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STUDENTS' KNOWLEDGE OF INTEGRATION OF GEOGEBRA IN LEARNING MATHEMATICS IN LOWER SECONDARY SCHOOLS IN UGANDA

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Abstract:
The use of technology in the pedagogical process is growing at a phenomenal rate and has revolutionized the way students learn. As a result, there is a need for integrating technology into students' mathematical activities. GeoGebra is a technology software that supports teaching and learning mathematics, especially geometry, algebra, and statistics. This study investigated the students' knowledge of the integration of GeoGebra in learning mathematics in lower secondary schools in Wakiso District, Uganda. The study utilized quasi-experimental and cross-sectional designs with 42 senior two students in the experimental and 43 in the control group. Data were collected using pre-tests, post-tests, and questionnaires to identify the students' difficult geometric concepts when learning mathematics, establish the impact of GeoGebra-based training on the students' learning, and examine the relationship between students' perceived ease of use of GeoGebra and its integration in learning mathematics. Independent samples t-test, Pearson's linear correlation, and descriptive statistics such as mean, standard deviation, percentages, and frequencies were employed to analyze the data. The study revealed that reflection on the Cartesian plane was the most abstract geometric concept to learn. The results further revealed a statistically significant mean difference between pre-test and post-test scores in favour of the experimental group after the intervention. Furthermore, a moderately significant positive linear correlation existed between students' perceived ease of use of GeoGebra and its integration in learning reflection on the Cartesian plane. Therefore, the study recommends urgently training students to incorporate this interactive educational software into their mathematics learning.

Keywords: GeoGebra, integration, students' knowledge, Mathematics learning, secondary school

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1. Introduction

Globally, the advocacy for using ICT and its tools in the teaching and learning of mathematics dates back to the 20th century. ICT has become an essential tool that supports innovative teaching and enhances students' continuous learning process (García-Valcárcel Muñoz-Repiso, & Tejedor, 2009). Uganda launched its initial National ICT policy in 2003, emphasizing improving investment in educational ICT equipment and imparting teachers with the necessary ICT skills (Farrell, 2007). Subsequently, another ICT policy framework of 2014 was launched that envisioned a Uganda where national development broadly and human resource development more specifically would be achieved through efficient application of ICT and digital literacies (The National ICT policy, 2014). Several initiatives, such as I-Network Uganda, Uconnect, Connect Ed, and School Net Uganda, have been launched to promote digital literacy and ICT integration in educational institutions across the country (Andema, Kendrick & Norton, 2013; Guloba & Atwine, 2021). Despite all the national efforts, it has been observed that there is a low integration of ICT in teaching and learning mathematics (Guloba & Atwine, 2021). Studies have indicated that this is due to low internet connectivity, lack of proper ICT skills, and electricity supply (Habibu *et al.*, 2012; Nyakito *et al.*, 2021). GeoGebra comes in as a solution to some of the challenges basically on the issues of internet access and connectivity because it is a free downloadable software and can be accessed at anytime and anywhere while offline or online (Taman & Dasari, 2021., Hohenwarter, *et al.* 2008). GeoGebra was designed to combine features of dynamic geometry software (e.g., Cabri Geometry, Geometer's Sketchpad) and computer algebra systems (e.g., Derive, Maple) in a single, integrated, and easy-to-use system for teaching and learning mathematics (Hohenwarter, Jarvis, & Lavicza, 2008). GeoGebra has a user-friendly interface and a web platform that makes it convenient for users worldwide to access several mathematical resources (Hohenwarter & Fuchs, 2004). GeoGebra software makes abstract geometric objects be visualized and manipulated quickly, accurately, and efficiently (Taman & Dasari, 2021). When students are competent in integrating GeoGebra into geometry learning, they learn abstract transformation concepts easily (Dahal *et al.*, 2019).

1.1 Purpose and Objectives of the Study

The study aimed to enhance the students' knowledge of integrating GeoGebra into mathematics learning in lower secondary schools in Wakiso District, Uganda. The specific objectives of the study were to identify the students' difficult geometric concepts when learning mathematics, establish the impact of GeoGebra-based training on the students' learning of the identified difficult geometrical concepts, and examine the relationship between students' perceived ease of use of GeoGebra and its integration in learning mathematics.

1.2 Theoretical Framework

The study was guided by two theories: Technological Pedagogical Content Knowledge (TPACK) and Technology Acceptance Model (TAM). The TPACK framework by Mishra and Koehler (2006) is a useful frame for thinking about the knowledge that students must have to integrate technology into learning and how they might develop it. TPACK has seven knowledge domains namely: content knowledge, pedagogical knowledge, technological knowledge, pedagogical content knowledge, technological content knowledge, technological pedagogical knowledge, and technological pedagogical content knowledge. Using TPACK as a framework for measuring learning knowledge could potentially impact the type of training designed for students (Schmidt, *et al.* 2009). Therefore, this study focused on three constructs: technological knowledge, technological content knowledge, and content knowledge to train students and improve their knowledge. In contrast, the Technology Acceptance Model (TAM) is one of the most popular and parsimonious frequently used models for assessing acceptance of new technology. TAM was proposed by Davis in 1989 (Davis, 1989; Davis, Bagozzi, & Warshaw, 1989) and originated from the Theory of Reasoned Action (Ajzen & Fishbein, 1980), which claims that its user's beliefs and perceptions influence the intention to use a computer-based technology. TAM assumes that when users perceive that a type of technology is useful and easy to use, they will be willing to use it (Davis, 1989). According to TAM, two main variables, perceived usefulness (PU) and perceived ease of use (PEU), are fundamental determinants of user acceptance. This study focused on perceived ease of use (PEU), which refers to the degree to which a person believes that using a particular technology will be free of effort (Davis *et al.*, 1989).

2. Literature Review

In this section, literature related to the respective three specific objectives of this study was reviewed.

2.1 Difficult Geometric Concepts in Learning Mathematics

Difficult geometric concepts are concepts that pose challenges to teachers and students. When students are obstructed by difficult concepts, they lose interest and confidence in the content leading to low learning outcomes and achievement disorder (Retnawati, *et al.* 2017). Different scholars have studied difficult geometric concepts. For instance, Ubi, Odiong, and Igiri (2018) conducted a study on geometry viewed as difficult mathematics in senior secondary schools in Nigeria. They found that geometric concepts perceived as difficult to learn by students included congruent triangles, circle theorem, construction and locus, surface areas of solid figures, volume of solid figures, latitude and longitude, coordinates geometry, bearing, and distances. Further still, Barut and Retnawati (2020) conducted a study to investigate students' difficulties and level of thinking in Indonesia. They revealed that high school students in Indonesia faced difficulties such as being unable to identify the geometric shapes based on their formal definition properly, lack of visualization ability, failure to understand specific terms or symbols of geometry, and insufficiency in providing proper reasoning related to relationships within geometric shapes. In the same vein, Ngirishi and Bansilal (2019) explored the understanding of basic geometry concepts by grade 10 and grade 11 learners in South Africa in terms of van Hiele's levels of geometry thinking, which included visual, analysis, informal deduction, formal deduction, and rigour levels. They revealed that students had problems in defining geometric terms, interrelations of properties and shapes, and changing semiotic representations. Students in Nigeria attributed their geometric learning difficulties to have emanated from unavailability of instructional materials, teachers' method of instruction, and misconception of concepts (Fabiyi, 2017).

2.2 The Impact of GeoGebra-Based Training on Learning Mathematics

GeoGebra-based training involves nurturing individuals to become proficient in using GeoGebra for learning. It plays a vital role in learning mathematics. For instance, Ocal (2017) in Turkey investigated whether instruction with GeoGebra affected students' achievement in terms of their conceptual and procedural knowledge. He indicated that instruction with GeoGebra positively affected students' scores regarding conceptual knowledge and their overall scores. In addition, Owusu, Bonyah, and Arthur (2023) examined the impact of the dynamic mathematics software, GeoGebra, on university students' mathematics understanding of polar coordinates in Ghana. Their results revealed that students who were taught polar coordinates with the aid of GeoGebra performed better than those taught with the conventional approach. Furthermore, Otieno, Owiti, and Wanjala (2017) explored the effectiveness of using GeoGebra instruction software as a pedagogical tool in secondary school mathematics in Kenya, as contrasted to conventional teaching methods on students' achievement. They revealed a significant difference in the achievement of students taught using GeoGebra and those taught using conventional teaching methods. Similarly, Azucena, Gacayan, Tabat, Cuanan, and Pentang (2022) made an educational intervention in Algebra to demonstrate that the GeoGebra software is applicable and valuable as mathematics instructional material in the Philippines. They revealed that GeoGebra effectively improved algebra confidence, enhanced learning, remediated the students' least mastered skills, and motivated students to learn and improve their knowledge.

2.3 Perceived Ease of Use of GeoGebra and its Integration in Learning Mathematics

Despite GeoGebra's positive impact on teaching and learning mathematics, it is still vital to understand how users perceive and employ it during the teaching and learning process. The perceptions of GeoGebra and its integration into mathematics learning across various levels of educational institutions have been the subject of numerous empirical research studies. For instance, Owusu, Bonyah, and Arthur (2023) in Ghana revealed that students demonstrated positive attitudes and perceptions concerning using GeoGebra software in learning polar coordinates. More so, Horzum and Unlu (2017) in Turkey conducted a study to determine the views of pre-service mathematics teachers

(PMTs) about GeoGebra and its use after being exposed to the processes of designing GeoGebra activities. They indicated that all of the PMTs thought that GeoGebra positively affected their professional development and that GeoGebra could contribute to students' academic achievement. They further revealed that all the PMTs were willing to use GeoGebra in their professional career. Further still, Ibibo and Tubona (2019) investigated students' perceptions and performance across ability levels on GeoGebra Software usage in learning circle geometry in public schools in Nigeria. Their results showed that students had positive perceptions of the use of GeoGebra software for teaching and learning circle geometry. They further revealed that students of all ability levels benefitted from using GeoGebra software in teaching and learning circle geometry. In addition, Awaji (2022) conducted a study on students 'perceptions of using GeoGebra software in mathematics learning in Bisha, Saudi Arabia. He revealed that students believed that GeoGebra software enhanced their understanding of mathematics and improved their learning and visualization. He further revealed that students using GeoGebra software required less writing and drawing shapes, and using the software made learning easier and took less effort.

3. Research Methodology

3.1 Research Design and Research Approach

The study employed a quantitative research approach. This approach relies on methodological principles of positivism and thus adheres to the development of a positivist research design. According to Orodho (2009), quantitative research is employed when control is necessary to explore topics in-depth, discover unexpected findings, and conduct statistical data analysis. The study further used a quasi-experimental research design, which included a pre-test -post-test control group and experimental design. In applying the quasi-experimental design, White and Sabarwal (2014) outlined that the researcher selects the sample of subjects, determines the treatment, decides which groups to receive the treatment, controls variables other than the treatment, and ultimately assesses the effect of the treatment on the groups. The study also employed a cross-sectional design because data were collected to make inferences about a population of interest at one given point in time once and for all (Creswell, Klassen, Clark & Smith, 2011).

3.2 Population

The study targeted students in 580 lower secondary schools in 15 sub-counties in Wakiso District in Uganda. However, the accessible population was limited to students in eight lower secondary schools with well-stocked computer laboratories and other ICT facilities in one sub-county in the said district.

3.3 Sample Size and Sampling Strategies

The study used simple random sampling to select one sub-county from 15 sub-counties. Simple random sampling was also used to select one lower secondary school from eight lower secondary schools that had well-stocked computer laboratories. The study further employed simple random sampling to select the senior two classes among the four lower secondary school classes to participate in the study. The senior two class had 85 students, all of whom were used as the sample size for this study. To assign participants to experimental and control groups, the researchers used the lottery method of simple random sampling to assign 42 students to an experimental group and 43 students to the control group. The simple random sampling method was chosen because it gives each participant an equal chance of being selected and produces a sample representative of the population under study (Creswell, 2003).

3.4 Data Collection Methods and Instruments

We employed a survey method to collect data about the first and third objectives. Self-administered questionnaires (SAQs) were given to the students to collect data about objectives one and three. SAQs were used because they accommodated large numbers of respondents to generalize findings (Best & Kahn, 1993). The SAQ for objective one consisted of two sections, A and B. The questions in Section A were on demography to classify respondents by sex and age. Then, section B consisted of the geometrical concepts covered in the lower secondary mathematics curriculum and instructional tools their teachers used. The SAQ for objective three had sections A, B, and C, filled by the experimental group exposed to GeoGebra training. The questions in Section A were on demography to classify respondents by sex and age. Section B was on students' perceived ease of use of GeoGebra and contained 12 items adapted from Holden and Rada (2011) and had a reliability of $\alpha = 0.89$. Section C comprised 10 items on integration of GeoGebra. Their reliability was obtained by computing Cronbach Alpha, the automatically programmed method in the Statistical Package for Social Scientists (SPSS) that resulted in $\alpha = 0.85$. The questionnaire's content validity index (CVI) was also evaluated, leading to a Content Validity Index of 0.83 for items on perceived ease of use of GeoGebra and 0.8 for items on integration of GeoGebra. Tilden, Nelson, and May (1990) verified that the proper CVI of more than 0.70 confirms the acceptability of items in a questionnaire.

The second objective used an experimental method with pre-test and post-test items to collect data. The pre-test consisted of nine questions focusing on drawing the lines of reflection, reflection of points, objects, and images on the Cartesian plane which were used to assess students' knowledge before the intervention. The post-test questions were similar to the pre-test questions but were interchanged in numbering to appear different in the structure. The nine questions were marked out of 80 with two questions awarded five marks each and the other seven awarded ten marks each. After the GeoGebra intervention, a post-test based on the reflection on the Cartesian plane was administered to both groups to determine the impact of GeoGebra on their performance and achievement. The pre and post-test items were approved as valid by the subject experts in the mathematics department at the school of study. The items were piloted and the level of reliability was very good, with a correlation score of r = 0.94. Madan and Kensinger (2017) asserted that if coefficients yield above 0.8, they are considered very good.

3.5 The Structure of the Intervention

The first phase took three days and involved collecting baseline data from the participants, including background information and students' difficult geometric concepts. The second phase started by giving students from both the experimental and control groups a pre-test on reflection on the Cartesian plane to establish their level of knowledge. The pre-test determined the initial entry points and compared mean differences between the two groups before training. The test established the two groups' baseline understanding of reflection on the Cartesian plane. After the pre-test, the experimental group was taught using GeoGebra software. In contrast, the control group was taught using traditional methods such as chalkboard demonstrations and textbooks. Each group was taught for six weeks with a schedule of two hours once a week. Afterwards, a post-test on reflection on the Cartesian plane was administered to determine how students performed after learning reflection on the Cartesian plane using or without using GeoGebra.

3.6 Data Analysis

Data were analyzed using descriptive and inferential statistics (Amin, 2005). We computed frequencies and percentages of the abstract geometrical concepts covered in the lower secondary mathematics curriculum and the demographic variables to analyze data for objective one. The pre-and post-test data for objective two were analyzed using independent samples t-tests calculated at a 5% confidence level. The t-test was used to test for statistical significance mean differences between the control and experimental groups at the beginning and the end of the training. Furthermore, objective three data were analyzed in the form of frequencies, percentages, means, and standard deviations of items based on the perceived ease of use of GeoGebra and on its integration in learning reflection on the Cartesian plane. Pearson's Linear Correlation examined the relationship between students' perceived ease of use of GeoGebra and its integration in learning reflection on the Cartesian plane.

3.7 Ethical Considerations

Ethics were ensured in this study, where we obtained all necessary permissions and sought consent from all the study participants, who were provided with the necessary information about the purpose and objectives of the study, potential benefits, risks, and procedures. Confidentiality in this study was ensured, and respondents involved were requested not to indicate their names anywhere on the SAQs or test scripts. Participants were informed that they were free to withdraw from the study at any time and were assured that the information they provided in this study was only for research purposes.

4. Findings

4.1 Response Rate and Demographic Characteristics of Respondents

The sample size for this study was 85 senior two students in the selected secondary school in Wakiso District. A total of 85 questionnaires were distributed to senior two students and all of the 85 questionnaires were returned by the respondents to answer objective one. The sample size of 85 senior two students also participated in the pre-test and post-test examinations for objective two, and 42 senior two students for the experimental group were given 42 questionnaires, all of which were returned to answer objective three. This implies a response rate of 100% in all cases, and thus, data were used for analysis. The response rate was excellent for allowing the generalization of the study findings. The demographic characteristics considered included the sex and age of the 85 respondents of the study. Table 1 presents the distribution of respondents by their demographic variables.

Table 1: Demographic Characteristics of Respondents

Item	Variables	Categories	Frequency	Percentage (%)
1	Sex of Respondent	Male	39	45.9
		Female	46	54.1
2	Age in Years	10-12	3	3.5
		13-15	62	72.9
		16 and above	20	23.5

According to the results in Table 1, most of the respondents were female students, with a higher percentage of 54.1. Regarding the age of the respondents, most respondents, with a percentage of 72.9, were between 13 and 15 years old.

4.2 Difficult Geometric Concepts that Caused Challenges to Students When Learning Mathematics

The study's first objective was to identify difficult geometric concepts that challenged students in learning mathematics. Eighty-five senior two students as respondents were given a questionnaire that contained nine geometry concepts extracted from their lower secondary school curriculum from which the most challenging concept was selected. The concepts they were tasked to select from were taught by their teachers during the previous class (senior one). This means that the choice was made based on the experience of the learned geometric concepts. The questionnaire also involved the causes of the identified difficult geometric concept from which respondents selected their choice. Furthermore, respondents identified and gave instructional tools their teachers used to teach geometry concepts. The difficult geometric concept, its cause, and instructional tool(s) were identified and analyzed using descriptive statistics such as frequencies and percentages. Respondents' ratings of their responses are presented in Table 2.

Table 2: Respondents' Rating on Difficult Geometric Concepts that Cause Challenges to them in Learning Mathematics

Item	Variable	Categories	Frequency	Percentage (%)
1	Geometric concepts most difficult to learn	Perpendicular and parallel lines	1	1.2
		Constructing angles	4	4.7
		Drawing polygons	2	2.4
		Measuring length and angles	1	1.2
		Constructing geometric figures	2	2.4
		Identifying lines of symmetry for different figures	1	1.2
		Applying reflection in a cartesian plane	42	49.4
		Forming linear equations with given points	23	27.1
		Drawing the graph of a line given its equation	9	10.6
2	What causes the identified geometric concept to be difficult?	I have a belief that the geometry concept is difficult	19	22.4
		Insufficient problem-solving in this geometric concept	19	22.4
		Some Geometry concepts do not interest me.	11	12.9
		Teaching methods used by teachers in teaching this geometry concept	26	30.6
		Unavailability of Instructional Materials	10	11.8
3	Which instructional tool(s) do teachers use to teach geometry concepts?	Chalkboard only	32	37.6
		Notes	4	4.7
		Textbooks	48	56.5
		Digital tools such as software	0	0
		Projectors	1	1.2
		Desktops	0	0
		Phone	0	0

According to the results in Table 2, respondents were asked to identify the most difficult geometric concept from geometry concepts extracted from their lower secondary school curriculum. It was revealed that the majority of the respondents, with a percentage of 49.4, identified applying reflection on a cartesian plane as the most difficult geometric concept. Additionally, when asked what caused the identified geometric concept to be difficult, the majority of the respondents, with a percentage of 30.6, revealed that the identified concept was difficult due to the teaching methods teachers used in teaching this geometry concept. This indicated an urgent need for different and preferably more interactive teaching approaches to effectively curb these challenges affecting students' achievement in mathematics learning broadly.

Furthermore, when respondents were asked about the instructional tool(s) their teachers used to teach geometry concepts, the majority of the respondents, with a percentage of 56.5, revealed that their teachers used textbooks to teach geometry concepts. This showed that teachers used traditional teaching methods of teaching geometry concepts, such as textbooks, instead of utilizing digital methodologies in teaching and learning mathematics. This also indicated a need for students to be equipped with more interactive sessions with digital instructional tools, and hands-on approaches for these difficult concepts to be eased, leading to improved achievement and visualization of mathematics concepts.

4.3 The Impact of GeoGebra-Based Training on Students' Learning of the Identified Difficult Geometrical Concepts

The second objective was to establish the impact of GeoGebra-based training on students' learning of the identified difficult geometrical concepts. When students identified reflection on the Cartesian plane as a difficult geometric concept, we administered a pre-test to both experimental and control groups.

4.3.1 Pre-test Achievement Scores of the Control and Experimental Groups

The data obtained from the pre-test scores were subjected to a statistical analysis using an independent samples t-test. An independent samples t-test was conducted to determine and test the null hypothesis.

H_{01}: There was no statistically significant difference between the pre-test mean scores of the two groups at a 5% significance level.

Table 3 summarizes the results, presenting the statistics of the pre-test scores of the control and the experimental groups.

Table 3: Independent Samples t-Test of Pre-Test Scores for the Control and Experimental Groups

Variable	N	Mean	Standard Deviation	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff
Experimental	42	4.23	6.86	0.07	83	0.94	0.11	1.54
Control	43	4.34	7.33					

p-value at a significance level, $p > 0.05$.

Table 3 shows that the mean score of the experimental group was 4.23 out of 80, while the control group's mean score was 4.34 out of 80. The standard deviation in both groups did not differ so much from their mean. Table 3 further revealed that the p-value (sig. 2-tailed) for the t-test for the equality of means was 0.94, greater than 0.05. The t value of 0.07 was small, showing a small mean difference between the groups. This implied that the difference in the means was not statistically significant ($t(83) = 0.07$, $p = 0.94 > 0.05$). Since $p > 0.05$, the null hypothesis was accepted. This statistically indicated that learners in both groups had comparable achievement levels and a similar understanding of reflection on the Cartesian plane before the beginning of the intervention.

4.3.2 The Intervention

We taught 42 students in the experimental group the concept of reflection on the Cartesian plane with the help of GeoGebra software, while 43 students in the control group were taught reflection on the Cartesian plane using the traditional approach of chalkboard demonstration and textbooks. We taught each group for six weeks with a schedule of two hours once a week. The experimental group was first guided on how to use the GeoGebra software interface, including the GeoGebra software menu and construction tools, as shown in the sample Figure 1.

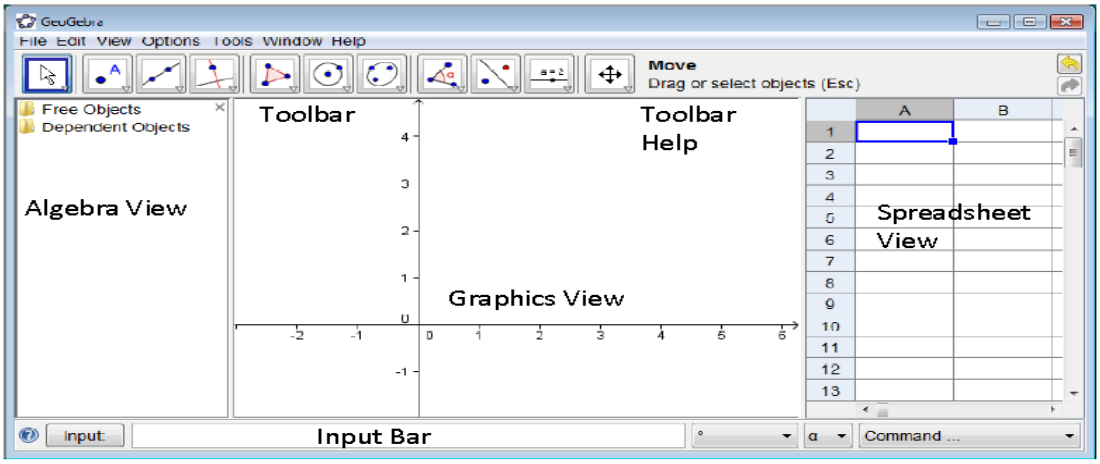
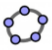
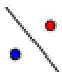


Figure 1: GeoGebra Interface

When the experimental group was familiar with the Software interface, we trained students to use GeoGebra to learn reflection on the Cartesian plane. For example, in determining the coordinates of the image of A (3, 2), if A is reflected across the *x*-axis. They were guided as follows;

- Open a GeoGebra window 
- Select Grid  to show the grid.
- Type (3, 2) in the Input bar or plot the point directly on the grid  by choosing the point icon. 
- Select the Reflect about Line option 
- Click the point A (3, 2) and the *x*-axis.
- Then, the GeoGebra outlook is displayed in the screenshot Figure 2.

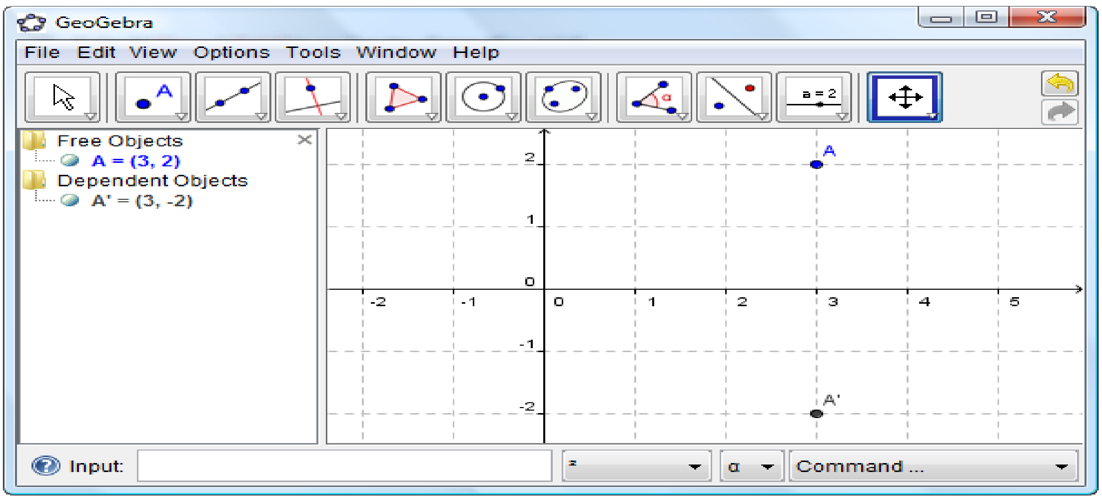


Figure 2. Reflection of A Point on the Cartesian Plane

Figure 2 shows that the coordinates of the image of A (3, 2) if A is reflected across the *x*-axis is A[1] (3, -2).

4.3.3 Post-test Achievement Scores

After the instructional intervention, students in the experimental and control groups were given a post-test examination. The data obtained from the post-test scores were subjected to a statistical analysis using an independent samples t-test. An independent samples t-test was conducted to test the null hypothesis.

H_{02}: There was no statistically significant difference between the post-test mean scores of the two groups at a 5% significance level.

Table 4 summarizes the results, presenting the statistics of post-test scores of the control and experimental groups.

Table 4: Independent Samples t-Test of Post-Test Scores for the Control and Experimental Groups

Variable	N	Mean	Standard Deviation	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff
Experimental	42	71.3	7.91	-11.7	83	.000	43.4	3.70
Control	43	27.9	22.6					

p-value at a significance level, $p < 0.05$.

Table 4 revealed that the control group had a mean score of 27.9 out of 80 and a standard deviation of 22.6. In contrast, the experimental group had a mean score of 71.3 out of 80 and a standard deviation of 7.91, resulting in a mean difference of 43.4, which was large. The control group had a large standard deviation as compared to the experimental group. This showed that the students' scores in the control group were more spread out from the mean than in the experimental group. Additionally, the p-value (sig. 2-tailed) for the t-test for the equality of means was 0.000 less than 0.05. The t-value of -11.7 was large, showing a large mean difference between groups. This implied that the difference in the means was statistically significant ($t(83) = -11.7$, $p = 0.00 < 0.05$). Since $p < 0.05$, the null hypothesis was rejected. These results indicated that GeoGebra-based pedagogy significantly improved students' knowledge in reflection on the Cartesian plane as compared to the traditional approach.

4.3.4 Comparison of Pre-test and Post-test Achievement Scores

The achievement scores from the pre-test and post-test were compared. Table 5 compares students' pre-test and post-test achievement scores in reflection on the Cartesian plane.

Table 5: Comparison of Pre-test and Post-test Achievement Scores

	Experimental Group				Control Group			
Category	N	Mean	SD	Mean Diff	N	Mean	SD	Mean Diff
Pre-test	42	4.23	6.86	67.0	43	4.34	7.33	23.5
Post-test	42	71.3	7.91		43	27.9	22.6	

Table 5 shows that in the pre-test, students in both experimental and control groups had the same achievement levels in reflection on the Cartesian plane. After the intervention, the experimental group demonstrated a significant improvement, with a mean score of 71.3 out of 80 and a slightly small standard deviation of 7.91, showing that the students' scores were uniformly distributed. In contrast, the control group's post-test mean score was 27.9 out of 80, with a standard deviation of 22.6. This demonstrated that students' post-test scores were widely distributed compared to the experimental group. Based on the significant improvement in the scores of the experimental group, GeoGebra software significantly improved students' knowledge in reflection on the Cartesian plane.

An independent samples t-test was further conducted to test the null hypothesis that.,

H_{03}: There was no statistically significant mean difference between students' pre-test and post-test achievement scores in the learning of reflection on the Cartesian plane.

Table 6 indicates the results of the independent samples t-test of the mean differences for pre-test and post-test achievement scores in both groups.

Table 6: Independent Samples t-Test for the Mean Differences

	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff
Difference	-12.6	83	.000	-43.5	3.45
	-12.6	67.5	.000	-43.5	3.43

p-value at a significance level, p < 0.05.

Table 6 shows that the p-value (sig. 2-tailed) was 0.00 less than 0.05. The table also indicates that the t-value -12.6 was large, showing a large mean difference between the groups. This implied that the difference in the means was statistically significant ($t(83) = -12.6$, $p = 0.00 < 0.05$). Since $p < 0.05$, the null hypothesis was rejected. Based on the findings, there was a statistically significant mean difference between students' pre-test achievement scores and post-test achievement scores in their learning of reflection on the Cartesian plane.

4.4 Relationship between Students' Perceived Ease of Use of GeoGebra and its Integration in Learning Reflection on the Cartesian Plane

The third objective of the study was to establish the relationship between the perceived ease of use of GeoGebra and its integration in learning reflection on the Cartesian plane. When the experimental group completed the post-test, they were given a questionnaire to assess their perceived ease of use of GeoGebra and its integration in learning reflection on the Cartesian plane. Section A comprised 12 items on the perceived ease of use of GeoGebra, and section B comprised 10 items on the integration of GeoGebra.

4.4.1 Perceived Ease of Use of GeoGebra Software in Learning Reflection on the Cartesian Plane

In this section, the responses were measured using a five-point Likert scale where 1 = Strongly Disagree (SD), 2 = Disagree (D), 3 = Neutral (N), 4 = Agree (A), and 5 = Strongly Agree (SA).

Table 7 gives the descriptive results, namely frequencies, percentages, means, and standard deviations of the items on perceived ease of use of GeoGebra in learning reflection on the Cartesian plane.

Table 7: Respondents' Rating of their Responses on Perceived Ease of Use of GeoGebra in Learning Reflection on the Cartesian Plane

Item	Description	SD Count (%)	D Count (%)	N Count (%)	A Count (%)	SA Count (%)	Mean	Std.
PEU1	My interaction with the GeoGebra is clear and understandable	0 (0)	0 (0)	3 (7.1)	15 (35.7)	24 (57.1)	4.50	0.63
PEU2	Interacting with the GeoGebra does not require a lot of mental effort.	1 (2.4)	1 (2.4)	6 (14.3)	19 (45.2)	15 (35.7)	4.09	0.90
PEU3	I find GeoGebra software easy to use.	0 (0)	0 (0)	1 (2.4)	13 (31)	28 (66.7)	4.64	0.53
PEU4	I find it easy to get GeoGebra to do what I want it to do.	1 (2.4)	2 (4.8)	3 (7.1)	19 (45.2)	17 (40.5)	4.16	0.93
PEU5	I find GeoGebra to be flexible to interact with.	2 (4.8)	0 (0)	5 (11.9)	20 (47.6)	15 (35.7)	4.09	0.95
PEU6	GeoGebra software provides helpful guidance in performing tasks.	1 (2.4)	1 (2.4)	3 (7.1)	19 (45.2)	18 (42.9)	4.23	0.87
PEU7	The GeoGebra has good functionality (features), such as construction tools, algebra views, and graphic views	0 (0)	2 (4.8)	4 (9.5)	18 (42.9)	18 (42.9)	4.23	0.82
PEU8	I find it difficult to use GeoGebra software	28 (66.7)	4 (9.5)	5 (11.9)	4 (9.5)	1 (2.4)	1.71	1.15
PEU9	I find it easy to remember how to perform tasks using GeoGebra.	2 (4.8)	2 (4.8)	5 (11.9)	17 (40.5)	16 (38.1)	4.02	1.07
PEU10	I can explain reflection concepts with GeoGebra easily	0 (0)	1 (2.4)	5 (11.9)	20 (47.6)	16 (38.1)	4.21	0.75
PEU11	I become confused when I use GeoGebra software in learning reflection	27 (64.3)	7 (16.7)	2 (4.8)	5 (11.9)	1 (2.4)	1.71	1.15
PEU12	The user interface of GeoGebra is user-friendly	3 (7.1)	0 (0)	3 (7.1)	14 (33.3)	22 (52.4)	4.23	1.10
	Overall mean						**3.82**	

From Table 7, the overall mean response on all the items that measured the perceived ease of use of GeoGebra software in learning reflection on the cartesian plane was 3.82. When rounded off to the nearest whole, this mean corresponds with code 4 on the five-point Likert scale, which indicates an agreed response. Therefore, this revealed that students agreed that they perceive GeoGebra software to be easy to use in learning reflection on the Cartesian plane.

4.4.2 Integration of GeoGebra in Learning Reflection on the Cartesian Plane

The first five items of this section were on students' engagement (SE), and the last five were on students' achievement (SA). The responses were measured using a five-point Likert scale where 1 = Strongly Disagree (SD), 2 = Disagree (D), 3 = Neutral (N), 4 = Agree (A), and 5 = Strongly Agree (SA).

Table 8: Respondents' Rating of their Responses on Integration of GeoGebra in Learning Reflection on the Cartesian Plane

Item	Description	SD Count (%)	D Count (%)	N Count (%)	A Count (%)	SA Count (%)	Mean	Standard Deviation
SE1	I can use GeoGebra to reflect an object on a line y = x to form an image	0 (0)	0 (0)	0 (0)	17 (40.5)	25 (59.5)	4.59	0.49
SE2	I can use GeoGebra to reflect a point on any line on the cartesian plane	1 (2.4)	0 (0)	2 (4.8)	14 (33.3)	25 (59.5)	4.47	0.80
SE3	I can collaborate with others to use GeoGebra in reflecting an object on the y and x-axes	2 (4.8)	1 (2.4)	0 (0)	11 (26.2)	28 (66.7)	4.47	0.99
SE4	I can use GeoGebra construction tools to create an object using a polygon tool	1 (2.4)	0 (0)	1 (2.4)	14 (33.3)	26 (61.9)	4.52	0.77
SE5	GeoGebra creates a good visualization of an object and an image after reflecting on the cartesian plane	1 (2.4)	2 (4.8)	3 (7.1)	11 (26.2)	25 (59.5)	4.35	0.98
SA1	Using GeoGebra tools helped me reflect on a point on the y and x-axes	1 (2.4)	0 (0)	1 (2.4)	13 (31.0)	27 (64.3)	4.54	0.77
SA2	GeoGebra was able to help me create an image after reflecting an object in the line	1 (2.4)	0 (0)	2 (4.8)	11 (26.2)	28 (66.7)	4.54	0.80
SA3	GeoGebra tools help me construct the line of reflection when given an object and image	1 (2.4)	0 (0)	1 (2.4)	15 (35.7)	25 (59.5)	4.50	0.77
SA4	GeoGebra was able to help me grasp reflection concepts more easily	0 (0)	1 (2.4)	2 (4.8)	14 (33.3)	25 (59.5)	4.50	0.70
SA5	Using GeoGebra helps me reflect an object on a line y = -x to form an image	1 (2.4)	0 (0)	2 (4.8)	14 (33.3)	25 (59.5)	4.47	0.80
	Overall						**4.50**	

Table 8 gives the descriptive results, namely frequencies, percentages, means, and standard deviations of the items on integrating GeoGebra in learning reflection on the Cartesian plane.

From Table 8**,** the overall mean for GeoGebra integration in learning reflection on the Cartesian plane, including student engagement and student achievement, was 4.50. When rounded off to the nearest whole, this mean corresponds with code 5 on the five-point Likert scale, which indicates a strongly agreed response. This means that the respondents strongly agreed that GeoGebra improved their engagement and performance in reflection on the Cartesian plane. This further reveals that GeoGebra empowers students to understand, explore, and master difficult geometric concepts easily. We tested the null hypothesis for the third objective,

H_{04}: There was no statistically significant relationship between students' perceived ease of use of GeoGebra and its integration in learning reflection on the Cartesian plane.

We used Pearson's Linear Correlation Coefficient (PLCC), to test the relationship whose coefficient, r, was 0.53, showing a positive linear relationship between students' perceived ease of use of GeoGebra and its integration in learning reflection on the Cartesian plane. However, given the size of the coefficient, this was of moderate strength. This correlation indicated that as the students' perceived ease of use of GeoGebra increased, its integration also moderately increased. Furthermore, PLCC revealed a significant value/ p-value of 0.00, which was far less than α- the value of 0.05. Since $p < \alpha$, the null hypothesis was rejected, implying that students' perceived ease of use and integration of GeoGebra in learning reflection on the Cartesian plane were moderately significantly positively linearly correlated.

5. Discussion

The study sought to enhance the students' knowledge of integration of GeoGebra into mathematics learning in lower secondary schools in Wakiso District, Uganda. The study's results revealed that reflection on the Cartesian plane was found to be the most difficult geometric concept among senior two students. This was revealed by 49.4% of the respondents.

This finding was in agreement with other scholars; for instance, Fabiyi, (2017) in Nigeria revealed that students found more difficulty in congruent triangles, locus, surface areas of solid figures, solid figures' volume, latitude, longitude, bearing, coordinate geometry and distances. Furthermore, Barut and Retnawati (2020) in Indonesia revealed that students faced some difficulties, such as being unable to identify the geometry shapes based on their formal definition properly, lack of visualization ability, failure to understand specific terms or symbols of geometry, and insufficiency in providing proper reasoning related to relationships within geometric shapes. Similarly, the learners in South Africa had problems defining geometric terms, interrelations of properties and shapes, and changing semiotic representations (Ngirishi & Bansilal, 2019).

The study's findings further indicated that the identified concept was difficult due to the teaching methods teachers employed in teaching this geometric concept. This finding also aligns with the study by Ubi, Odiong, and Igiri (2018) in Nigeria who revealed that senior two learners viewed geometry concepts as difficult due to the teacher's teaching methods. This implies that teaching methods are very vital in teaching geometry concepts. In their study in Sri Lanka, Juman, Mathavan, Ambegedara, and Udagedara (2022) revealed that student-based learning approaches were more effective than conventional methods for teaching Geometry. Therefore, policymakers should ensure that the mathematics curriculum includes appropriate teaching and learning approaches like student-based approaches. The student-based approaches may include hands-on activities and the integration of digital tools in geometry learning. These approaches help students construct knowledge through interaction with others and technological tools, improving their understanding of geometry concepts. Further still, policymakers should organize continuous professional development courses to help teachers acquire skills to integrate such approaches into their teaching. According to Mikael and Asa (2019), skillful teachers are important agents of change concerning quality teaching, which goes beyond teaching methods and available resources. When teachers have the required skills, they will focus on educational practices that provide all learners with the knowledge and skills necessary to contribute to the global society.

The results further revealed that using GeoGebra resulted in higher achievement scores in the experimental group and a statistically significant mean difference between students taught reflection on a cartesian plane with GeoGebra and those taught with traditional methods. Thus, incorporating GeoGebra software in learning helps students learn more effectively. This finding was in agreement with Seloraji and Eu (2017) in Malaysia, who found that GeoGebra enhanced year one students' performance in geometrical reflection. It also helped students explore the concepts more in detail and develop their geometry knowledge. Similarly, Ocal (2017) in Turkey revealed that instruction with GeoGebra had a positive effect on university students' scores regarding conceptual knowledge and their overall scores. Furthermore, Zulnaidi and Zamri (2016) in Malaysia revealed that form two students who used GeoGebra to learn mathematics had higher mathematical conceptual and procedural knowledge than those who learned through conventional methods. This implies that GeoGebra-based training enhanced the students' achievement in reflection on the Cartesian plane. It is also an important educational tool that supports the traditional lecture method of teaching reflection on the Cartesian plane and shifts the education system from teacher-centered to learner-centered (Dahal, Shrestha, & Pant, 2019).

Therefore, teachers should emphasize GeoGebra-based pedagogies as they improve students' knowledge. However, in some countries like Uganda, teachers' ICT usage during teaching and learning is minimal because of a lack of technological skills and inadequate training that intensely influences the use of ICT in the mathematics classroom (Muweesi, *et al.*, 2022). Therefore, there is an urgent need for Uganda and other such countries to organize continuous professional development courses to equip in-service teachers with technological knowledge and skills and how to integrate them into the teaching and learning process. Regular in-service training helps mathematics instructors to be up to date with contemporary teaching techniques of the 21st-century teachers and keep pace with the changing times.

The study further revealed that respondents agreed to have perceived GeoGebra software to be easy to use in their learning of reflection on the Cartesian plane (Table 8). This finding is in agreement with Awaji (2022) in Saudi Arabia, who revealed that grade eight students using GeoGebra software required less writing and drawing shapes because using the software made learning easier and took less effort. According to Davis (1989) when users perceive that a type of technology is useful and easy to use, they will be willing to use it. Mensah, Ansu, Karadaar, and Junior (2023) revealed that teachers were willing to integrate GeoGebra in their lessons once they were equipped with the knowledge and skills to integrate the software in their mathematics lessons. According to NCTM (2000), the teacher is the most important element known to impact student learning. In this regard, policymakers should develop policies that raise awareness of the trending technologies like GeoGebra software used in mathematics education as a learning technology tool.

Concerning the relationship between students' perceived ease of use of GeoGebra and its integration in learning reflection on the Cartesian plane, a significant positive linear correlation of moderate strength was found. This revealed that students acquired knowledge during the training to integrate GeoGebra into their learning, and they strongly agreed that GeoGebra improved their engagement and achievement in learning reflection on the Cartesian plane (Table 9). This was in agreement with Rajagopal, Ismail, Ali, and Sulaiman (2015), who revealed that there was a significant relationship between perceived ease of use, perceived usefulness, and students' attitudes towards GeoGebra. This implies that countries like Uganda should incorporate GeoGebra in the mathematics curriculum to utilize the potential benefits of GeoGebra in learning mathematics.

6. Conclusion

Based on the discussion of the findings, GeoGebra has proved to be more effective in enhancing students' knowledge. The hands-on and interactive approach of the software had a positive effect on students' engagement and achievement. It enabled learners to understand concepts much better than those not exposed to the software. Thus, the study recommends more intensive training for students in integrating GeoGebra into their mathematics learning. This can be done through seminars and incorporating the use of GeoGebra into the school mathematics curriculum. Despite the significant contribution of this study, it had limitations. For example, the study utilized only a quantitative approach, yet more data could have been obtained if the qualitative approach had been embedded. Thus, further studies that are dominantly qualitative or mixed can be done to analyze students' knowledge of integrating GeoGebra in mathematics and incorporate students' verbatim opinions.

Authors' Contributions

This work is a result of research conducted for the award of a degree of Master of Education in Science Education (MESE) of Makerere University. Thus, the first author, Glorious Karungi, is a MESE student, who will be graduating in January 2025. The second author, Marjorie Sarah Kabuye Batiibwe is the first author's research supervisor appointed by Makerere University and has guided the first author throughout this research journey, right from the proposal to the final thesis writing. As a student, the first author collected the data, analyzed them, and wrote the first draft of this manuscript and a research report. The second author guided the first author in data analysis, discussion of the findings, and generally writing the thesis which was submitted for examination in July 2024. Further, she has structured and edited the manuscript. We have both approved this manuscript for submission. We further confirm that the manuscript's content has not been published or submitted for publication elsewhere. However, the 89-paged monograph from which this manuscript emanated has been submitted to Makerere University for the award of a MESE degree for the first author. We all read and approved the final manuscript.

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Data Availability

All data generated and analyzed during this study are included in this published article.

Ethics Approval and Consent to Participate

The Makerere University School of Social Sciences Research Ethics Committee exempted this study from research clearance.

Competing Interests Statement

The authors have no relevant financial or non-financial competing interests to disclose.

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