provide continuous professional development programs, such as training workshops and seminars, to equip teachers with the necessary skills to effectively utilize GeoGebra in classroom instruction. Strengthening ICT integration will not only improve students' mathematics achievement but also prepare them for the demands of 21st-century learning.
3. Future researchers are encouraged to conduct qualitative studies on the integration of GeoGebra in mathematics instruction, focusing on students' and teachers' experiences, challenges, and strategies. Additionally, similar studies may be replicated across other strands, grade levels, or mathematical topics to further validate the effectiveness of GeoGebra in diverse contexts

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