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Original Article

Students' Knowledge of Integration of GeoGebra in Mathematics Classes in Uganda

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ABSTRACT

GeoGebra, an open-source Dynamic Mathematics Software (DMS), has emerged as a transformative tool in mathematics education, allowing students and teachers to visualize, explore, and manipulate geometric concepts in dynamic virtual environments. This study investigated the students' knowledge of integration of GeoGebra in mathematics classes in lower secondary schools in Rwampara District, Southwestern Uganda. The objectives of this study were to identify the most abstract geometrical concepts posing challenges to students, examine the impact of GeoGebra training on the identified abstract concepts, and assess the relationship between students' attitudes and the integration of GeoGebra. This study utilized a quantitative approach, employing quasi-experimental and cross-sectional survey designs. Data were collected from 103 students using questionnaires and pre-and post-tests to evaluate the impact of GeoGebra software intervention. Independent samples t-test, Pearson's linear correlation, and descriptive statistics such as means, standard deviations, and frequencies were employed as data analysis methods. The study found that the students identified rotational transformation as the most abstract geometrical concept. The pre-test results indicated that respondents had similar baseline knowledge of rotational transformation. However, after the GeoGebra intervention, the post-test results showed that the difference in mean scores between the experimental and control groups was statistically significant. Additionally, the experimental group demonstrated a positive attitude towards the software. The study concluded that while rotational transformation posed a significant challenge for students, GeoGebra significantly improved their conceptual understanding and performance in this geometry concept. The study recommended that teachers should strongly consider integrating GeoGebra into their ICT-based teaching and learning resources to help improve students' conceptual understanding, motivation, attitude, and achievement in rotational transformations and other geometric concepts.

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INTRODUCTION

As far back as the 20th century, the National Council of Teachers of Mathematics (NCTM) in the USA provided a vision of technology's roles in mathematics teaching and learning. According to Mwangi and Khatete (2017), teachers and students must have regular access to Information Communication and Technology (ICT) that support and advance mathematical sense-making, reasoning, problem-solving, and communication. Baya'a and Daher (2013) stated that effective teachers optimize the potential of ICT to develop students' understanding, stimulate their interest, and increase their proficiency in mathematics. Thus, when teachers use ICT strategically, they can provide greater access to mathematics for all students. However, Engelbrecht et al. (2020) maintained that the transformative view of ICT in mathematics education requires teachers to examine what new ways of pedagogies and curricula are appropriate for a new generation working with new tools.

Historically, technology was introduced in mathematical classrooms to provide ancillary tools for teachers, such as using televisions to represent class contents (Ran et al., 2022). Policy documents such as Global Technology and Innovation Reports of 2018 and 2021 underscore the potential of ICT in supporting students' exploration and understanding of mathematical concepts and procedures. These potential benefits include the development of students' higher-order thinking skills (Susanti & Darhim, 2014), the facilitation of students' mathematics conceptual understanding and mathematical modeling (Maschietto, 2018), and the creation of inquiry-based and constructivist learning environments (Psycharis et al., 2013; Olive et al., 2010).

Uganda launched its first National ICT policy in 2003, and emphasis was placed on providing equipment and teacher training and on the importance of integrating ICTs in teaching and learning (Uganda Communications Commission, 2014). Similarly, another education ICT policy, 2006, was launched to integrate ICT into the mainstream educational curricula and provide equitable access to students at all levels (Lutalo & Bisaso, 2020). Recognizing the growing importance of ICT and the need for a computer-literate population, the Ministry of Education and Sports in Uganda has made significant efforts to establish computer laboratories and implement a computer curriculum in schools (Newby et al., 2013). This initiative, backed by the Ministry's unwavering commitment, has seen steady progress, with an increasing number of schools receiving equipment for computer laboratories.

Despite increased government investments in educational ICT, the adoption and integration of ICT within the Ugandan education system remains low. Studies by Mbabazi et al. (2022) and Mukhula et al. (2021) found a low adoption rate of ICT integration in Ugandan secondary schools. This problem is partly due to constraints on finance, computer equipment, skills, and expertise, for example, teachers and students' insufficient capabilities to effectively utilize the limited ICT resources available, grappling with being ICT literate and competent, and limited pedagogical skills to integrate technology in teaching and learning effectively (Buabeng-Andoh, 2012). Certainly, other challenges of intermittent electricity supply and limited internet connectivity in Uganda add another layer of complexity to the effective integration of technology in educational institutions. In many rural areas of Uganda, access to a stable internet connection is unreliable or nonexistent. This lack of connectivity hampers students' ability to leverage online resources, participate in remote training, and fully utilize web-based educational tools (Nyakito et al., 2021). It also restricts their opportunities to develop a deep understanding of mathematical concepts and limits their ability to

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engage with knowledge in an active, self-directed, and constructive way (Singh & Shikha, 2018).

GeoGebra software, as a new technology, has emerged as an optimal solution to many challenges teachers and students face when incorporating ICT in the teaching and learning of mathematics. GeoGebra is a free software application that can be downloaded on phones and computers and accessed offline or online anytime, anywhere. This offline capability makes it particularly suitable for areas with limited internet access (Taman & Dasari, 2021). Scholars have researched GeoGebra and have confirmed its effectiveness in teaching and learning mathematics. Preiner (2008) notes that GeoGebra provides a virtual environment where students can simultaneously explore numeric, algebraic, and geometric aspects, fostering visualization, manipulation, and experimentation. Marek (2014) asserts that GeoGebra helps students conduct experiments, solve mathematical problems, and perform research in the classroom and at home. Diković (2009) and Uwurukundo et al. (2020) found that GeoGebra enhances the visualization and understanding of various mathematical topics, including geometry. Although GeoGebra has many advantages, it has not been fully embraced in Uganda, and learners still struggle to learn geometry. For example, according to Uganda National Examination Board (UNEB) reports from 2015, 2016, 2018, and 2022, many Uganda Certificate of Education (UCE) candidates struggled with geometrical questions. This suggests a lack of understanding of geometry concepts, inadequate content knowledge, and a negative attitude toward geometrical concepts. Therefore, this study sought to enhance students' knowledge of GeoGebra integration as the solution to the students' gaps in learning Geometry. The specific objectives of this study were to:

- Establish the geometrical concepts in the lower secondary mathematics curriculum that pose challenges for students
- Examine the impact of an intervention with GeoGebra on the students' learning of the established abstract geometrical concepts
- Assess the students' attitudes toward the integration of GeoGebra in mathematics classes after the intervention

LITERATURE REVIEW

Abstract geometrical concepts in lower secondary school mathematics that pose challenges to students

When students encounter abstract concepts, they often struggle to comprehend and visualize them, leading to confusion, frustration, disengagement, and decreased confidence in their mathematical abilities. Consequently, these geometrical concepts are perceived as abstract and complex (Fabiyi, 2017). This phenomenon of difficult geometrical concepts has been widely studied. For example, Ubi et al. (2018) found that secondary school students in Nigeria perceived geometry concepts such as coordinate geometry, circle theorem, and construction as difficult due to inconsistent class practices, lack of instructional materials, and inadequate instructional time. Noto et al. (2019) observed that Indonesian pre-service mathematics teachers faced five difficulties concerning the epistemology of geometry transformation: difficulties in applying concepts, challenges in visualizing geometric objects, struggles with determining principles, issues with understanding problems, and difficulties in mathematical proofs.

Moreover, Baruti and Ratnawati (2020) noted that grade 12 students' difficulties and levels of thinking in Geometry in Indonesia were their inability to correctly identify geometric shapes based on formal definitions, a lack of visualization skills, difficulty understanding specific geometric terms and symbols, and insufficient reasoning regarding relationships between geometric shapes. Similarly, Brijlall and Abakah (2022), who investigated South Africa's high school learners' challenges in solving circle geometry problems, found that they did not understand circle geometry concepts, resulting in an inability to connect different geometry concepts to solve them. In West Sumatra, Indonesia, Cesaria and Herman (2019) found that students had difficulties learning geometry, specifically in understanding the provided material of polyhedrons, and the teaching materials did not match the students' characteristics well. All these studies confirm that learners have difficulties learning Geometry.

Impact of GeoGebra Training on Students' Learning of the Abstract Geometrical Concepts

GeoGebra, as a new technology in mathematics teaching and learning, exemplifies the need for training to ensure that teachers and students develop competence and determine when and how to use it effectively (Andersen & Misfeldt, 2010). The impact of GeoGebra in teaching and learning has been extensively investigated by researchers, who have provided various findings. For example, Bekene et al. (2022) found that the university students in Ethiopia who learned trigonometric functions using GeoGebra had a higher difference in mean achievement scores than those who learned using traditional methods. Similarly, Mwingirwa and Miheso (2016), who investigated teachers' technology uptake and use of GeoGebra in mathematics teaching in Kenya, found that teachers who received GeoGebra training valued and appreciated it, and most were open to incorporating it into their teaching.

In a study conducted on grade 10 students in Mpumalanga Province, South Africa, Manganyana et al. (2020) found that students taught with GeoGebra had a significant mean score difference compared to those taught with traditional methods. Kaushal et al. (2017), who explored the relationship between the use of GeoGebra and TPACK of secondary school pre-service mathematics teachers, found that their TPACK levels changed after participating in the GeoGebra workshop. In the same spirit, in Turkey, Abdulaziz et al. (2021) found that students who used GeoGebra in learning outperformed those who did not in achievement scores. Similarly, Benning et al. (2023) observed that Ghana's senior high school mathematics teachers significantly changed their pedagogical beliefs, attitudes, and technological competence after the GeoGebra professional development program. All these studies confirm the benefits of GeoGebra-based interventions.

Students' Attitudes towards the Integration of GeoGebra in Mathematics Classes

Attitude toward mathematics -and technology refers to students' self-reported enjoyment, interest, and level of anxiety toward learning mathematics with technology (Pilli, 2008, in Akgül 2014). According to Bindak (2004), students with a positive attitude toward technology are likelier to participate in classroom activities and achieve higher academic success. Numerous studies have examined students' attitudes toward integrating GeoGebra into mathematics teaching. For example, in a study on the students' perceptions of using GeoGebra in teaching mathematics in Nepal, Joshi and Singh (2020) found positive perceptions of using GeoGebra to learn linear equations. Similarly, Owusu et al. (2023) and Rosyid and Umaru (2019) found that university students in Ghana and junior high schools in Indonesia indicated a positive attitude toward using GeoGebra software to learn polar coordinates and implementing the GeoGebra-assisted Missouri mathematics project, respectively. Also, Rajagopal (2019) and Shadaan and Leong (2022) found that grade-9 students in Malaysia held a positive attitude toward using GeoGebra as a valuable tool for learning about circles.

According to the reviewed related literature, the integration of GeoGebra into mathematics classes has been primarily investigated in educational settings of more developed countries such as Turkey and the US, with limited representation from African countries, indicating a solid contextual gap in African countries. This distinctly highlighted the need for a study that considered enhancing students' knowledge through training in GeoGebra integration in Uganda. Additionally, apart from only a few of the studies reviewed, such as Rajagopal et al. (2019), others were short on theorization and hence had no frameworks on which their findings were anchored. Yet Ellis and Levi (2008) emphasized the importance of a solid theoretical foundation for scholarly contributions, suggesting that studies devoid of such frameworks contribute little to the body of knowledge. To address this gap, the present study drew upon two theoretical frameworks: Technological Pedagogical Content Knowledge (TPACK) and the Theory of Planned Behavior

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(TPB). Whereas the evidence gleaned from the literature indicates that students exposed to GeoGebra demonstrated improved achievement and conceptual knowledge in different mathematical concepts and positive attitudes and perceptions toward learning mathematical concepts, one cannot be sure if these findings could be consistent in Uganda, especially where the use of GeoGebra is a relatively new phenomenon with limited research. Hence, this study filled these identified gaps.

METHODOLOGY

Research approach and design

The study was quantitative, using quasi-experimental and cross-sectional survey quantitative designs. We chose a quasi-experimental design to test the relationship between the students' scores before and after the GeoGebra intervention and a cross-sectional survey to gather data from a large sample and generalize the findings to the population of our interest.

Study population

The study was conducted in Rwampara District, Uganda, with 14 secondary schools. Of these, six had sufficient functional computer laboratories. In each school, there were four lower secondary school classes: Senior One (S.1), Senior Two (S.2), Senior Three (S.3), and Senior Four (S.4).

Sample size and Sampling strategies

We used simple random sampling to select one lower secondary school with a functional computer laboratory from six schools. Given that S.4 students were preparing for their national examinations, we selected S.3 students for our study on the basis that they had studied substantial Geometry concepts. All the 103 S.3 students in this school participated in this study, hence census sampling. Consequently, we used lottery to assign 51 students to the experimental and 52 to the control groups.

Data collection methods and instruments

We collected data through survey and experimental methods, using self-administered questionnaires and pre-and post-tests. We used two SAQs. The first questionnaire consisted of six open- and closed-ended questions used to collect data on objective one. The second SAQ, which collected data on objective three, had two sections, A and B, with 16 and 10 items, respectively. Students rated their responses based on a five-point Likert scale: Disagree = 1, Disagree = 2, Undecided = 3, Agree = 4, and Strongly Agree = 5. Both SAQs were valid since the content validity indices were 0.87 and 0.81, respectively. Using SPSS 22.0, we calculated Cronbach's reliability coefficients of the first and second SAQs, which were 0.76 and 0.7, respectively.

A pre-test and a post-test were used to collect data on objective two. The eight pre-post-test questions were centered around basic concepts of rotational transformation: finding the object's image, centre, and rotation angle. Mathematics experts reviewed the items for face validity and confirmed their appropriateness based on relevance, clarity, simplicity, and ambiguity. Following their judgment, we computed a Cronbach reliability coefficient of 0.92 using SPSS 22.0, showing that the instruments were suitable for the study. All test items carried equal weight (5 marks), resulting in a total score of 40.

Intervention

We first held familiarization meetings with the school administration, mathematics teachers, and students. During this phase, we installed GeoGebra software on the functional computers. Before the classroom training activities commenced, all students took a pre-test to determine their baseline knowledge of rotational transformation. We then developed a training manual and lesson plan to teach the experimental and control groups about rotational transformation. The experimental group was taught using GeoGebra, while the control group was taught using conventional methods such as demonstration and guided discussion. Both groups learned similar content on rotational transformation over six sessions spanning four weeks, each lasting 120 minutes. At the end of the intervention, both groups were administered a post-test to determine the impact of the GeoGebra on learning rotational transformation concepts.

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Data Analysis

The pre-and post-test data were analyzed using an independent samples t-test at a significance level of 0.05 to determine if the intervention impacted students' performance and understanding of rotational transformation concepts. Data about students' demographic characteristics, attitudes, and integration of GeoGebra were analyzed using descriptive statistics such as means, frequencies, and standard deviations. Pearson linear correlation was used to assess the relationship between students' attitudes and the integration of GeoGebra in learning rotational transformation.

Ethical considerations

We upheld high ethical standards and obtained all required permissions and consents. During data collection, anonymity and confidentiality were assured, and respondents were asked not to include their initials on test scripts or questionnaires.

FINDINGS

Abstract Geometric Concepts that Pose Challenges for Students in the Lower Secondary School Mathematics Curriculum

We examined the geometrical concepts that S.3 students perceived as challenging in the lower secondary school mathematics curriculum. Each student completed a questionnaire with two closed and four open-ended questions. Table 1 presents the descriptive statistics for the respondents' ratings about the abstract geometry concepts (AGC) and the instructional tools used (ITU) in teaching these concepts.

Table 1: Descriptive Statistics on Respondents' Ratings of Abstract Geometrical Concepts (AGC) and Instructional Tools Used (ITU).

Item	Description	Count	Percent (%)
AGC1	Geometric Construction	12	11.7
AGC2	General angle properties	7	6.8
AGC3	Reflection	3	2.9
AGC4	Similarities and Enlargement	24	23.3
AGC5	Circle	2	1.9
AGC6	Rotational transformation	45	43.7
AGC7	Length and area properties of 2D figures	5	4.9
AGC8	Nets, areas, and volumes of solids	5	4.9
ITU1	Chalkboard & textbook only	88	85.4
ITU2	Shared notes	12	11.7
ITU3	Digital tools such as phones, laptops, projectors, tablets, software, desktop	3	2.9

In Table 1, the findings revealed that most respondents, 43.7%, perceived rotational transformation as the most difficult geometrical concept. Also, most respondents 85.4% reported relying solely on chalkboards and textbooks while learning these concepts. This implies that there was limited use of collaborative digital resources, indicating a gap in leveraging more interactive sessions with digital instructional tools. Again, when we asked them about the specific challenges they encountered while learning rotational transformation, they revealed that they had insufficient teacher explanation, limited instructional time, and abstract teaching style as contributing factors to the abstractness of these concepts. Finally, when asked how teachers could best help them learn the most difficult geometrical concepts, most respondents suggested incorporating collaborative activities and digital tools.

Impact of training students with GeoGebra on the abstract Geometrical concepts

After respondents identified rotational transformation as the most challenging geometry topic, we administered eight pre-test items to students to assess their prior knowledge of these concepts. The test focused on determining the objects' image, Centre, and rotation angle. The pre-test results were statistically analyzed using the

Independent Samples t-test under the null hypothesis:

H_{01}: There is no significant difference between the pre-test scores of experimental and control groups.

Table 2: Independent samples t-test for the Pre-test Scores on the Rotational Transformation

Pre-Test	Group	Number	Mean	S. D	Df	Sig (2 tailed)	T
	Experimental group	51	10.75	4.82	101	0.92	-0.105
	Control group	52	10.85	4.94			

**t-value is significant at p<0.05

In Table 2, the t-statistic (t (101) = -0.105) shows a negligible difference between the mean pre-test scores of the experimental and control groups. The p-value of 0.92 indicates that the difference in the pre-test scores was not statistically significant. Therefore, with $p > 0.05$, we accepted the null hypothesis and concluded that the respondents had a similar conceptual understanding of rotational transformations before the intervention. This provided a starting point for assessing the impact of the intervention on enhancing students' conceptual understanding of rotational transformation concepts.

Post-Test Phase

After the classroom training sessions, the control and experimental groups were given a post-test to assess the potential impact of the GeoGebra intervention on their understanding of rotational transformation concepts. An independent samples t-test was conducted to test the following hypothesis:

H_{02}: There was no significant difference in the post-test scores between the control and experimental groups.

Table 3: Results of the Independent samples t-test on Post-Test Scores

	Group	Number	Mean	SD	Std mean	Sig (2-tailed)	t	df
Post-test	Experimental	47	39.0	2.79	15.7	0.000	-13.25	95
	Control	50	23.3	6.79				

**t-value is significant at level, p < 0.05

The findings in Table 3 show that the post-test score for the experimental group was 39.0 out of 40, while the control group had a mean score of 23.3 out of 40. This demonstrates an improvement in performance for both groups. However, the experimental group scored much higher than the control group.

In Table 3, the t-statistic (t (95) = -13.25) indicates a significant difference between the post-test scores of the experimental and control groups. Since the p-value obtained was much lower than the significance level of 0.05, the observed difference in the mean post-test scores was statistically significant. Therefore, with $p < 0.05$, we rejected the null hypothesis and concluded that the intervention significantly improved the experimental group's performance in rotational transformation compared to the control group.

Comparison of Pre-Test Achievement Scores and Post-Test Achievement Scores

After analyzing the pre-and post-test results, we compared the two sets to determine if the impact was statistically significant. To determine the significance, we formulated and tested the following hypothesis using a dependent samples t-test:

H_{01}: There was no statistically significant mean difference between the pre-test and post-test scores.

Table 4: Comparison of Pre-test Achievement Scores and Post-test Achievement Scores

Group	Number	Mean	Standard Deviation	Sig (2-tailed)	T	Df
Pre-Test	103	10.5	4.7	0.000	-19.52	96
Post-Test	97	30.7	9.5			

**t-value at the significance level, p < 0.05

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Table 4 indicates a significant increase in the mean scores from the pre-test (M=10.5) to the post-test (M=30.8). This substantial increase in the mean scores shows that the intervention positively impacted the respondents' understanding of rotational transformation concepts. Also, the results show a significant difference between the pre-test and post-test mean scores, with t (96) = -19.52 and p = 0.000 ($p < 0.05$). The observed mean difference was statistically significant since the p-value was below the significance level, $\alpha = 0.05$. Therefore, with $p < 0.05$, we rejected the null hypothesis and concluded that GeoGebra software significantly improved respondents' conceptual understanding and mastery of rotational transformation concepts.

Students' Attitude and Integration of GeoGebra in Mathematics Classes

After the experimental group finished the post-test, we immediately gave them a questionnaire to assess their attitude towards GeoGebra in learning rotational transformation. The respondents rated themselves on a five-point Likert scale, as illustrated in the subsequent sections.

Students Attitudes Towards Learning Rotational Transformation

The respondents' attitudes toward learning rotational transformation were conceptualized as students' engagement (SE), students' self-efficacy (SSE), and students' participation and collaboration (SPC). Table 5 shows the descriptive statistics regarding respondents' attitudes toward learning rotational transformation.

Table 5: Ratings on Respondents' Attitudes Toward Learning Rotational Transformation.

Item	Description	SD Count (%)	D Count (%)	U Count (%)	A Count (%)	SA Count (%)	Mean	SD
SE1	I actively participated in plotting the points and lines.	00 (00)	00 (00)	00 (00)	15 (31.9)	32 (68.1)	4.68	0.471
SE2	I actively collaborated with my peers in group activities, plotting vertices of 2D objects using GeoGebra.	00 (00)	00 (00)	00 (00)	6 (12.8)	41 (87.2)	4.87	0.34
SE3	I actively used GeoGebra tools to plot figures on the grid	00 (00)	00 (00)	00 (00)	10 (21.3)	37 (78.7)	4.79	0.41
SE4	I discovered using GeoGebra that the object is directly congruent to the image after rotation	00 (00)	00 (00)	00 (00)	5 (10.6)	42 (89.4)	4.89	0.32
SE5	I enjoyed using GeoGebra to construct perpendicular lines, bisect lines, and measure angles	00 (00)	00 (00)	00 (00)	6 (12.8)	41 (87.2)	4.87	0.34
SS1	GeoGebra boosted my confidence to find the image of the object with ease	00 (00)	00 (00)	00 (00)	9 (19.1)	38 (80.9)	4.81	0.40
SSE2	GeoGebra sufficiently supported me in finding the Centre of rotation	00 (00)	2 (4.3)	00 (00)	7 (14.9)	38 (80.9)	4.72	0.68
SSE3	I found it easy and exciting while using GeoGebra to find the angle of rotation and direction	00 (00)	00 (00)	00 (00)	11 (23.4)	36 (76.6)	4.75	0.43
SSE4	GeoGebra made it easier for me to visually observe the equality of distance between the object and its corresponding image from the point of rotation	00 (00)	00 (00)	00 (00)	10 (22.3)	37 (78.7)	4.77	0.43

Item	Description	SD Count (%)	D Count (%)	U Count (%)	A Count (%)	SA Count (%)	Mean	SD
SSE5	I found it exciting that the perpendicular lines through the lines joining the vertices of the object and the image intersect at the Centre of rotation	00 (00)	00 (00)	00 (00)	17 (36.2)	30 (63.8)	4.64	0.49
SPC1	I actively collaborated with peers while using GeoGebra to determine the direction of the angle of rotation area of the object and the image	00 (00)	00 (00)	00 (00)	16 (34)	31 (66)	4.65	0.48
SPC2	I actively collaborated with peers while using GeoGebra to determine the area of the object and image	00 (00)	00 (00)	00 (00)	9 (19.1)	38 (8.9)	4.81	0.40
SPC3	I appreciated GeoGebra's support in determining the Centre of rotation	00 (00)	00 (00)	00 (00)	14 (29.8)	33 (70.2)	4.70	0.46
SPC4	I collaborated with peers while using GeoGebra to find the image of the object after rotation	00 (00)	00 (00)	00 (00)	9 (17)	38 (83)	4.82	0.38
SPC5	I worked with peers in groups while using GeoGebra to visually observe that the distance between the object and the corresponding image from the Centre of rotation is equal	00 (00)	00 (00)	00 (00)	6 (12.8)	41 (87.2)	4.62	0.61
SPC6	I collaborated with peers to plot 2-D objects on the grid using GeoGebra.	00 (00)	00 (00)	00 (00)	22 (46.8)	25 (53.2)	4.53	0.50
	Overall						4.75	0.212

In Table 5, the mean response of the respondents regarding their attitude towards learning rotational transformation with GeoGebra was 4.75 corresponding to code 5 on the Likert scale, indicating strongly Agree. This finding confirms that the respondents showed a positive attitude towards learning rotational transformation using GeoGebra.

Integration of GeoGebra in the Teaching of Rotational Transformation

Table 6 shows the descriptive statistics regarding respondents' integration of GeoGebra in learning rotational transformation, conceptualized as Students' Involvement (SI) and Students' Achievement (SA).

Table 6: Respondents' Rating of Their Responses on the Integration of GeoGebra in Learning Rotational Transformation

Item	Description	SD Count (%)	D Count (%)	U Count (%)	A Count (%)	SA Count (%)	Mean	SD
SI1	I enjoyed using GeoGebra tools to plot vertices of 2-D objects on the grid	00 (00)	00 (00)	00 (00)	6 (12.8)	41 (87.2)	4.87	0.34
SI2	I actively collaborated with peers to find the image of the object	00 (00)	00 (00)	00 (00)	9 (19.1)	38 (80.9)	4.81	0.40

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Item	Description	SD Count (%)	D Count (%)	U Count (%)	A Count (%)	SA Count (%)	Mean	SD
	after rotating it through a point and angle							
SI3	I have learned how to determine the angle and direction of rotation using GeoGebra tools	00 (00)	00 (00)	00 (00)	9 (19.1)	38 (80.9)	4.81	0.40
SI4	I discovered, using GeoGebra, that the distance between the object's vertex and its corresponding image vertex from the point of rotation is equal	00 (00)	00 (00)	00 (00)	10 (21.3)	37 (78.7)	4.81	0.40
SI5	GeoGebra tools helped me discover that the object and the mage are directly congruent	00 (00)	00 (00)	00 (00)	9 (19.1)	38 (80.9)	4.79	0.41
SA1	GeoGebra helped notice that ant two perpendicular lines through the lines that join the vertices of the object and the corresponding image intersect at the Centre of rotation	00 (00)	00 (00)	00 (00)	9 (19.1)	38 (80.9)	4.81	0.40
SA2	I discovered, using GeoGebra, how to determine the angle and Centre of rotation	00 (00)	00 (00)	00 (00)	10 (21.3)	37 (78.7)	4.81	0.40
SA3	GeoGebra helped me discover that the object and the corresponding image are directly congruent	00 (00)	00 (00)	00 (00)	8 (17)	39 (83)	4.83	0.38
SA4	GeoGebra made it easier for me to see that the distance between the objects and the corresponding image's vertex is equal	00 (00)	00 (00)	00 (00)	6 (12.8)	42 (89.4)	4.87	0.33
SA5	GeoGebra helped me rotate an object through an angle with ease	00 (00)	00 (00)	00 (00)	5 (10.6)	42 (89.4)	4.89	0.31
Overall							4.83	0.22

Table 6 shows the respondents' overall mean response was 4.83, corresponding to code 5 on the Likert scale. This strong agreement confirms that GeoGebra aided the respondents' involvement, improved their achievement, and made it easier for them to explore complex rotational transformation concepts.

Relationship Between Students' Attitude and Integration of GeoGebra in Learning Rotational Transformation

To determine whether there was a relationship between students' attitudes and the integration of GeoGebra in learning rotational transformation, we calculated aggregate indices for the constructs to make them linear. We then formulated and tested the following hypothesis using Pearson's correlation coefficient at a 95% significance level.

H_{02}: There was no significant relationship between the students' attitudes and the integration of GeoGebra after the intervention.

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Table 7: Pearson Linear Correlation Results for the Relationship between Students' Attitude and Integration of GeoGebra in Mathematics Classes

		Students 'Attitude	Integration of GeoGebra
Students 'Attitude	Pearson Correlation	1	-.090
	Sig (2-tailed)		.549
	N	47	47
Integration of GeoGebra	Pearson Correlation	-.090	1
	Sig (2-tailed)	.549	
	N	47	47

In Table 7, the Pearson correlation coefficient, r = -0.090, indicates a weak negative linear correlation between the students' attitudes and the integration of GeoGebra. The p-value of 0.549 was greater than the significance level of 0.05, indicating that the correlation was not statistically significant. Therefore, with p > 0.05, we accepted the null hypothesis and concluded that no relationship existed between students' attitudes and the integration of GeoGebra in learning rotational transformation.

DISCUSSION OF THE FINDINGS

The descriptive statistics results from the study's first objective revealed that most respondents (43.7%) identified rotational transformation as the most challenging geometrical concept among senior three students. In particular, the respondents reported difficulties in visualizing key geometrical aspects and principles of rotational transformation, such as determining the direction, rotating an object through an angle, constructing perpendicular bisectors, and struggling with understanding other fundamental concepts. These findings align with Ubi et al.'s (2018) study, which found that coordinate geometry, circle theorem, and construction were particularly challenging for senior secondary school students in Nigeria. Furthermore, Noto et al. (2019) revealed that pre-service mathematics teachers in Indonesia faced difficulties with transformational geometry, including visualizing geometric objects, understanding problems, and using mathematical proofs. Similarly, Brijlall and Abakah (2020) found that high school students in South Africa struggled to understand circle geometry concepts and the application of theorems. While students often find geometry concepts challenging, the National Conference of State Legislatures and Nellie Mae Education Foundation (2020) suggest that learner-centered methods allow students to gain competency and mastery at their own pace, improve their communication and collaboration skills, and devise learning strategies. Therefore, to achieve this in the Ugandan context, the government, through the Ministry of Education and Sports (MoES), alongside development partners, should prioritize professional development programs to equip teachers with innovative instructional strategies.

The study's results further indicated no significant difference between the pre-test experimental group and control group scores (p >0 .05), suggesting that respondents from both groups performed at the same level. This implied that before the intervention, the respondents from both groups had similar abilities regarding their knowledge of rotational transformation. This finding aligns with the findings of Maphutha et al. (2022), who revealed that grade 11 students in South Africa demonstrated similar abilities in solving 2D trigonometrical problems after taking a pre-test.

After the intervention, the study's results indicated that both groups showed improvement. However, the experimental group scored higher than the control group, and the mean difference was statistically significant in favor of the experimental group. In the same vein, the dependent samples t-test results showed that the scores were higher in the post-test (M=30.7) compared to the pre-test (M=10.5), and the difference was statistically significant. This suggests that the GeoGebra intervention positively improved respondents' performance in rotational transformation concepts. These findings are supported by previous studies, which revealed that respondents exposed to GeoGebra instruction performed significantly better than those taught conventionally (Bekene et al., 2022; Benning et al., 2023; Mwingirwa & Miheso, 2016). These findings concretize that using GeoGebra enhances and motivates students to learn mathematical concepts. Therefore, policymakers should consider the inclusion of GeoGebra in the mathematics curriculum and support professional development programs to enhance teachers' technological pedagogical content knowledge (TPACK) to ensure the effective implementation of GeoGebra in mathematics classes.

Moreover, this study's findings revealed that the overall mean response to all items that assessed students' attitude toward learning rotational transformation using GeoGebra was 4.75, corresponding to code 5, "Strongly agree" on a five-point Likert scale. This implied that students strongly agreed that GeoGebra created a collaborative, conducive, and engaging learning environment where they actively learned rotational transformation concepts. According to Yimer and Feza (2019), when students approach learning with optimism, enthusiasm, and a positive mindset, they tend to engage deeply with the material, persevere through challenges, and view mistakes as opportunities for growth rather than setbacks. These findings align with the findings of Joshi and Singh (2020), who asserted that students' learning, when approached with the help of ICT, students tend to engage in learning with confidence and a positive mind. Meanwhile, Owusu et al. (2023) found that the University students at the Menka-University of Skills and Technology in Kumasi, Ghana, portrayed a positive attitude towards the GeoGebra software and learning geometrical concepts.

On the other hand, Rajagopal et al. (2019) observed that the high school students in Malaysia showed a positive attitude when they were introduced to the integration of GeoGebra in learning 2-Dobjects. Therefore, these shreds of evidence affirm that GeoGebra software significantly improves students' attitudes and enhances engagement and teamwork. Thus, this implies that GeoGebra integration in mathematics classes should be sufficiently supported through professional development programs to ensure proficiency when effectively integrating it into mathematics teaching strategies.

CONCLUSION AND RECOMMENDATION

Students in Uganda had trouble understanding rotational transformation concepts, such as determining the direction and angle of rotation and constructing perpendicular bisectors. This study sought to enhance students' knowledge of integrating GeoGebra in mathematics classes. The results showed that the GeoGebra intervention positively impacted students' performance and improved their attitudes toward learning rotational transformation. This suggests that in partnership with curriculum developers, the Ministry of Education and Sports in Uganda should prioritize ongoing professional development for mathematics teachers to keep them updated with the latest educational technologies and methodologies. Additionally, schools should be provided with modern computer laboratories, reliable internet access, and designated spaces for technology-assisted learning to help students visualize abstract concepts.

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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 interest statement

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

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