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Research Article

Enhancing Performance in Learning Calculus 1 Through Integration of Technology

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ABSTRACT

This study compared the effectiveness of implementing the GeoGebra, which is a dynamic mathematics software, in the teaching of the Polynomial Curve Sketching (PCS) module of Calculus 1. More specifically, it aimed at determining if there was any improvement in students' achievement in graphing polynomials after using GeoGebra as compared to traditional teaching and also at finding out the students' learning experiences after the intervention. This study was carried out as a classroom-based action research using a quasi-experimental pre test-post test comparison design with the two intact classes of first year Bachelor of Science in Mathematics students from Bulacan State University. Control group= 55 students, experimental group= 55 students. The intervention took place in a 5-hour teaching unit, within one week. Students' achievement was assessed by researcher-made pretest and posttest on Polynomial Curve Sketching and Focus Group Discussions (FGD) were carried out to gain qualitative information about students' experiences of using GeoGebra. The results showed that both groups made progress following instruction but that the experimental group made greater progress on the post test than the control group. The experimental group increased from a mean pretest score of 4.4520 (SD = 2.1068) to a mean posttest score of 10.0302 (SD = 1.9881), whereas the control group improved from a mean pretest score of 4.1241 (SD = 1.6123) to a mean posttest score of 7.4733 (SD = 3.0592). The results of statistical analysis showed that the integrated lesson using GeoGebra in the Polynomial Curve Sketching lesson, resulted in the achievement of students' learning immediately after the lesson, which was greater than the achievement of students who did not use the GeoGebra application in the learning process. The qualitative results also showed that the students showed their conceptual understanding with GeoGebra as a learning tool for visualizing the graphs of polynomials, as well as for solving problems in the lesson and engaging in the lesson. However, students also voiced their worries about reliance on technology, access to digital devices, and the need for traditional graphing proficiency. The conclusions drew from the findings indicate that GeoGebra is a good auxiliary teaching aid for

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Polynomial Curve Sketching and can be applied in similar teaching that needs to use a graphical method and exploratory thinking.

Keywords: *action research, calculus 1, geogebra, mathematics education, polynomial curve sketching, technology integration*

Introduction

Calculus is one of the most basic and important areas of mathematics and serves as the foundation for further study and research in science, engineering, technology, and other quantitative fields. It cultivates students' analytical thinking, mathematical modeling skills, and problem-solving skills, which are important aspects of undergraduate mathematics education (Stewart, 2015). Although important, many students in learning calculus have difficulties due to the abstract concepts, symbolic representations, and the need to connect algebraic, graphical, and analytical ways of thinking. These learning challenges can lead to misunderstandings, poor academic performance, and decreased confidence in their ability to solve mathematical problems (Esquibel, 2019).

The recent advancements in educational technology have revolutionized the teaching of mathematics by creating interactive learning spaces that help students visualize, explore, and develop conceptual understanding. In this group of technologies, GeoGebra has emerged as one of the most popular dynamic mathematics software applications due to its ability to combine algebraic, graphical, geometric, and calculus representations into a single learning environment (Hohenwarter & Preiner, 2020). Dynamic visualization also allows students to interact with mathematical objects, see changes in the visuals almost instantaneously, and see relationships among various mathematical concepts that may be hard to understand through traditional teaching methods. Past research has consistently shown that, when used correctly, technology can be a supportive tool in mathematics instruction to improve students' conceptual understanding, mathematical reasoning, and classroom engagement (Sim & Tan, 2021).

Visualization is a key skill in Calculus 1, especially in Polynomial Curve Sketching. In this topic, students will examine polynomial functions, determining their intercepts, turning points, intervals on which they increase and decrease, intervals on which they are concave up and concave down, and end behavior, in preparation for sketching accurate graphs. These ideas are used in the development of topics that follow in calculus, but many students struggle to visualize symbolic solutions. Board-based teaching sometimes restricts opportunities for students to see the 'big picture' of how varying algebraic expressions affect the shape of the polynomial graph. It is therefore possible for students to correctly execute algebraic operations without, at the same time, building an explanatory understanding. It is therefore possible that students can correctly execute algebraic procedures without, at the same time, building an explanatory understanding.

To tackle these challenges, GeoGebra provides instructional features that enable students to dynamically build and manipulate graphs while watching the associated algebraic representations appear and disappear. Immediate visual feedback allows students to check their work and understand their misconceptions, and provides them with many more scenarios to graph than they could build manually. These interactive learning environments stimulate active learning and deepen conceptual understanding of mathematical relationships (Hohenwarter & Preiner, 2020). GeoGebra is not a substitute for standard mathematical procedures; rather, it is a tool that can aid the teaching-learning process, allowing students to see the symbolic manipulation of algebraic expressions in the light of their graphical interpretation.

The use of GeoGebra in mathematics education has been proven through several studies. Previous studies found that using GeoGebra in the classroom positively affects students' mathematical achievement, conceptual understanding, visualization skills, and learning engagement (García, 2022). Similarly, it has been reported that the software creates an interactive learning environment that allows exploration, provides instant feedback, and supports cooperative learning, leading to better learning. However, most of the literature so far has focused on the use of GeoGebra across an entire mathematics or calculus course and for a considerable time in the classroom. Few studies have evaluated its effectiveness in an individual instruction module within the context of regular classroom teaching.

To address this need, the current research will focus on the Polynomial Curve Sketching module in Calculus 1. Rather than looking at the general impact on students' performance or attitudes towards calculus, the study focused on the short-term impact of GeoGebra integration in a 5h course compared to a 1w week course. The study also emphasizes a specific lesson, enabling a better assessment of GeoGebra's contribution to the teaching and learning process in an actual classroom. This targeted reporting also provides a clearer context for interpreting results in terms of the intervention's length and prevents conclusions that go beyond what the gathered evidence can support.

In particular, the study aimed to address the following research questions:

1. What were the students' pretest and posttest achievement scores for the Polynomial Curve Sketching module? .
2. What were the differences in achievement level of students in conventional learning and in GeoGebra learning?
3. What were students' learning experiences when using GeoGebra in the Polynomial Curve Sketching lesson?

This study's results are useful for mathematics teachers, as they provide evidence for the effective use of the GeoGebra tool in mathematics instruction, especially in graphing-related lessons. The findings could also help curriculum developers and schools to develop technology-enhanced teaching methods that enable students to deepen their mathematical knowledge. Secondly, the study is a contribution to the literature on technology integration because of the insight it offers into how a targeted intervention in one classroom can help enhance learning in a specific topic within the calculus curriculum and how to apply that information in future classroom-based action research.

Materials and Methods

Research Design

The methodology used in this study is based on the classroom-based action research model, which was used to improve the Polynomial Curve Sketching module in the Calculus 1 class by integrating GeoGebra. The use of action research was deemed appropriate to address a difficulty identified in the classroom and to assess the effectiveness of an innovative program of instruction being implemented in the context of the researchers' teaching. The study was conducted using the action research process, which includes the following steps: defining the instructional problem, designing an intervention, implementing the intervention, monitoring students' learning outcomes, and reflecting on the intervention's effectiveness to inform future instruction.

To check the effectiveness of the intervention, this study used the quasi-experimental pretest-posttest comparison design with two intact classes. The conventional instruction was given to one class (control group), and the conventional instruction integrated with GeoGebra was given to the other class (experimental group). Given the fact that the classes already were in place before the intervention, and random assignment was not possible, the quasi-experimental method was appropriate for comparing the learning outcomes of the two instructional methods. The quantitative results were further corroborated with the qualitative data collected from Focus Group Discussions (FGD) with students in the school, which enabled the researchers to visit the students' classroom learning experiences in addition to their achievement.

Research Participants

The students included in the study were the first year Bachelor of Science in Mathematics students attending the Calculus 1 course for the first semester of the Academic Year 2022-2023 of Bulacan State University. The study was conducted with two whole classes. In this study, the control group consisted of 55 students who were taught using traditional teaching method, and the experimental group consisted of 55 students who were taught using GeoGebra as an assistant teaching tool in the classroom. This meant that there were 110 students taking part. The instructional intervention was directed only at the Polynomial Curve Sketching unit of Calculus 1. GeoGebra was mainly used to assist students in visualization of graphs, graphical analysis and exploration of concepts, but not instead of their manual mathematical procedures.

Sampling Technique

The study employed convenience sampling because the participants were selected from existing Calculus 1 classes handled during the regular academic semester. The intact classes were assigned as the control and experimental groups based on existing class sections, making random assignment impractical within the normal instructional setting.

Research Instruments

A combination of quantitative and qualitative research instruments were used in the study. The quantitative test was a researcher-designed multiple-choice achievement test, which included 15 items, used for both pretest and posttest. The test focused particularly on the students' knowledge and understanding of the module Polynomial Curve Sketching, graph interpretation, critical points, intervals of increase and decrease, concavity and graph construction. The instrument was expertly validated to obtain content validity before administration.

The qualitative part was done using Focus Group Discussion (FGD) guides to collect reflections from students about their learning experiences using GeoGebra. Students' views on the usefulness of the software, its role in conceptual understanding, and the difficulties faced in implementation, together with recommendations for enhancing technology-assisted instruction, were discussed.

Data Collection Procedure

Before the intervention, both control and experimental groups took the pretest to establish pretest levels of understanding of the Polynomial Curve Sketching lesson. Then, the control group was instructed using the traditional lecture-discussion method, and the experimental group was instructed by providing demonstrations and guided graphing activities in GeoGebra for the same instructional content. The experimental group performed the following tasks throughout the lesson using GeoGebra: visualization of polynomial functions, exploration of graphical features and the verification of mathematical solutions.

All students completed the posttest immediately after the instructional module on the same achievement instrument. The posttest was employed to assess the impact of the instructional intervention immediately after the lesson targeted for the students' achievement was delivered.

After data collection on the quantitative data, Focus Group Discussions were held for selected students of the experimental group. Students' learning experiences, perceived benefits, challenges they faced while using GeoGebra, and recommendations for better integrating technology in mathematics teaching were discussed. The qualitative results were used to complement and explain the quantitative results.

Data Analysis

Students' achievement was summarized using descriptive statistics (frequency counts, percentages, means and standard deviations) before and after the intervention.

Independent-samples t tests were used to compare means of the control and experimental group while paired-samples t tests were used to establish if there were significant differences between the pretest and posttest scores for each group. To verify the statistical assumptions, the Levene's Test for Equality of Variances was performed before the independent-samples t-test was used to test the difference of means.

Thematic analysis was used to analyze qualitative data from the Focus Group Discussions. The students' answers were recorded, coded, clustered into common themes and then synthesized into overarching themes that characterized the students' experiences with GeoGebra during the Polynomial Curve Sketching lesson. The analysis was not designed to provide single answers but to seek for commonalities and similar experiences between the participants.

Ethical Considerations

Before collecting the data, the permission was granted by the relevant University authorities. Students were informed of the purpose of the study, that participation was voluntary and free of any academic implications if they chose to withdraw at any time. Achievement tests and Focus Group Discussions were both conducted with informed consent.

The anonymity and confidentiality of the students was ensured throughout the study by keeping students' identities confidential in any report or publication. All data gathered had been used only for research purposes, and all data had been managed in the manner acceptable to educational research.

Results and Discussions

The student performance results for five increasingly difficult polynomial curve sketching problems completed following the instructional intervention are shown in the table below (Table 1). The findings reveal that there is a clear distinction between the level of task completion of the control and experimental group. Students with the conventional teaching approach tended to solve less problems correctly, while students who were taught with the aid of GeoGebra were more successful solving more difficult graphing tasks.

Table 1. Students' Performance on Polynomial Curve Sketching Tasks

	Number of Students					Total
	Solved Problem No.1 only	Solved Problem Nos. 1 & 2 only	Solved Problem Nos. 1, 2 & 3 only	Solved Problem Nos. 1, 2, 3 and 4	Solved Problem Nos. 1, 2, 3, 4, 5	
Control Group	1	23	28	2	1	55
	1.82%	41.20%	50.91%	3.64%	1.82%	100%
Experimental Group	0	0	17	27	11	55
	0%	0%	30.91%	49.09%	20%	100%

The results indicated that the use of GeoGebra has improved the students' skills in interpreting polynomial functions and making correct sketching. The software allowed students to explore important aspects of a graph (such as turning points, intercepts, and the nature of the polynomial function) while minimizing the cognitive effort required for graphing. Students did not need to spend a significant amount of time drawing the graphs; instead they spent time interpreting mathematical relationships and checking the validity of their answers.

The results of the experimental group were better than that of the control group, suggesting that technology-based visualization can contribute to the conceptual understanding of polynomial graphing. GeoGebra became an instructional scaffold to assist students in linking algebraic procedures with their graphical representations. This is significant because Polynomial Curve Sketching is an important skill that needs students to be able to combine symbolic manipulation and visual interpretation, which is a skill area that many students find difficult.

The results are aligned with those of earlier research that has found that GeoGebra can assist teachers in the teaching and learning of mathematics by fostering conceptual understanding, mathematical visualization, and active learning (Abdullah, 2020; García-García et al., 2022; Sim & Tan, 2021). This work extends this existing set of evidence by showing that even in a five hour instructional unit, using GeoGebra in the Polynomial Curve Sketching lesson can enhance students' on-task performance in graphing related tasks. It is important to note that this intervention was conducted in one instructional module; the results should only be interpreted as evidence of the effectiveness of GeoGebra in this topic and not as evidence of long-term gains in students' overall achievement in Calculus 1.

Table 2 shows the descriptive statistics of the pre-test scores of the control group and experimental group before the implementation of the instructional intervention. The results show the prior knowledge of both groups was similar prior to the start of instruction in the Polynomial Curve Sketching module. Minimal differences in the mean scores were detected, but these differences were small and indicate a similar academic preparedness for the two groups beginning the study.

Table 2. Comparison of Pre-test Scores Between the Control Group and the Experimental Group

Group Statistics					
Grouping Variable		N	Mean	Std. Deviation	Std. Error Mean
Pre-test Scores	Control group	55	4.1241	1.6123	.2176
	Experimental group	55	4.4520	2.1068	.2840

For quasi-experimental studies, a comparable baseline performance is crucial as it enhances the validity of the subsequent comparisons between the groups. Any difference in students' mathematical knowledge that is revealed in the post-test is more likely to be due to the instructional approach than to pre-existing differences in students' mathematical knowledge.

The distribution of scores also seems to be similar in the pretest and posttest, indicating that the group had different knowledge about polynomial graphing before the intervention, which is similar to what is common in undergraduate math classrooms. The baseline similarity allowed the effectiveness of the integration of GeoGebra in the classroom to be assessed.

Overall, the pre-test results suggest that both groups started the project with similar learning conditions, thus facilitating the evaluation of the learning trajectory followed in the Polynomial Curve Sketching lesson.

The results of the independent-samples t-test performed to check for any significant difference between the pre-test scores of the control and experimental groups before the instructional intervention was given are shown in Table 3. Results showed no difference between the two groups prior to the intervention. The students had similar background knowledge and understanding about the Polynomial Curve Sketching module prior to the study.

Table 3. Independent Samples Test Comparing the Pre-test Scores of the Control and Experimental Groups

		Levene's test of equality of Variance		t- test for equality of means		
		F	Sig	T	df	Sig (2-tailed)
Pre test Scores	Equal variances assumed	3.060	.071	-.902	108	.324
	Equal variances not assumed			-.902	92.72	.322

This finding confirms the assumption that the two intact classes were academically equated prior to the use of the instructional strategies. Thus, any meaningful pre–post differences that are detected are less likely to be driven by pre-existing differences in mathematical ability among students and more likely to be due to the teaching strategies used during the intervention.

Moreover, the non-significant result adds to the internal validity of the quasi-experimental component of the study by showing equivalence across groups at baseline. Comparable pre-intervention performance is an important prerequisite to the assessment of the effectiveness of an educational intervention because it makes it less likely that performance differences attributable to students' performance at the start of the intervention are responsible for the difference at the end of the intervention.

The overall results show that the students in both groups started with similar academic conditions thus giving a proper ground for evaluating the impact of using GeoGebra in the lesson of Polynomial Curve Sketching.

The descriptive data for the post test scores of the control and experimental groups as obtained at the end of the instructional intervention is given in Table 4. The findings show that students in the Polynomial Curve Sketching module implemented with GeoGebra had better academic achievement than students taught in the traditional method. This finding indicates that the study of polynomial graphing concepts with the aid of GeoGebra in classroom activities was able to give extra support to the learning process, making it easier for students to learn.

Table 4. Comparison of the Post-test Scores Between the Control Group and the Experimental Group

Group Statistics					
Grouping Variable		N	Mean	Std. Deviation	Std. Error Mean
Post Test Scores	Control Group	55	7.4733	3.0592	0.4128
	Experimental Group	55	10.0302	1.9881	0.2681

Experimental group results showed greater performance in the post test, suggesting that the dynamic visualization characteristics of GeoGebra facilitated the students to relate graphically with algebraically in a better way. The ability to see the immediate effect of changing mathematical expressions in a polynomial graph encouraged learners to grasp the meaning of the mathematical expressions beyond the procedures of calculating. This, in turn, enabled pupils to explore features of graphs, to check their solutions, and to compare algebra and graph representations of relationships.

The other interesting finding is the relative uniformity of the performance of students in the experimental group. This indicates that the technology-supported instruction was successful not only for the high-achieving students, but also for students of all ability levels. The interactive learning environment allowed for feedback and visual confirmation immediately after, which might have limited misconceptions and helped to build students' confidence in the task of graphing.

The results of the descriptive analysis showed that in general the use of GeoGebra in learning activities Polynomial Curve Sketching helped to improve the immediate learning results. The differences in these observations are, however, more properly assessed by the independent-samples t-test shown in the following table.

The results of the independent-samples t-test performed to ascertain whether the difference observed between the post-test scores of the control group and the experimental group was statistically significant are presented in Table 5. The results reveal that the students' performance in the GeoGebra instructional approach is significantly higher compared to the students' performance in the conventional instructional approach. This finding indicates that there was an impact on the students' immediate learning achievements when the GeoGebra was integrated into the Polynomial Curve Sketching lesson.

The difference in the two groups is quite large, thereby substantiating the effectiveness of the technology-assisted instruction in enabling the conceptual understanding of polynomial graphing. Using GeoGebra, students could dynamically explore relationships between algebraic expressions and their graphical representations to validate solutions, identify behavior of the graphs and develop a deeper understanding of the concepts they were learning about. The enhanced learning effects of the experimental group might have been influenced by opportunities for visualization and instant feedback.

Table 5. Independent Samples Test Comparing the Post-test Scores of the Control and Experimental Groups

		Levene's test of equality of Variance		t- test for equality of means		
		F	Sig	t	df	Sig (2-tailed)
Posttest Scores	Equal variances assumed	30.647	0.000	- 8.022	108	0.000
	Equal variances not assumed			- 8.022	92.72	0.000

The results are corroborated with similar studies which showed that the use of Dynamic Mathematics Software improves students' conceptual understanding and mathematical achievement because it helps them to be active and visual learners (Abdullah, 2020; García-García et al., 2022; Sim & Tan, 2021). However, the results are only applicable to the Polynomial Curve Sketching lesson and not to the whole Calculus 1 course.

The control group results are shown in table 6 before and after the conventional instruction of the Polynomial Curve Sketching lesson. The results showed that students' improvement after instruction, meaning the traditional lecture-discussion method was effective in the learning of students to improve their understanding of the content of the lesson.

Table 6. Comparison of the Pre-test and Post-test Scores of the Control Group

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Posttest Control Group	7.4733	55	3.0592	0.4128
	Pretest Control Group	4.1241	55	1.6123	0.2176

The observed improvement is indicative of the benefit of systematic classroom instruction in building students' knowledge and understanding of polynomial graphing procedures. They could enhance their performance after the lesson by interpreting teacher explanations, working through examples, and practising guided examples. This discovery highlights the continued significance of traditional teaching methods in mathematics education, especially in the context of systematic classroom practice and opportunities for application.

While improvement was seen within the control group, the magnitude of learning gains needs to be interpreted in conjunction with the results of the experimental group, in order to evaluate the added instructional value of tech nology-assisted instruction over traditional instruction techniques.

Table 7 shows the comparison of the achievement of the experimental group before and after the use of GeoGebra in the Polynomial Curve Sketching lesson. The results showed that students' performance after the module is quite good, this meant that the instructional intervention could help students when learning during the instructional module, so that the students' performance in post test is significantly improved after the module was carried out.

The results of the experimental group show improvement, which can be explained by the interactive learning environment that GeoGebra has created. The software enabled students to interact with polynomial functions and see the change in the graph in real-time, providing them with a connection between symbolic procedures and the graphical interpretation of the functions. The use of several mathematical representations allowed students to interact with the concepts, self-check solutions and gain deeper understanding of polynomial graphing.

Table 7. Comparison of the Pre-test and Post-test Scores of the Experimental Group

		Mean	N	Standard Deviation	Std. Error Mean
Pair 1	Posttest Experimental Group	10.0302	55	1.9881	0.0268
	Pretest Experimental Group	4.4520	55	2.1068	0.2840

Furthermore, the graphical and interactive capabilities of GeoGebra could have made graphing less cognitive load as students could make a greater effort into the interpretation of the mathematical relationships instead of only on the computation. Consequently, students' achievement increased post intervention.

The results are in line with the previous studies which suggested that the technology-assisted instruction is effective in enhancing mathematical visualization, conceptual understanding and engagement in the classroom (Abdullah, 2020; Hohenwarter & Preiner, 2020; Sim & Tan, 2021). However, it should be noted that this slight improvement was seen over a relatively short period of time and should be treated as evidence that the intervention using GeoGebra was effective in the Polynomial Curve Sketching module and not as evidence for overall improvements in students' performance in Calculus 1.

The findings from the paired-samples t-test performed to test the significance of the changes in the scores of the control group when they were taught the conventional method in the Polynomial Curve Sketching lesson are summarized in Table 8 below. An analysis of students' scores reveals that there is a statistically significant difference between students' post-test and pre-test scores, thus, the traditional instructional approach has a positive effect on student achievement of the lesson.

Table 8. Paired Samples Test Between the Pre-test and Post-test Scores of the Control Group

		Paired Differences							
		Mean	Std Deviation	Std Error Mean	95% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Post test Control Pre test Control	3.3492	3.4473	.4699	-4.7219	11.4203	17.183	54	.000

The results obtained from the improvement in the control group indicate that the traditional teaching model is still effective in cultivating the students' knowledge of the concepts of graphing polynomials. During the teaching period, students used discussions facilitated by teachers, worked examples, and activities in the classroom to reinforce both their procedural and conceptual understanding.

However, the findings of the control group should be taken in conjunction with that of the experimental group. Conventional instruction improved students' achievement results, but the comparison of the groups gives a better understanding of whether the integration of GeoGebra had educational benefits beyond that provided by traditional instruction.

The results indicate that the structured classroom instruction has a significant contribution on enhancing the students' understanding on mathematical concepts. But technology-assisted teaching can enhance learning by adding to the graphing process by allowing students to visualize and explore without having to go through the process of graphing by hand.

Table 9 shows the outcome of the paired-samples t-test for pre and post-test scores of the experimental group after implementing GeoGebra in the Polynomial Curve Sketching lesson. The results of the analysis show that there was a statistical significance in the improvement of students' achievement after the instructional intervention, which shows that GeoGebra was an effective tool in supporting students' learning in the targeted instructional module.

Table 9. Paired Samples Test Between the Pre-test and Post-test Scores of the Experimental Group

		Paired Differences							
		Mean	Standard Deviation	Std Error Mean	95% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Posttest Experimental Pretest Experimental	5.5782	2.9465	.3996	-6.0366	17.193	29.058	54	.000

The interactive capabilities of GeoGebra helped students gain a deeper understanding of the concepts of graphing polynomials, which is reflected in the significant improvement of achievement. The software connected algebraic expressions with its graphical counterparts in a dynamic way, helping students to explore the relationship between the two, to check their answers, and to see the changes if they change the polynomial functions. These learning experiences probably helped to reinforce students' concepts and mitigate frequent misconceptions in manual graphing.

In addition, the technology-based teaching-learning setting fostered student active learning by enabling students to explore mathematical ideas and to get immediate visual instruction. This opportunity for exploration and self-verification could have been used to build students' self-confidence in solving graphing problems and could have helped improve their post-test performance.

The result corroborates previous studies that proved that dynamic mathematics software can stimulate students' interest in learning mathematics, improve students' conceptual understanding and visualization of mathematics concepts (Abdullah, 2020; García-García et al., 2022; Hohenwarter & Preiner, 2020). The findings in this study imply GeoGebra was effective to be used in teaching Polynomial Curve Sketching as an instructional support. It is important to note, however, that this intervention took place in one lesson that lasted five hours and was completed within 1 week, so the results are not necessarily representative of any sustained effect of this intervention on students' overall achievement in Calculus 1.

Students' Perceptions and Insights about the use of GeoGebra during the Polynomial Curve Sketching Lesson. The results of the Focus Group Discussions (FGDs) indicated that overall the students' perception of GeoGebra as a teaching aid was positive and had a positive impact on their learning in the Polynomial Curve Sketching lesson. Three main themes emerged from the qualitative data analysis that portray students' experience in the integration of GeoGebra in classroom teaching.

Improved Visualization and Conceptualization. A widely stated view was that GeoGebra helped students to visualize polynomial functions and to see the relationships between algebraic expressions and their visual representations. Participants described how the software helped them to see the effects of changes in graphs as they worked with mathematical expressions, providing them with snapshots of objects and making the abstract concepts more concrete and easier to understand. This dynamic visualization enabled students to confirm their answers, identify errors, and gain a deeper understanding of the concepts in polynomial graphing. Many noted that the software made graphing easier and gave them time to think more about the mathematical relationships than graphing.

Enhanced Learning Experience of Engagement and Problem Solving. Students also mentioned that GeoGebra is an interactive and enjoyable teaching tool to make their activities in the classroom more interactive. They gained interest in the lesson and active engagement in lesson discussion because of having the opportunity to see mathematical ideas in dynamic graphing. Feedback was immediate and graphical, allowing participants to try out various solution approaches and see the results as well as gaining confidence in solving graphing problems. The use of teacher demonstration was not the only pathway for students to learn mathematics; they could also explore the concepts themselves, fostering more active learning.

The challenges encountered in technology integration. Although students appreciate the learning advantages of GeoGebra, they also come across a number of difficulties when using GeoGebra. A few participants shared concerns about inequity of access to digital devices, as students without personal devices had less access to technology-supported activities. Others pointed to the need to keep practicing manual graphing techniques, especially in class tests that might not allow digital graphing. A few students also recognized that using technology too much might limit opportunities to acquire procedural fluency when mathematics is not the basis for the use of technology. Therefore, the participants suggested that the use of GeoGebra is not a replacement of conventional mathematical education but as a supplement.

Qualitative results confirm that GeoGebra positively influenced the learning process, as it helped the students to visualize, deepen the conceptual understanding, and make the classroom more active in the teaching and learning process in the Polynomial Curve Sketching lesson. Meanwhile, students understood that effective technology integration involves a variety of interesting technology and teaching strategies that will incorporate digital representation with opportunities for students to learn to graph manually and to think mathematically. Based on these findings, using GeoGebra as an educational tool is suggested to be used in addition to other pedagogical methods in mathematics education, not instead of it.

Students' Recommendations for Improving the Polynomial Curve Sketching Module. The Focus Group Discussions (FGDs) were helpful in gaining insights on the ways in which the Polynomial Curve Sketching module can be further enriched in terms of student learning. In addition to describing the advantages and disadvantages of implementing GeoGebra, participants provided suggestions on how to integrate technology and pedagogical approaches. The responses were analyzed theatrically to produce four grand themes which can be helpful to mathematics teachers in creating better technology-enhanced learning experiences.

Present the concept to the students and offer scaffolding as necessary. Students pointed out that when the training activities are designed from simpler to more complex examples, students will be more likely to understand the learning. They said that starting with the basics of graphing before moving on to the more advanced polynomial graphs helped them to see how the lesson was supposed to go and to gain confidence in how to solve graphing problems. Participants also appreciated the step-by-step demonstration as they were able to learn not only how to make graphs but also to understand the mathematics behind the steps followed. The results of this study indicate that effective sequence in teaching is still important even in the face of technology integration in mathematics.

Make use of technology to enhance mathematical visualization. It was strongly recommended that the use of GeoGebra and other visualization tools in mathematics teaching be continued. Pupils were able to describe how, by using dynamic graphing, they were able to see the instant changes in the graph when they changed the mathematical expression and this greatly helped their understanding of the behaviour of the polynomials when they were graphing them. They felt technology was particularly useful when it came to linking symbolic calculations with graphical interpretations, which helped to make abstract mathematical concepts more concrete and comprehensible. Students, however, stated that technology should be used in addition to and not in place of the manual graphing activities because both methods help to build conceptual understanding and procedural skills.

Promote Active, Collaborative and Contextual Learning. Students were suggested to develop more opportunities to engage in active learning by involving problem solving, discussion in class and real life application of polynomial functions. They reported that engaging in collaborative problem solving with peers enabled them to identify different solution approaches and better resolve their misunderstandings than would the individual solutions. Moreover, it was mentioned that the use of real-life situations in explaining mathematical concepts made the participants feel motivated and appreciated during the lesson. The observations highlight the need for the learner-centred approach for teaching that will allow the students to explore, collaborate and apply mathematical knowledge meaningfully.

Give ongoing academic support and positive learning experiences. A prevailing need that was recommended was for ongoing academic assistance during the learning process. Students found frequent review sessions, prompt feedback, individualized teaching methods, and the chance to review challenging topics before testing to be very beneficial. They also noted the importance of positive reinforcement and recognition of learning progress, which encouraged them to take part in classroom activities and gave them an increase in confidence. The participants noted that a positive learning atmosphere fosters perseverance in tackling complex mathematical issues and helps to create a more positive learning experience.

Overall, the recommendations suggest that the use of educational technology is not enough to make the Polynomial Curve Sketching module effective. Although GeoGebra contributes to the significant improvement of visualization and conceptual understanding, students noticed that the implementation of GeoGebra requires careful design of lessons, learning experiences, participation of students in classrooms, and continuous learning support. The results demonstrate how technology can be a valuable instructional tool when appropriately used with good teaching practices that encourage meaningful learning, critical thinking, and a lasting student connection. This integrated approach can contribute to the effective use of GeoGebra in math teaching for undergraduate students' various learning needs.

Conclusion

The effectiveness of the use of GeoGebra in the Polynomial Curve Sketching module of the Calculus 1 course was investigated in this study using a classroom-based action research with a quasi-experimental pre-test and post-test comparison design. The results revealed that both the conventional method and the GeoGebra-assisted conventional method helped students to learn, but the immediate learning outcomes of students in the GeoGebra-assisted conventional method were better than those of the students in the conventional method. The results show that GeoGebra was found to be an effective complementary teaching tool when using it to develop students' concept of polynomial graphing.

The quantitative results were further supported with qualitative results from the Focus Group Discussions. The students felt GeoGebra was a practical tool for teaching that improved the ability to visualize graphs, deepen the understanding of concepts, make learners active in class, and give instant feedback in learning activities. In parallel, participants realized the need to enhance technology-assisted instruction with some manual graphing opportunities and mathematical reasoning.

The results indicate that the educational contribution of GeoGebra is not just its technological aspects, but also its use in the effective education pedagogy. The research also underscores the fact that the successful use of technology goes beyond the use of digital tools. Students highlighted the importance of giving them proper instruction, learning activities that build up, learning activities that encourage them to learn together and ongoing academic support to maximize learning outcomes.

The recommendations suggest that the effective use of sounds pedagogical methods and suitable educational technology can ensure meaningful mathematics learning. The results show the effectiveness of the use of GeoGebra in the lesson of Polynomial curve sketching but they need to be considered in the framework of the study. The results apply to the immediate learning outcome of the students in a topic, not to the overall performance in Calculus 1, and the intervention took place during the five-hour topic (one week) as part of the whole topic. Recommendations for future studies with longer instructional time, a wider variety of calculus topics and student participants are suggested to further explore the enduring effects of technology enhanced mathematics instruction.

In general, this study gave empirical evidence that advanced student's learning using GeoGebra in graphing oriented mathematics lesson can be enriched by increasing students' understanding of the concept, facilitating students in visualizing the concept, and increasing the engagement of students in the classroom. GeoGebra, used together with learner oriented teaching methodology can be an effective teaching tool for improving mathematics education in Higher Education.

Recommendations

The study results show the following recommendations for teaching and learning improvement of the Polynomial Curve Sketching module and for future research on technology-supported mathematics instruction. A first step is that Math teachers are encouraged to use GeoGebra as a supplemental tool in learning when teaching topics in Calculus 1 that involve graphing. The software should be used in conjunction with traditional teaching methods and present students with dynamic visualization so as to help them understand the relationship between the process of using algebraic methods and the process of using graphs. This integration can help to conceptualize the situation while still giving students the opportunity to practice manual graphing skills and analysis. Second, teachers need to have a learner-centered instructional style and incorporate technology with planned and systematic learning activities. The material studied should start with basic ideas and then build up to more advanced applications with guided demonstrations, collaborative problem solving, discussion and real-life mathematical applications.

These approaches could enhance students' conceptual understanding, boost the level of engagement in class, and foster mathematical thinking. Third, schools must have sufficient technology and professional development to help teachers effectively integrate digital tools into mathematics instruction. Access to learning technologies and pedagogical and technological skills for instructors can help to enhance more meaningful and inclusive learning.

Lastly, future studies are encouraged to take place with larger and more diverse samples of students, other topics in calculus, and extended intervention times. Further research is required to investigate the long-term impact of GeoGebra on students' mathematical results, mathematical understanding, learning retention, and attitudes towards mathematics, as the present investigation yielded only results for the Polynomial Curve Sketching module in a 5-hour lesson. Future studies can also be conducted to compare GeoGebra with other emerging technologies in education and explore its effectiveness in various mathematical fields and learning environments.

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