Students’ Performance and ICT Capabilities in Quadratic Functions Using GeoGebra

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Abstract:
The study explored the relationship between information and communication technology (ICT) self-efficacies and students’ mathematics performance using the GeoGebra software in teaching quadratic functions to senior high school (SHS) students in the West Gonja Municipality of the savannah region. ICT capabilities were defined as the functionalities offered by ICT in mathematics education that students identify and utilize to address their learning needs, including computational and graphing capabilities. The pretest/post-test non-equivalent control group design with a quantitative research approach were employed for data collection. A sample of 120 participants were selected from three Senior High Schools in the West Gonja Municipality via the stratified random sampling technique. Data were collected through performance tests and students survey questionnaire and analyzed using descriptive statistics, independent samples t-test and correlation analysis. Notably, the study observed that there was comparable/significant difference between the posttest mean scores of students taught using GeoGebra and students taught without it. The results also indicated GeoGebra as an effective technological tool for improving students’ computational and graphing competencies, both of which revealed significant and positive association with mathematics performance. Analysis of the responses of students' opinions/perceptions of GeoGebra as an ICT tool in teaching quadratic functions revealed an overwhelming majority of students had positive perceptions of GeoGebra, considering it an effective tool for teaching and learning quadratic functions, enhancing their understanding, computational skills, and motivation. They also expressed willingness to recommend it to their peers, indicating strong support for its integration into mathematics education. As a result, the study proposed the full integration of ICT into the SHSs’ curriculum. Additionally, it recommended
focusing on enhancing the ICT competencies of SHS students to effectively leverage ICT in their educational endeavors.

Keywords: GeoGebra, ICT Capabilities, Mathematics Performance, Quadratic functions.

Introduction

The term Information and Communication Technology (ICT) is expansive and covers a variety of technologies, including the internet, mobile phones, social media, computing, artificial intelligence, big data, and cloud. The proliferation of these technologies has led to a fundamental shift in the way people interact and engage with the environment surrounding them (Myers et al., 2020). According to Alenezi (2023), the uses of ICT are vast and varied, with applications in numerous sectors of the economy. One of the key advantages of ICT is that it has significantly reduced the quantity of time and effort that humans must invest in getting things done. This has been achieved through the automation of many tasks that were once performed manually, resulting in increased efficiency and productivity (Bhandari & Bhandari, 2023). Furthermore, the use of ICT has increased the precision, validity, and reliability of many processes, reducing the likelihood of errors or mistakes.

The impact of ICT can be felt in various industries, encompassing education, healthcare, business, and governance. The integration of ICT into these areas has led to a transformation of their structures, strategies, and policies, as well as the employment patterns and social practices associated with them (Tiwari, 2022). For example, the use of online education platforms has made education more accessible and flexible, while telemedicine has expanded healthcare services to remote or underserved areas. In the world of business, ICT has facilitated the rise of e-commerce, enabling businesses to reach new customers and markets globally. In the realm of governance, the use of digital technologies has increased transparency and accountability, while also enhancing citizen participation in decision-making processes. As the pace of technological advancement continues to accelerate, the potential for further transformation across these sectors remains vast (Dzisah, 2022).

ICT has transformed the delivery of education, making it more accessible and efficient (Alsarayreh, 2023). As opined by Jiang et al. (2023), adoption of ICT tools in education in recent times has grown in popularity. These tools include calculators, laptop computers, tablets, and smartphones, as well as software and applications designed for educational purposes. According to Adeniji (2023) and Karim et al. (2023), mathematics education is one area where ICT has had a significant impact, as it has been used to improve student learning and performance. Priyanda et al. (2020) opined that ICT offers many benefits (such as improved knowledge retention, enhanced collaboration, and student engagement) and engenders a new wave of revolution in educational spheres.

To foster mathematical proficiency in students, it is essential to make mathematics lessons engaging by incorporating ICTs. ICTs are among the most efficient means to encourage student involvement in hands-on activities, ultimately enhancing their self-efficacy and the skills required for improved performance in mathematics. GeoGebra stands out as an ICT tool known for its remarkable impact on enhancing students’ abilities in computation, graphing, motivation, and engagement, ultimately leading to improved academic performance in mathematics (Efa et al., 2023; Schaver 2019; Tindan et al., 2023). GeoGebra serves as an interactive mathematics platform designed for instructing and grasping mathematical concepts across various educational levels, spanning from elementary to university. Users can shape figures through mouse, touch screen, or input bar commands. The program’s philosophy hinges on the firm belief that every student can grasp mathematics when provided with the chance to learn and
solve problems matching their current abilities. Its approach centers on the principle of learning by doing, emphasizing the need for extensive practice to master mathematical skills and comprehend underlying concepts. By offering ample opportunities for practice, students can progressively advance to more challenging mathematical problems, fostering confidence and dispelling any apprehension towards the subject (Akwensi et al., 2023). Numerous research endeavors have explored the influence and advantages of particular ICT functionalities such as graphing, computation, and engagement on students’ academic achievements in mathematics. These studies have specifically investigated the utilization of GeoGebra to enhance these capabilities (Kusnadi, 2023).

**Statement of the Problem**

ICT has transformed the delivery of education, making it more accessible and efficient. The integration of ICT tools in education in recent times has witnessed an exponential increase and demand. These tools range from both hardware, software, and applications designed for academic intentions. Ishaq et al., (2020), Priyanda et al. (2020) and Agudelo et al. (2019) opined that ICT offers many benefits and engenders a new wave of revolution in educational spheres. A study by Gómez-Fernández and Mediavilla (2021) revealed a favorable correlation between ICT utilization and academic performance.

Quadratic functions are essential in various areas of mathematics and science, as they describe a wide range of real-world phenomena, such as projectile motion, the shape of certain curves, and optimization problems (Schaver, 2019). These functions involve mathematical operations like squaring, multiplication, and addition or subtraction of variables. Students must practice these algebraic manipulations, which are fundamental skills in mathematics (Aggrey & Kwakye, 2022). Solving quadratic equations also requires students to apply the quadratic formula, factorization methods or graphical methods, improving their problem-solving abilities. Graphing quadratic functions helps students visualize the relationship between the variables and the shape of the parabola. Students learn to identify key features of the graph, including elements like the vertex, \( y - \text{intercept} \), axis of symmetry, \( x - \text{intercepts} \) (roots), and which enhances their graph interpretation skills. Solving problems related to quadratic functions helps students develop critical thinking skills. Students need to identify patterns, make connections between mathematical representations, and formulate strategies for finding solutions.

GeoGebra has been identified as a dynamic mathematics program that integrates graphing, statistics, geometry, algebra, calculus, and spreadsheets into a user-friendly interface. It is a free and open-source tool that is widely used in mathematics education and research. GeoGebra provides a variety of interactive mathematical tools and features to help students, teachers, and researchers explore, visualize, and understand mathematical concepts. It is often used to enhance mathematical understanding and make the learning process more engaging and intuitive and has been found to have a significant effect on students’ conceptual and procedural knowledge (Ocal, 2017).

Research investigations into the impact of utilizing software on students’ learning abilities such as computation, graphing and so on in quadratics or graphing quadratic functions are limited, however several of them, including Schaver (2019) have found the use of GeoGebra as an effective ICT tool for elevating students graphing and computational skills. Analysis of the self-evaluation report of Ndewura Jakpa Senior High School in the West Gonja Municipality has it that, the integration and full usage of ICT in teaching and learning is limited, which may be hindering the potential of students in enhancing their achievement (NDESCO’s SIP, 2022). Besides, there has been no related study on the connection between ICT capabilities and mathematics achievement among senior high school (SHS) students in the municipality. Therefore, it was crucial to investigate how specific ICT capabilities through the use of GeoGebra in teaching quadratic functions may impact student’s mathematics achievement in the West Gonja Municipality, to
assess the relevance for improvement in the use of ICT for instructional purposes.

**Objectives of the Study**

This study was carried out to:

1. assess if there is a difference in the posttest mean scores between students instructed with the GeoGebra software and those using the conventional method.

2. evaluate students’ perspectives on GeoGebra within the realm of quadratic equations.

**Research Hypothesis**

This hypothesis was investigated.

**H₀**: There is no significant difference in the posttest mean scores between students instructed with the GeoGebra software and those taught without it.

**Literature Review**

The study’s objective was to look into the performance of students and ICT capabilities in quadratic functions using the GeoGebra software. The study by Gbordzekpor et al. (2023) investigated the impact of multimedia resources on mathematics instruction. The research involved dividing students into two groups: one taught through traditional methods and the other using multimedia assets. Results showed that the multimedia group performed significantly better, indicating improved understanding and performance. The use of multimedia resources was found to enhance students’ engagement and motivation, making learning more interesting and enjoyable compared to traditional methods. Overall, the study suggests that integrating multimedia resources into mathematics education positively influences students’ engagement, motivation, understanding, and information retention, thereby improving their overall mathematics performance. However, it does not address the influence of teachers’ and students’ proficiency in utilizing multimedia resources on their mathematics performance.

Another study by Raja and Lakshmi Priya (2022) focused on computer-based tools, such as simulations and virtual manipulatives, to investigate their influence on third-grade students’ conceptual understanding of fractions and motivation in mathematics lessons (Zakari et al., 2021). The research employed a quasi-experimental design with three groups: one receiving concrete manipulative-assisted training, another virtual manipulative-assisted training, and a control group with conventional pedagogical methods. The Fraction Comprehension Test (FCT) and Mathematics Lesson Motivation Scale (MLMS) were used for data collection. The analysis, conducted using One-way MANOVA, revealed a statistically significant improvement in understanding fractions for students using manipulatives, with 24% of the change attributed to their use. However, no significant disparities were found in motivation for mathematics lessons. Interestingly, the study showed no superiority between concrete and virtual manipulative use, suggesting educators can choose either type based on their teaching goals. The research outcome implies that a complementary use of manipulatives can lead to improved outcomes in teaching mathematics, particularly fractions, providing valuable insights for future work in the field.

Yu et al. (2022) conducted a meta-analysis to investigate the potential of electronic play set-ups as educational tools for STEM subjects. The analysis included 33 studies published between 2010 and 2020, with a total of 3894 participants. The results indicated that digital games had a significant overall positive effect on learning outcomes in STEM education. When compared with similar instructional pedagogies, electronically-assisted activities showed promise in improving learning gains. The meta-analysis also explored moderator variables such as management procedure, field of study, learning stage, game category, gaming system, and intervention duration.

The findings suggested that digital gaming for STEM education was more effective for higher education students than for K-12 students. Additionally, the type of game, gaming platform,
and intervention duration had a relatively smaller impact on the efficacy of electronically-assisted learning activities as educational tools. Overall, the study supports the notion that electronic play set-ups can be beneficial for enhancing STEM education, with specific considerations for educational level influencing their effectiveness.

Numerous studies have explored the effects of GeoGebra on students’ mathematical skills, and the literature highlights several key findings. For instance, a study by Martinez (2017) studied the effects of integrating GeoGebra, an iPad application, on SHS students’ understanding of High School Geometry. The research was prompted by the concern that a significant proportion of 12th-grade U.S. students did not achieve proficiency in mathematics, as revealed by the National Assessment of Educational Progress (NAEP) in 2010. The Common Core State Standards (CCSS) recommended integrating technology, like GeoGebra, into mathematics education to enhance engagement with high-level mathematical concepts. The research leveraged an experimental quantitative framework with a treatment group utilizing GeoGebra relative to a control group that did not use GeoGebra, the intervention spanned five weeks with the treatment group incorporating GeoGebra while the control group adhered to regular instruction. Independent and paired t-tests were employed to assess the Module 5 math test scores for both groups. The results suggested an enhancement in student scores when GeoGebra was utilized, although the improvement was not statistically significantly outpacing that observed in the control group. As a result, the study suggests the need for further research to continuously assess the effectiveness of incorporating specifically GeoGebra, in instructional practices.

Another study by Akwensi et al. (2023), assessed the impact of GeoGebra software on the academic achievements of SHS students in mensuration. The study adopted a quantitative method, employing a quasi-experimental design with pretest-posttest non-equivalent control groups. Data collection involved tests and questionnaires, and the analysis included descriptive statistics and an independent sample t-test. The study included 60 second-year SHS students from the Upper East Region, divided into control and experimental groups. The independent t-test analysis demonstrated a significant difference in posttest mean scores between these groups, indicating that students who used GeoGebra software showed improved academic performance. Additionally, the questionnaire data revealed uplifting remarks from students regarding integrating GeoGebra software into the instruction and studying of mensuration.

Furthermore Zulnaidi et al. (2020) in a quasi-experimental study, examined the impact of employing GeoGebra software as an instructional tool on the academic performance of Form Two students. The research involved 80 Form Two students, divided into a treatment group of 40 and a control group of 40. The data were reviewed with ANATES 4 and SPSS 24.0 software. The findings revealed pronounced differences in student progress, particularly in topics related to functions and limit functions, based on their group type. Both teachers and students expressed approval of GeoGebra’s use in mathematics education. GeoGebra’s ability to visually depict the application of mathematical procedures, especially through graphs, was seen as a valuable aid in helping students master and comprehend concepts related to functions and limit functions. Although the use of GeoGebra was noted to be time-consuming, it was found to make the learning process more active and facilitate active interaction between teachers and students.

With regards to conceptual and procedural knowledge, Suratno and Waliyanti (2023) delved into the vital role of problem-solving abilities in mathematics learning and emphasizes the need for effective strategies to cultivate these skills, particularly within the school context. The study focuses on the utilization of GeoGebra in problem-based learning as a means to enhance students’ problem-solving capacity. A quasi-experimental research methodology was employed, specifically using the Posttest-Only Design with Nonequivalent Groups. The research findings indicate a significant positive impact on students’ problem-solving abilities.
When GeoGebra is integrated into problem-based learning. This study underscores the potential of technology, specifically GeoGebra, to be a valuable tool for nurturing students’ problem-solving skills in the context of mathematics education. The empirical evidence highlights the effectiveness of this approach and its relevance to the broader goal of enhancing problem-solving capabilities among students.

On computational self-efficacies, Schaver (2019) delved into the efficiency of GeoGebra on students’ mathematics progress, with a focus on student achievement scores, critical thinking/problem-solving skills, and student engagement and motivation. Two groups of high school geometry students from different years were compared: one group in 2018 received traditional teaching methods, while the other group in 2019 used GeoGebra for learning mathematics. Student scores were collected from teacher-made assessments over both years and averaged. The study also involved observations and a survey to test the effects of GeoGebra on students’ critical thinking and problem-solving skills, and their classroom engagement and motivation. In conclusion, the literature strongly supports the positive effects of using GeoGebra in enhancing students’ computational and graphing competencies and overall performance in mathematics. Its dynamic, interactive, and visual features contribute to improved conceptual understanding, problem-solving skills, graphing proficiency, and motivation. Therefore, GeoGebra is a valuable tool for educators seeking to enhance students’ mathematical learning experiences and outcomes.

Methodology

The study was carried out using the quantitative research approach with a positivist paradigm as the philosophical stance and a pretest-posttest non-equivalent control group. The quantitative approach was chosen for its ability of ensuring the generalization of the findings to larger populations, its ability to use statistical analysis to identify significant relationships between variables, and the ability to test hypotheses using rigorous and systematic methods. The two-group pretest-posttest non-equivalent control group design was to enable the researcher evaluate the effectiveness of the intervention (GeoGebra) and also determined if there was any significant difference in the performance of participants of the various groups.

The population of the study were all final year senior high school students in the Savannah region while the target population included final year students of the Damongo Senior High School (DASS), Ndewura Jakpa Senior High/Technical School (NDESCO) and Saint Anne’s Girls Senior High School (SAGISS) all in the West Gonja Municipality. A total of 956 final year students were however accessible in the schools. The study involved a sample size of 120 final year students from an accessible population of 956 students. This number was determined based on guidelines of the rule of thumb (the 10-to-1 rule) for sample size determination. The stratified random sampling of the probabilistic sampling methods was used to populate the sample. The purpose for using the stratified random sampling was to ensure that the sample was representative of the larger population and that it included individuals from all the relevant subgroups (SHSs) in the population.

The evaluation of students’ proficiency in quadratic functions utilized an Achievement Test comprising five (5) open-ended theory questions derived from past WAEC questions on quadratic functions. Students' perspectives on GeoGebra software as a technological aid in the instruction of quadratic functions and its impact on their computational and graphing self-efficacies was gauged using a researcher-designed questionnaire consisting of nine statements employed in line with the research objectives. A pilot study was conducted to establish the instrument's reliability, yielding Cronbach's alpha reliability values of 0.764 and 0.706 respectively, attesting to their trustworthiness and exemplary performance.

Prior to data collection, introduction and ethical evaluation clearance letters were submitted to the school administrators whose institutions participated in the study. Upon review and
approval of these letters, permission was granted for the commencement of data collection. The study's objectives were explicitly communicated to participants in a pre-questionnaire interaction, clarifying its academic nature. Participants verbally consented, assured of the complete confidentiality of the information they provided. Initiating the data collection process, the examination served as the initial step, followed by the administration of the questionnaire. Subsequent analysis of both test and questionnaire results was undertaken in tandem, facilitating a comprehensive discussion of the findings.

**Results**

In examining the quantitative data, inferential statistics were employed. The responses gathered from participants were collated and input into SPSS for analysis. The connection between the primary variable and the resulting variable was established through this process. The results are outlined in the tables below.

**Hypothesis Testing**

**H_0**: There is no significant difference between the posttest mean scores of students taught using GeoGebra and students taught without GeoGebra.

To determine whether or not there was significant difference between the posttest mean scores of students taught using GeoGebra and those taught without GeoGebra, an independent sample t-test analysis was conducted on the mean scores of students in the two groups as presented in Table 1 and Table 2.

### Table 1. Analysis of Std. Error Mean based on Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>60</td>
<td>1.97</td>
<td>0.712</td>
<td>0.092</td>
</tr>
<tr>
<td>Control</td>
<td>60</td>
<td>3.10</td>
<td>0.796</td>
<td>0.103</td>
</tr>
</tbody>
</table>

**Source:** Field Data (2023)

In Table 1, the independent samples t-test was conducted to compare the posttest results of the experimental group and the control group. The table provides information about the means, standard deviations, and standard error of the mean (SEM) for both groups.

### Table 2. Independent Samples T-Test Base on Groups on Posttest Results

<table>
<thead>
<tr>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>0.848</td>
<td>0.359</td>
</tr>
<tr>
<td>-8.218</td>
<td>116.57</td>
</tr>
</tbody>
</table>

**Source:** Field Data (2023)
Descriptive Analysis of Survey Questionnaire Responses

To address the second research question on students’ perspectives on GeoGebra within the realm of quadratic equations, a comprehensive exploration of their responses was undertaken employing descriptive analysis techniques. This involved assessing the frequencies and percentages associated with each item concerning students’ perceptions of GeoGebra as a technological tool in the teaching of quadratic functions.

The outcomes of this analysis are presented in Table 3. The table encapsulates a detailed breakdown, shedding light on the varying degrees of student perspectives and their engagement with GeoGebra within the context of quadratic functions instruction. By dissecting the data in this manner, a nuanced understanding of how students perceive and interact with GeoGebra in the teaching of quadratic functions was facilitated. The tabulated results serve as a valuable resource for deciphering the multifaceted dynamics associated with the integration of this technological tool in the educational setting.

Table 3. Students’ Perceptions of GeoGebra as a Technological Tool in Teaching Quadratic functions

<table>
<thead>
<tr>
<th>Statement</th>
<th>S A</th>
<th>A</th>
<th>N</th>
<th>D</th>
<th>SD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>The use of GeoGebra made quadratic factorization easier to understand.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>33</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td>55.0</td>
<td>5.0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>GeoGebra helped me better visualize quadratic graphs and factorization.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>41</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>28.3</td>
<td>68.3</td>
<td>3.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>GeoGebra enhanced my computational skills in working with quadratic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>equations.</td>
<td>20</td>
<td>39</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>33.3</td>
<td>65</td>
<td>1.7</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>The interactive nature of GeoGebra made learning quadratic functions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>more interesting.</td>
<td>23</td>
<td>31</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>38.3</td>
<td>51.7</td>
<td>10.0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>GeoGebra helped me grasp the relationship between quadratic equations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and their graphs.</td>
<td>22</td>
<td>36</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>36.7</td>
<td>60.0</td>
<td>3.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>I believe GeoGebra is a valuable tool for learning math concepts like</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>quadratic functions.</td>
<td>24</td>
<td>34</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td>56.7</td>
<td>3.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>I felt more motivated to practice quadratic functions with GeoGebra.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>36</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>38.3</td>
<td>60.0</td>
<td>1.7</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>GeoGebra made quadratic factorization and graphing more accessible to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>me.</td>
<td>24</td>
<td>31</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>40.0</td>
<td>51.7</td>
<td>8.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>I would recommend using GeoGebra to other students for learning quadratic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>factorization.</td>
<td>20</td>
<td>29</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>33.3</td>
<td>48.3</td>
<td>18.3</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Field Data, 2023

The table presents the results of students' perceptions of GeoGebra as a technological tool in teaching quadratic functions, with responses categorized into Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D), and Strongly Disagree (SD).
Discussion

The Standard Error Mean (SEM) is a depiction of the precision or reliability of the sample averages (mean). It quantifies how much the sample mean is expected to vary from one sample to another. In the context of the independent samples t-test, the SEM is particularly relevant because it affects the calculation of the t-statistic. The findings derived from the data presented in Table 1 indicate that the SEM for the experimental group (0.092) is smaller than the SEM for the control group (0.103). A smaller SEM indicates that the sample mean for the experimental group is expected to be more consistent across different samples, suggesting higher precision in estimating the population mean. The t-test compares the difference in means between the two groups (1.97 for the experimental group and 3.10 for the control group) while taking into account the variability within each group, as measured by the SEM. A smaller SEM contributes to a more precise estimate of the mean difference, which can make it easier to detect statistically significant differences between the groups if they exist. In this case, the smaller SEM in the experimental group suggests that the mean difference of 1.13 (3.10 - 1.97) is likely a more reliable estimate of the population difference, given the lower sampling variability. The t-statistic calculated from the means, standard deviations, and sample sizes of the two groups, as well as the SEM, can be used to determine whether the observed mean difference is statistically significant. If the t-statistic is sufficiently large, it indicates that the groups are significantly different from each other.

In summary, the Standard Error Mean (SEM) plays a crucial role in assessing the reliability of the sample means and their differences in the context of the t-test. A smaller SEM typically leads to a more precise estimate of the population parameters and can make it easier to detect statistically significant differences between groups.

Table 2 presents the results of statistical tests, including Levene's Test for Equality of Variances and the t-test for Equality of Means. Levene's test is used to assess whether the variances of the two groups being compared are approximately equal. In this case, the F-statistic is 0.848, and the associated p-value (Sig.) is 0.359. When conducting this test, a higher p-value suggests that there is no significant difference in variances between the groups. Therefore, in this context, it appears that the assumption of equal variances is reasonable (p > 0.05). The t-test for equality of means is used to assess whether there is a statistically significant disparity in the averages of two groups. In this case, the t-statistic is -8.218, and the associated p-value is extremely small (p = 0.000). A small p-value (typically less than 0.05) suggests that there is strong evidence to reject the null hypothesis that the means of the two groups are equal.

Based on these results, t-test indicates that there is a significant difference in means between the two groups. The mean difference is -1.133, suggesting that the control group has a lower mean than the experimental group. The 95% confidence interval of the difference (-1.406 to -0.860) does not include zero, which further supports the conclusion that the means of the two groups are significantly different. In summary, when equal variances are assumed (as indicated by Levene's test), the t-test suggests a significant difference in means between the two groups, with the first group having a lower mean score. The results are statistically significant (p < 0.05).

Given these findings, it is reasonable to reject the null hypothesis (H₀: There is no significant difference between the posttest mean scores of students taught using GeoGebra and students taught without GeoGebra in West Gonja Municipal). Instead, the evidence supports the alternative hypothesis, indicating that there is significant difference between the posttest mean scores of students taught using GeoGebra and students taught without GeoGebra. These results corroborate the findings of Vourletsis and Politis, (2023), Zhang and Wong (2023), Javiad et al. (2023), and Obafemi (2023).

The results of Table 3 demonstrate overwhelmingly positive feedback from students.
regarding the integration of GeoGebra software into teaching and learning. A total of 95.0% of students (combining SA and A) found that GeoGebra made quadratic factorization easier to understand, indicating strong agreement with the statement. Additionally, a substantial of 96.6% of students (combining SA and A) reported that GeoGebra aided them in visualizing quadratic graphs and factorization, reflecting a high level of agreement, with corresponding percentage total of 98.3% of students (combining SA and A) felt that GeoGebra improved their computational skills in quadratic equations, indicating strong agreement. Further analysis of the responses revealed that 30% and 63.3% (90.0%, combining SA and A) of students found that the interactive nature of GeoGebra increased their interest in learning quadratic functions, with a minor 10% remaining neutral on this matter. Moreover, a significant majority of students affirmed that GeoGebra aided them in grasping the relationship between quadratic equations and their graphs, as 36.7% strongly agreed and 60% agreed, while only 3.3% responded with neutrality. GeoGebra was widely recognized as a valuable tool for learning math concepts like quadratic functions, with 40% strongly agreeing and 56.7% agreeing, while a small percentage (3.3%) remained undecided. In terms of motivation, 38.3% and 60% strongly agreed and agreed that they felt more motivated to practice quadratic functions with GeoGebra, with only a minor fraction (1.7%) responding as undecided. Regarding recommendations to other students, 33.3% strongly agreed, 48.3% agreed, and 11% remained neutral.

In summary, the overwhelming majority of students had positive perceptions of GeoGebra, considering it an effective tool for teaching and learning quadratic functions, enhancing their understanding, computational skills, and motivation. They also expressed a willingness to recommend it to their peers, indicating strong support for its integration into mathematics education. This affirms similar findings by.

Conclusion

Based on the robust statistical analysis of students’ scores and responses, the inference drawn from the findings is that there is a substantial difference in the mean scores of post-tests among students taught with and without GeoGebra. The findings from Levene's test, which supported the assumption of equal variances between the groups, and the t-test for equality of means indicated a substantial difference, with a mean difference of -1.133, strongly substantiate that student taught with GeoGebra outperformed those taught without it. The extremely low p-value of 0.000 in the t-test provides compelling evidence to support the rejection of the null hypothesis.

Analysis of the responses of the survey information gathered from the questionnaire pointed to an overwhelmingly majority of students had positive perceptions of GeoGebra as an effective tool for teaching and learning quadratic functions, enhancing their understanding, computational skills, and motivation, and were willing to recommend it to their peers.

The study concluded based on the findings that, the students’ appraisal of GeoGebra as a technological aid in teaching quadratic functions indicate overwhelmingly positive feedback. This collective evidence underscores the efficiency of GeoGebra as a valuable tool for enhancing students’ competencies in the context of teaching quadratic functions to SHS students in the West Gonja Municipality.

Recommendation

Based on the findings, the study recommended GeoGebra as an effective tool for teaching and learning quadratic functions to SHS students, enhancing their understanding, computational skills, and motivation. Consequently, the study recommends the integration of ICTs (including GeoGebra) into educational practices as beneficial and impactful strategy for improving students’ performance and comprehension in mathematics especially at the SHS level.
Implication of the Study
The research findings have significant implications for educational practices in SHSs. The strong connection between the GeoGebra software and overall student performance underscore the critical need to prioritize effective ICT integration within the SHS curriculum. The study recognizes digital engagement and motivational self-efficacies as critical factors, highlighting the significance of technology in facilitating remote and blended learning. Educational institutions should continue to leverage digital engagement platforms that enable active learning beyond the traditional classroom.

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Conflicts of Interest
The authors declare no conflict of interest.

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