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Enhancing Students' Attitudes in Learning 3-Dimension Geometry using GeoGebra

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Abstract. Using technology for learning geometry has been found to have a positive impact on students' skills and attitudes. GeoGebra software is effective in encouraging teachers to employ technology as a supporting tool to improve student potential in their learning of mathematics. However, GeoGebra software has not yet been formally introduced into the teaching and learning of mathematics in Rwanda. This research aimed to ascertain Rwandan upper secondary school students' attitudes when learning geometry with GeoGebra. A total of 84 participants from four schools were purposively sampled and categorized into two quasi-experimental design groups. A group of 44 students was the control group, and 40 students formed an experimental group. Attitude scales were administered to both groups pre and post intervention. Students in the control group were taught geometry in the traditional way, and students in the experimental group studied 3D geometry using GeoGebra software as a supporting tool. To collect data, we used a standardized attitude scale. The results reveal a statistically significant difference between the groups and, therefore, confirm the effectiveness of GeoGebra in improving students' attitudes when learning 3-D geometry. However, a correlation analysis did not find a high correlation between students' performance and attitude. Based on the results, the researchers recommended integrating GeoGebra software at different levels of education in Rwanda, in mathematics curricula generally, and in geometry in particular.

Keywords: GeoGebra; Geometry; Mathematics; Rwandan secondary schools; student attitudes

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1. Introduction

Mathematical ideas, procedures, patterns, and rules are fundamental to every aspect of our day-to-day actions. Since mathematics is now a part of daily life, it has become crucial to include mathematics instruction from an early age in our schooling (Mollah, 2017).Mathematics is regarded as the mother of all sciences, and the universe cannot move without mathematical knowledge and skills (Mollah, 2017). At the same time, mathematics has proven to be a complex subject for secondary school students in different countries (Mukuka et al., 2021; Niyukuri et al., 2020) – not only in Rwanda (Ukobizaba et al., 2019). This difficulty is evident in the challenges that have been observed in teaching and learning mathematics at different levels of education in different contexts. Globally, students from many countries, excluding some East Asian countries, such as China, Japan, Singapore, and South Korea, have struggled to perform at or above international benchmarks in most of the international assessments that have been administered to date (Echazarra & Radinger, 2019; Gronmo et al., 2016). According to Mollah (2017), students face failure and difficulties in mastering mathematics content. These difficulties affect students' attitudes toward mathematics and the nature of mathematics negatively, discourage them from learning, their enjoyment of mathematics (Jackson, 2008), and the teaching approaches used (Oberlin, 1982). Brady and Bowd (2005), in a study on mathematics anxiety, prior experience, and confidence of pre-service education students to teach mathematics, claim that students struggle to understand because they are taught mathematics with inappropriate methods; therefore, teachers should create a good teaching environment by applying practical ways of teaching and learning mathematics (Brady & Bowd, 2005).

Length (2013) and Majerek (2014) in their studies argued that geometry has been found to be an interesting and valuable branch of mathematics. This in agreement with Le and Kim (2017) and Ibrahim and llyas (2016) whose study findings confirmed the importance of geometry in our daily life and this deals with the properties of lines, angles, curves, shapes, and so on. Geometry helps students associate patterns in mathematics and equips them with the ability to apply the acquired knowledge when solving real-life problems (Kutluca, 2013). Traditionally, geometry concepts are taught using chalk, pencil, and paper, resulting in students finding it difficult to produce geometrical representation correctly (Sariyasa, 2016). The traditional teaching approach has been found lacking in providing opportunities for students to develop their understanding of geometry concepts and develop a positive attitude towards geometry (Jelatu, 2018). As a result, the traditional approach is less effective in helping students to develop their level of thinking. For instance, students recall geometry experiences as unpleasant and often consider geometry to be a challenging topic in mathematics (Le & Kim, 2017). This was also revealed by Uwurukundo et al. (2022) when conducting a study on students' achievement and attitudes toward geometry (Niyukuri et al., 2020). GeoGebra has been recognized as one of the teaching and learning tools that offers support for enhancing students' understanding of geometry-related topics (Doğan & İçel, 2010; Hanč et al., 2011; Murni et al., 2017).

In accordance with current Rwandan education policies, information and communication technologies (ICTs) are considered important tools for improving students’ attitudes and performance at all levels of education (Rwanda Education Board [REB], 2016). ICT tools and software have changed the ways people communicate and have enhanced significant transformations in a variety of fields, including industry, agriculture, medicine, and many other sectors. The REB (2016) recommends that ICT tools are integrated into the learning of mathematics in secondary schools, due to the importance of mathematics for several technology and science domains. In a review of literature, Uwurukundo et al. (2020) explain that mathematics domains include geometry, algebra, calculus, and trigonometry, and argue that students can explore the software and acquire mathematics knowledge more independently than students who are subjected to traditional learning methods. The expectation is that exposing students to new technology for teaching and learning of mathematics improves their competencies and achievement, both in the classroom and in their daily lives (Mathevula & Uwizeyimana, 2014).

GeoGebra, which is rapidly gaining popularity in education worldwide, has been found effective in enhancing the teaching and learning of mathematics. Almost two decades ago, GeoGebra was already available in 52 languages, used in 190 countries, and downloaded 300,000 times a month (Hohenwarter & Lavicza, 2003). Abu et al. (2010) found that GeoGebra increased students' confidence in mathematics; students become motivated when they used GeoGebra while learning mathematics. GeoGebra can help students grasp experiments, solve mathematics problems, and do research, either in the classroom or at home. Similarly, GeoGebra can develop visualization and understanding of different mathematical topics, including geometry (Akkaya et al., 2011; Majerek, 2014). Using a computer algebra system and an interactive, dynamic geometry system is likely to enhance students' cognitive abilities and interest in learning mathematics (Bye et al., 2007; Diković, 2009; Uwurukundo et al., 2020).

Insight into students' attitudes and beliefs is important if teachers are to understand the learning environment of mathematics, which has been affected by the introduction of computers and other technologies (Ukobizaba et al., 2019). GeoGebra has the potential to shape learners' knowledge acquisition and change teachers' teaching practices – teachers need to accept learners' autonomy (Uworwabayeho, 2009). In line with this perspective, teachers' awareness of students' attitudes towards geometry is useful, as teachers can identify those students who have negative attitudes towards geometry and take adequate precautions (Aktas & Aktas, 2012).

Saha et al. (2010), in a study that examined the effects of GeoGebra on the learning of coordinate geometry by students, found that the use of GeoGebra increased students' performance, and they argue that using GeoGebra might influence students to have positive attitudes towards the subject. For this reason, integrating ICT tools in the teaching and learning of mathematics using computer software (Fančovičová & Prokop, 2008), such as GeoGebra, appears to motivate students to access their resources, construct new ideas, and improve their competencies, thereby overcoming the challenges inherent in traditional teaching methods. As an example of a mathematics instruction technology tool, GeoGebra software has different effects on students' achievement, depending on how it is integrated into teaching and learning (Uwurukundo et al., 2020). Uwurukundo's study (2022) focused on the effect of GeoGebra software on secondary school students' achievement in 3-D geometry and found using GeoGebra improved students' performance. Therefore, there is a need to evaluate students' attitudes and the correlation between attitude and performance when learning with GeoGebra.

Because of the emphasis on the need to integrate ICT in the teaching and learning of mathematics, and other subjects, Nzaramyimana (2021) conducted a study to explore the effectiveness of GeoGebra for enhancing students' active learning, performance, and interest in learning mathematics. In turn, Uwurukundo et al. (2022) investigated the effect of GeoGebra software on secondary school students 'achievement in 3-D geometry – no other studies conducted in Rwanda have attempted to establish (statistically) the effectiveness of ICT tools such as GeoGebra on improving students' attitudes towards 3-D geometry in Rwandan secondary schools, or determine teachers' views on using GeoGebra when teaching mathematics. In that respect, the present study sought answers to the following research questions: *How does GeoGebra software affect students' attitudes about learning geometry? Is there a correlation between learners' performance and attitude scores?*

2. Methodology

This research adopted a quasi-experimental research approach and a non-equivalent group design (Fraenkel et al., 2012). A total of 84 students participated in the research and were allocated to either a control or experimental group. We purposively selected four schools: two in Northern Province (one boarding and one day school), and two in Kigali city (one boarding and one day school). We wished to conduct the research in schools with Mathematics Physics, and Computer (MPC) and Mathematics, Computer and Economics (MCE) subject combinations, because we wanted to include students with ICT backgrounds and who, thus, learned mathematics as their main subject. The schools that were selected had common characteristics. A second reason for selecting these four schools was that we had limited time and money to conduct the research. We decided to conduct the research with these subject combinations, as we wanted to control certain variables, including student ICT background. Intact classes were used, to avoid inconveniencing the schools' academic programs. Before data collection, the researchers submitted the research proposal to the University of Rwanda College of Education (URCE) and was accepted and approved in relation to ethics by the research and innovation unit. The ethical clearance was used to seek permissions at the district level; letters were provided for presentation to selected schools.

Research instruments, reliability, and validation

The researchers administered a questionnaire for an attitude test, which comprised 34 statements answered by a 5-point rating scale (Strongly disagree, Disagree, Undecided, Agree, and Strongly Agree). The questionnaire was adopted from various articles and books (Abdullah & Zakaria, 2011; Andamon & Tan, 2018; Baya'a & Daher, 2013; Ndibalema, 2014; Semerci & Aydın, 2018), and modified. Researchers at university level and mathematics teachers at secondary levels provided their their inputs, and it was piloted with students at other schools with the same characteristics as those selected for the study. Collected data were entered and analyzed using SPSS 23.0 to determine reliable validity. A principal component analysis (PCA) was conducted to assess the number of factors to be extracted. An Eigenvalue of 1 was set as the minimum cut-off point for extracting several factors. Prior to PCA, an assessment was conducted to qualify the data for PCA. Kaiser-Meyer-Olkin of sampling adequacy (KMO) indicated that the sample size was not sufficient (0.318). However, Berlet's test of sphericity was significant (Chi-square=496.878, df=435, Sig.=0.021), indicating that the data were fit for PCA with an unrotated solution.

Varimax solution was then used to extract five factors with a minimum loading value of 0.30. All the items except item 14 met the minimum loading value, ranging from 0.311 (item 13) to 0.839 (item 25). Internal reliability consistency was then determined using Cronbach's alpha of coefficient and corrected item-total correction. An item is considered to be reliable if it meets minimum values of Cronbach's alpha of 0.70 or higher, and a corrected item to the total correlation of at least 0.30. Four additional items did not comply with reliability levels, and they were removed from further analysis. In addition, factor 5 had the lowest reliability value, suggesting that it needed further investigation. After checking for instrument validity, we made some modifications based on the analysis done on the attitude questionnaire. We remained with 30 statements that were used to collect data on students' attitudes towards the learning of geometry, their interests, and the benefits of using ICT tools before and after learning 3-D geometry. The study was conducted from December 2020 to June 2021.

A researcher determined whether all schools that were selected had the same characteristics, such as availability of computer labs, internet connection, and teachers who could use computers in the teaching process, especially at the schools in the experimental group, and a calendar that was flexible enough so that 3-D geometry could be taught. After checking these variables, questionnaires for the pre and post attitude tests (assessment) were administered in English, which is the language of instruction in the Rwandan education system. After giving the pre-assessment to all students from both groups, the control group was subjected to conventional teaching and learning methods, such as blackboard and chalk, and groupwork and discussion by students, while the experimental group integrated the use of GeoGebra in the teaching and learning process of 3-D geometry, using computers and projectors. The first author presented a four-day workshop on the use of GeoGebra for teaching 3D geometry. After completing the workshop's activities, we requested all teachers of the experimental group to start teaching the 3-D geometry.

During the intervention, the corresponding author assisted teachers in the experimental group to download and install GeoGebra software and to conduct an introductory session to let students feel welcome; the students' first reactions to the tool were observed. The researchers visited both groups to observe how the process was proceeding, and to ensure that the methodology to be used for particular groups had been mastered. After the experiment, the post assessment questionnaire (the same instrument as the pretest) was administered for both control and experimental groups, to determine whether the methodology used during the teaching process of 3D geometry had affected student attitudes and performance. This study formed part of a large project that was undertaken for the first author's doctoral research. This article represents a follow-up of a previously published performance-based article (Uwurukundo et al., 2022). Thus, the present study reveals the attitude enhancement due to GeoGebra integration; the previous article had revealed its effect on student performance. Readers are referred to Uwurukundo et al. (2022) for a detailed description of the performance test that was used.

Final geometry attitude scale

After gathering data with a 30-item attitude scale, we reanalyzed the items and removed ten items that were duplicates or which investigated the same construct. This helped us to present valid and reliable data. The final twenty items were analyzed by grouping items or statements, and eight themes were formulated: Prerequisite knowledge (one item), Enjoyment in learning geometry (one item), Confidence (four items), Teaching method (four items), Resources (one item), Learning supporter (two items), ICT (four items), and Real life (three items). Then, four factors were formulated from these eight themes. Pre-requisite knowledge, Enjoyment in learning Geometry, and Confidence formed the Confidence (with six items) factor. Teaching method, Resources, and Learning supporter formed the Learning support (with seven items) factor. ICT and Real-life remained as they were as themes (see Table 1).

Table 1: Four factors and their corresponding items

		Attitude statements	Strongly disagree	Disagree	Undecided	Agree	Strongly agree
Confidence	1	My foundation in mathematics in primary school affects my performance in secondary school					
	2	I enjoy learning geometry					
	3	I am sure that I can learn geometry better					
	4	I feel confident when studying geometry					
	5	I can get good grades in geometry					
	6	It is very difficult to perform other mathematics topics except for geometry					
Learning support	7	Teaching methods of geometry contribute to my performance					
	8	Memorization helps in the learning of geometry					
	9	I do solve geometry problems at home because there is somebody to guide me					
	10	In the classroom, we have mathematical instruments and tools for drawings in geometry					
	11	My teacher is competent in teaching geometry					
	12	Students should be more involved in practical work than theoretical work					
	13	Working in groups improves my performance in geometry					
ICT	15	The use of computers in the teaching of mathematics affects my performance positively					
	15	Interactive websites make me perform better in geometry					
	16	Geometry is better when taught using ICT tools like software, computers, projects, the internet, etc.					
	17	ICT can facilitate me to learn geometry					
Real-life	18	Geometrical topics in schools are related to real-life situations					
	19	Knowing geometrical concepts will help me earn a living					
	20	I study geometry because I know how useful it is					

Analysis and Data presentation

We used an MS Excel 2016 spreadsheet to record and analyze data. In the first phase, we cleaned the data by removing records of students who did not complete both pre and post assessments. We also matched each student on performance to attitude scores, since we needed to collate the attitude results to our previously published performance scores (Uwurukundo et al., 2022). Thus, three students (one on the performance test and two on the attitude scale) in the control group were removed from the analysis. Similarly, two students in the performance test and four students on the attitude scale were filtered out of the experimental group. Therefore, this analysis comprises 84 students: 44 in the control and 40 in the experimental group.

In the second phase, we computed descriptive statistics, such as the percentage of students who chose a certain scale. COUNTIF functions were used to determine who had selected each response on the Likert scale. Table 2 presents the results of the geometry learning attitude scale. The table has four main columns: The first column has four factors depicted in the scale; the second column shows the number of items (from 1 to 20), and the third shows the number of students in the control group (as percentage, %) who selected one of the five Likert scale responses (strongly disagree, SD; disagree, D; undecided, U; agree, A and strongly agree, SA). The fourth main column shows the number of students in the experimental group who agreed or disagreed with the attitude statements. Both control and experimental columns have two columns that present the number of students at pre and post attitude assessment. All numbers of students on each scale (from SD to SA) are rounded to add up to 100%. For instance, on item_1 [My foundation of mathematics in primary school affects my performance in secondary school], 7% of students in the control group strongly disagreed with the statement at the pre assessment stage, 16% disagreed, 14% were not sure (undecided), 35% agreed, and 28% strongly agreed with the statement.

Table 2. Results of the attitude scale for two groups (control and experimental) on pre and post assessment

Factors	Items	Control group										Experimental group									
		Pre-assessment (%)					Post-assessment (%)					Pre-assessment (%)					Post-assessment (%)				
		SD	D	U	A	SA	SD	D	U	A	SA	SD	D	U	A	SA	SD	D	U	A	SA
Confidence	1	7	16	14	35	28	9	14	5	58	14	18	10	5	44	23	18	10	5	44	23
	2	21	28	14	28	9	0	2	2	57	39	18	35	28	20	0	3	10	0	43	45
	3	7	0	30	48	16	2	7	5	45	41	5	3	8	40	45	5	3	5	40	48
	4	20	25	20	23	11	14	25	18	32	11	18	53	15	10	5	0	8	3	39	50
	5	18	23	18	30	11	11	16	14	39	20	13	28	40	20	0	0	8	10	30	53
	6	30	39	11	16	5	7	20	11	43	18	23	13	10	28	26	23	13	10	28	26
Learning support	7	18	45	2	27	7	0	0	7	61	32	15	18	23	30	15	0	0	3	48	50
	8	14	57	11	14	5	5	16	11	48	20	0	20	23	40	18	3	10	5	45	38
	9	20	43	18	14	5	9	50	9	27	5	13	18	3	46	21	10	21	3	46	21
	10	27	27	16	25	5	20	20	7	43	9	10	33	33	20	5	10	10	5	43	33
	11	2	11	18	34	34	5	0	9	34	52	10	30	28	23	10	3	5	3	43	48
	12	2	7	5	44	42	5	5	5	39	48	8	40	20	28	5	0	13	8	33	46
	13	5	20	16	23	36	2	2	0	51	44	0	0	3	33	65	0	0	3	33	65
ICT	14	41	23	16	20	0	32	39	5	11	14	23	33	23	18	5	23	5	0	20	53
	15	36	41	16	5	2	25	41	14	9	11	13	58	30	0	0	0	0	5	63	33
	16	44	42	5	7	2	43	27	11	14	5	25	38	23	13	3	18	8	0	28	48
	17	25	30	18	18	9	43	27	18	7	5	25	35	30	10	0	5	10	10	20	55
Real life	18	9	9	20	45	16	7	12	21	58	2	10	10	15	35	30	10	10	13	35	33
	19	5	16	32	32	16	7	14	20	39	20	5	0	8	61	26	5	0	8	61	26
	20	9	25	25	30	11	7	9	16	47	21	0	8	5	58	30	0	8	5	55	33

In the third phase of analysis, we wanted to answer the first research question about whether GeoGebra enhanced students' attitudes towards learning geometry. First, we averaged strongly disagree and disagree into a single disagree theme, undecided remained an undecided theme, and agree and strongly agree were combined into an agree theme. Secondly, we analyzed control and experimental groups regarding attitude factors, such as confidence, learning support, ICT, and real life. We then checked the pre and post assessment of each group and computed the differences. This difference allowed us to generate inferential statistics between these two groups. Thus, we first averaged the scores along with all 20 items for each of the students; then, we measured the difference between post and pre attitude scores in the control and experimental groups. The experimental and control groups were exposed to a pre attitude questionnaire before the start of the treatment to ascertain whether the students who had been selected to participate in the study had comparable characteristics before the study. The independent samples t-Test was used to analyze whether there were significant differences in the mean attitude scores of the experimental and the control group. Before measuring this significance, we first presented a descriptive analysis.

In the fourth and last phase, we took average scores from each student's performance test and attitude scale and then computed the correlation between pre-tests (performance versus attitude) of control and experimental groups and between post-tests of the same groups.

3. Findings

Figures 1, 2, and 3 present the number (in %) of students who fall into three categories of an attitude scale. Figure 1 shows two parts, the left side shows results from pre assessment (before learning geometry) and the right side shows results from post assessment (after learning geometry using the traditional teaching method). For instance, on item_2 [I enjoy learning geometry] under the confidence factor, the attitude score increased from 37% to 95% of students from the pre to the post assessment.

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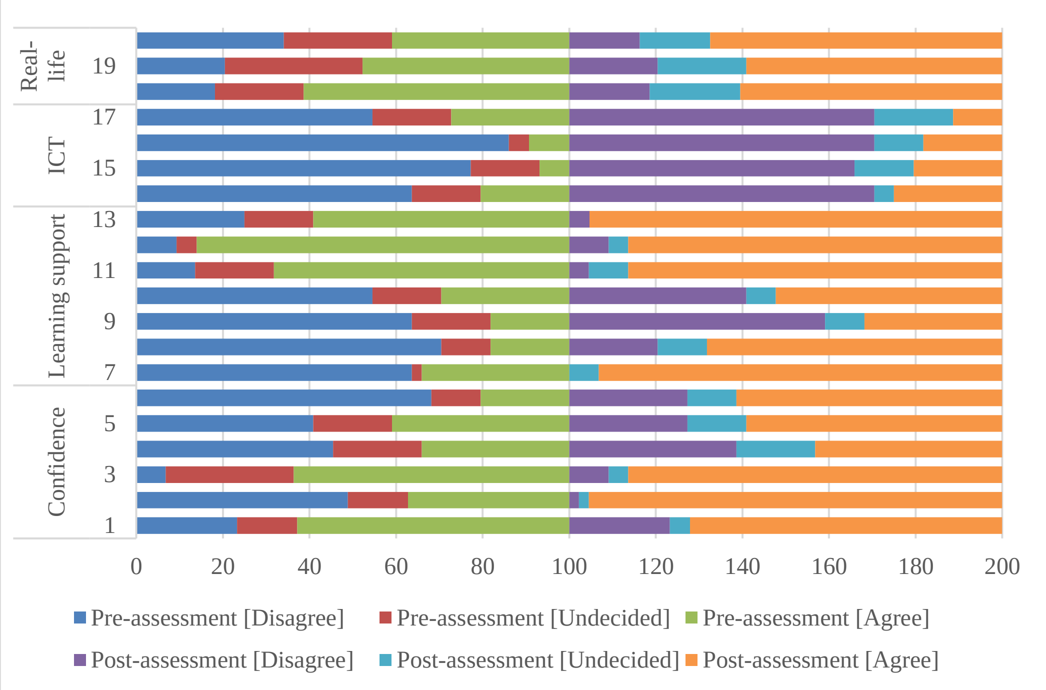

Figure 1. Percent of students in the control group from pre to post assessment

Figure 2 also comprises two parts. The left side shows results from the assessment before learning geometry, and the right side shows results from the assessment after learning geometry using GeoGebra software. For instance, the attitude toward learning on item_3 [I am sure that I can learn Geometry better] increased from 85% to 88% of students from pre to post assessment under the confidence factor.

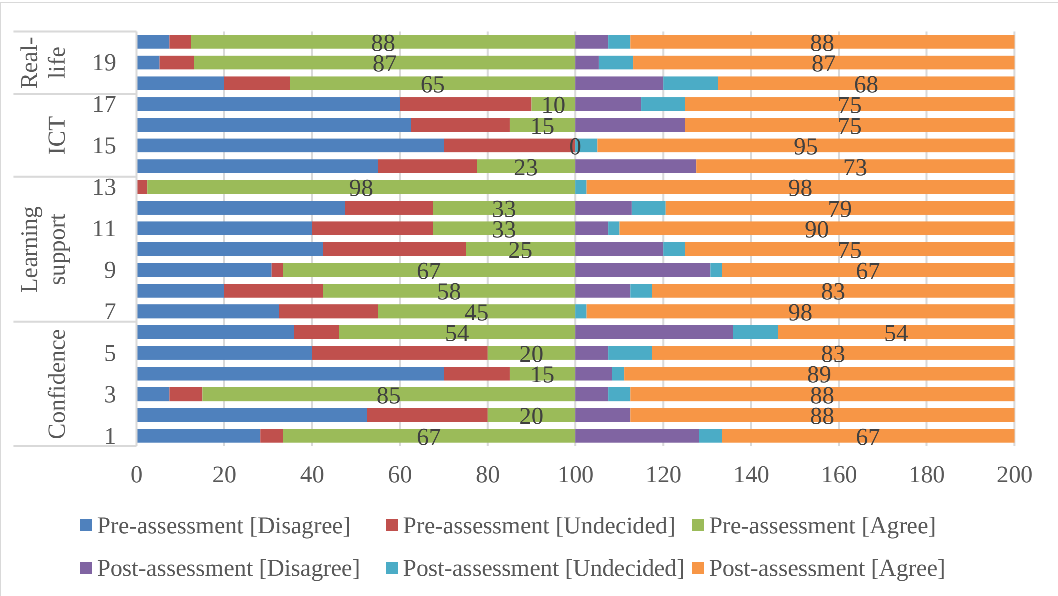

Figure 2. Percent of students in the experimental group from pre to post assessment

Figure 1 and Figure 2 seem to indicate a similar number of students who agreed and disagreed with the attitude items in both groups before learning. However, after learning, both groups of students seem to shift from disagreement to agreement. Although both groups seem to shift to agreement with statements, which indicates improved attitudes toward learning geometry, the two figures display a difference on most items, especially relating to the ICT factor, in favor of students who learned with GeoGebra. For instance, in Figure 1, on items 14, 15, 16, and 17, control group students still disagreed with the statements, even after learning. This proves that GeoGebra enhances students' attitudes towards learning geometry.

Figure 3 conglomerates all 20 attitude items into four factors. The figure has two sides; the left side shows pre assessment, while the right side shows post assessment. Each factor is presented by six bars: the first three bars are pre assessment, while the last three bars present post assessment. Except for the ICT factor, other factors show a more positive attitude, as students agreed with statements after learning (green color). Sixty-nine percent (69%) of students in the control group exhibited a negative attitude (disagreed) that ICT (yellow color) could enhance the learning of geometry.

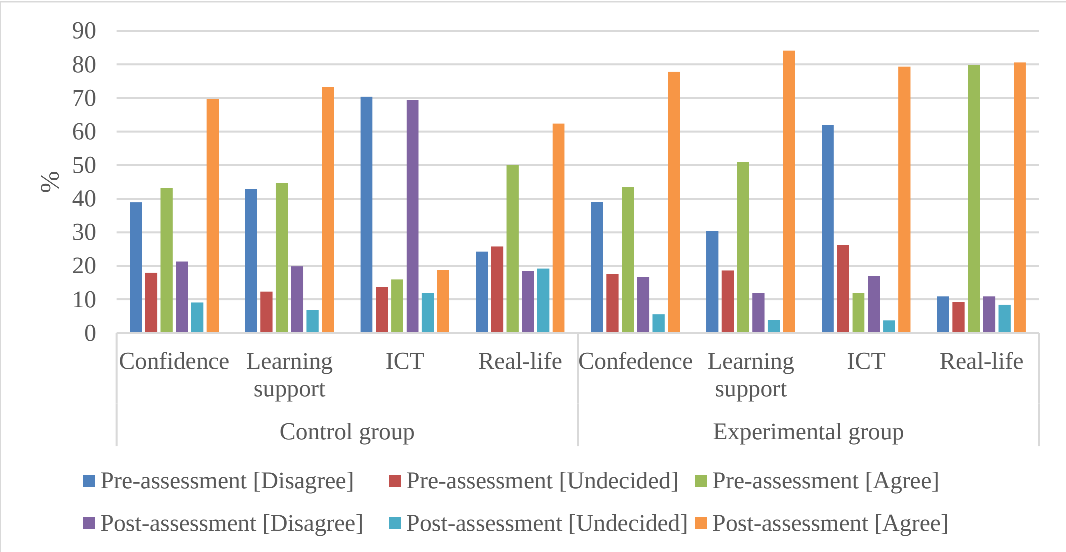

Figure 3. Control and experimental groups vis-à-vis attitude factors

To establish whether these differences in attitudes between the control group and the experimental group are significant, an independent samples t-Test was performed. Results displayed in Table 3 confirm that there was a significant difference in students' attitudes between the experimental and the control groups [t (59) = -3.85, p < .001, d = .89], in favor of the students who learned via GeoGebra.

Table 3. Results from t-Test of Two-Sample Assuming Unequal Variances attitude scale

	Sample	*Mean*	*SD*	*Df*	*t-Stat*	*t-Crit*	*p*	D
Control group	44	9.59	11.75	59	-3.85	1.67	<.001	.89
Experimental group	40	17.07	4.99					

Table 3 shows that the difference between mean scores of the experimental group in post and pre assessment of attitude was (M=17.07), with a standard deviation (*SD= 4.99)*, while the difference between post and pre assessment attitude scores of the control group was (M=9.59) with a standard deviation of (SD=4.99). This demonstrates that the groups' attitude means were different, and this difference was statistically significant. This indicates that using GeoGebra had greater effects on students' attitudes toward geometry than the conventional teaching method had, as the effect size (*d*) was large (.89).

We finally checked the correlation between students' performance and their attitudes towards learning geometry through either traditional or GeoGebra software. The results in Table 4 show that the correlation was low before and after learning geometry in both control and experimental groups. Students in the experimental group showed a negative correlation in pre assessment, though this was low.

Table 4. Correlation between performance and attitude scores

	Pre-assessment	Post-assessment
	Performance vs. Attitude	*Performance vs. Attitude*
Control group	0.060	0.166
Experimental group	-0.015	0.004

4. Discussion

Integrating technology in the teaching process of mathematics has been found to be effective. Using dynamic software such as GeoGebra is recommended as a supporting tool to facilitate the teaching and learning of mathematics, especially in geometry, algebra, and statistics (Tamam & Dasari, 2021; Khoza & Biyela, 2020; Ocal, 2017; Saha et al., 2010). This is in line with the findings of Murni et al. (2017), who found that students who are taught using a discovery learning model with GeoGebra media develop greater problem-solving abilities and more positive attitudes toward mathematics than students who are taught using a traditional learning model. Teaching senior five (S5) students with GeoGebra for learning geometry was found to be effective (Uwurukundo et al., 2022), and the present study proved that students' attitudes improved, although their attitudes did not correlate strongly with improved performance. It is likely that, if students perform well in a certain subject, they will then have a positive attitude toward it, or vice versa. However, our unique finding is that students performed well due to GeoGebra, and improved their attitudes due to GeoGebra, but the scores were not correlated. The finding may be the result of the nature of the performance test used (see Box 1 in Uwurukundo et al., 2022) or the attitude scale used (see Table 1 in the methods section). The corresponding author recommends that more studies are conducted to determine whether there is a strong relationship between improving performance and, at the same time, attitude when GeoGebra is integrated in teaching and learning.

For the confidence factor, attitude items exposed a link between the foundation of mathematics acquired in primary school and students' performance in secondary school, their enjoyment of learning geometry, their confidence regarding learning geometry in a better way and getting good grades, and their performance in geometry and the difficulty of other mathematics topics. Students who were taught using the traditional teaching method gained 70% while those who were taught using GeoGebra gained 78%. Thus, 8% of students enhanced their confidence attitude due to GeoGebra. Regarding learning support, such as teaching methods (memorization, problem-solving, drawing tools, practical work, groupwork), and support from elders, parents, and teachers, students reported feeling more supported in the experimental class. This is shown in Figure 3, which indicates that only 73% of students in the control group agreed with given statements (positive attitude) against 84% of students in the experimental group. Similarly, for the real-life factor, only 62% of students in the traditional agreed (had positive attitude), compared to 81% of students in the experimental group. Therefore, whether geometry topics taught in schools are related to real-life situations, whether knowing geometry concepts will help students earn a living, and whether students studied geometry because they realized how useful it was, students taught via GeoGebra lead to a more a positive attitude than teaching students in the traditional way did. Eventually, regarding the ICT item (investigating whether the use of computers in the teaching of mathematics affected students' performance positively, whether interactive websites helped them to perform better in geometry, whether learning geometry is easier when it is taught using ICT tools such as software, computers, projects, internet and so on, or whether ICT can help them to learn geometry) students in the experimental group responded more positively, and this indicates that GeoGebra as an ICT application enhances students' attitudes towards learning.

Our study also reveals similar results regarding students' attitudes toward confidence, learning support, and real-life attitude factors. Results show that GeoGebra is extremely effective in improving students' attitudes toward learning geometry using ICT. However, this improvement may depend on the teaching method. This finding is in agreement with Arbain and Shukor (2015), Mathevula and Uwizeyimana (2014), Niyukuri et al. (2020), Ocal (2017) and Uwurukundo et al. (2020), whose studies found that ICT, in general, could improve the way students perform in geometry, and that GeoGebra software is effective in improving students' achievement and attitudes towards geometry. In this study, the ICT factor had improved attitude scores in the experimental group, because the teachers of this group used GeoGebra in lessons, while the traditional class did not use this ICT-based software and showed no improvement in attitude. Future research could investigate this finding further. Authors such as Edmunds et al. (2012) and Zhang and Liu (2016) confirm that the usefulness and ease of use of ICT are key dimensions of students' attitudes towards technology. Research by Saha et al. (2010) found that students who had learned coordinate geometry using GeoGebra performed significantly better than students who had learned the traditional way. Nzaramyimana et al. (2021) conducted research on the effectiveness of GeoGebra on students' active learning, and their performance and interest in learning mathematics in Rwandan secondary schools using a quasi-experimental method, and found

GeoGebra was effective in boosting students' active learning, performance in, and enthusiasm for mathematics.

5. Conclusion

The aim of our study was to investigate the effect of GeoGebra software integration on students' attitudes towards 3D geometry. We involved 84 students from four schools in Rwanda. We assigned 44 students to a control group and asked their teachers to teach using traditional teaching methods; the other 40 students were assigned to an experimental group, and we asked their teachers to teach geometry with GeoGebra. Students studied 3D geometry, and their attitudes were measured before and after they had been taught. We found a statistically significant difference in attitudes in the two groups, in favor of the group taught by GeoGebra. We conclude that GeoGebra has the potential to improve students' attitudes towards learning 3D geometry, although the correlation between students' performance in geometry and their attitudes towards learning it through either traditional methods or GeoGebra software was low. Therefore, we recommend that educators adapt their teaching methods to GeoGebra, not only in S5, but at all levels of secondary school, and not only for geometry, but also for other domains of mathematics. The Rwanda Basic Education Board should train teachers to use ICT tools such as GeoGebra in the education system. Since our sample size was limited, further studies could investigate the effects of gender differences, school environments, student achievement, and teachers' appreciation of the use of GeoGebra.

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