African Journal of Teacher Education and Development
ISSN: (Online) 2958-0986, (Print) 2958-8650

The effect of dynamic geometry software use for teaching and learning Grade 11 circle geometry

Authors:
Sibonokuhle C. Ntshangase[1]
Mdutshekelwa Ndlovu[1]
Jumoke I. Oladele[1]

Affiliations:
[1]Department of Science and Technology Education, Faculty of Education, University of Johannesburg, Johannesburg, South Africa

Corresponding author:
Jumoke Oladele,
jumokeo@uj.ac.za

Dates:
Received: 02 Mar. 2024
Accepted: 10 July 2024
Published: 27 Sept. 2024

How to cite this article:
Ntshangase, S.C., Ndlovu, M. & Oladele, J.I., 2024, 'The effect of dynamic geometry software use for teaching and learning Grade 11 circle geometry', *African Journal of Teacher Education and Development* 3(1), a50. https://doi.org/10.4102/ajoted.v3i1.50

Background: Dynamic digital technologies (DDTs) are having an impact on children's learning because they have the ability to improve learning while also addressing the issue of lack of interest and motivation. DDTs can also serve as a viable solution to the current crisis state of mathematics education in South Africa.

Aim: The study examined how using GeoGebra dynamic geometry software in the teaching and learning of circle geometry in Grade 11 affected learners' performance as well as their experiences.

Setting: Eighty mathematics learners in Grade 11 participated in the study: 40 each in the experimental and control groups.

Methods: The explanatory mixed methods research design was employed for this study, which comprised an experimental and control group design, wherein the experimental group was taught using GeoGebra activities, a control group was taught using a traditional approach (quantitative) and focus group discussions were conducted to gather students' narratives about GeoGebra use (qualitative).

Results: The study's findings demonstrated that following the use of GeoGebra software for instruction, there were statistically significant differences between the experimental and control groups with $t = 4.1762$, $p = 0.000077$ and a Cohen's $d = 1.096277$, which connotes a significant effect size as it is more noteworthy than the 0.8 thresholds.

Conclusion: The study concluded that when learners are taught using GeoGebra software instead of traditional teaching methods, they seem to perform better academically in circle geometry and enjoy learning mathematics more.

Contribution: This study contributes to improving the quality of mathematics education by leveraging technology to enhance learning experiences and outcomes.

Keywords: ICT integration; GeoGebra; circle theorems; dynamic geometric software; visual and learner-centred approach.

Introduction

In this era of the Fourth Industrial Revolution (4IR), technology is ubiquitous in most aspects of daily life. Calls have been made for drastic changes to how education is delivered in schools, considering how teachers and learners can use technology (Boonmoh, Jumpakate & Karpklon 2021; Oladele, Ndlovu & Ayanwale 2022). If technology is integrated skillfully, it can address mathematical difficulties and enhance performance (Mokotjo & Mokhele-Makgalwaa 2021). Technology plays a growing role in knowledge acquisition, assimilation and content comprehension, and it has pedagogical advantages that can assist in addressing poor performance in mathematics teaching (Perienen 2019).

Dynamic digital technologies (DDTs) are influencing children's learning in their daily lives, including playing computer games and creating animations. These technologies can teach children about their interests and participation, fostering professional development in education. In South Africa, mathematics instruction is facing a crisis because of a lack of motivation and interest, necessitating innovative methods incorporating information and communication technology (ICT) in lessons (Chalaune & Subedi 2020; Victor-Akinyemi et al. 2021).

Mathematics is crucial for economic growth and career opportunities, particularly in science, mathematics and technology (Adelabu, Marange & Jogymol 2022). Geometry is a difficult topic in secondary school mathematics, and many teachers find it challenging to teach (Giannakopoulos 2017). It is also a challenging topic for many learners, leading to poor performance (Sunzuma & Maharaj 2019; Uygun 2020). Geometry's primary goals are to help learners gain spatial intuition, deductive reasoning and numerical understanding, but it is often perceived as a difficult subject (Bikić, Maričić & Pikula 2016; Smith, Julie & Gierdien 2020). Geometry is a crucial aspect of South Africa's mathematics curriculum, with 50 marks out of 150, making up 33.3% of the Grade 12 National Senior Certificate (NSC) Paper 2 (Adelabu et al. 2022; Giannakopoulos 2017).

From 2008 to 2012, Euclidean Geometry was voluntary in South African Grades 11 and 12 curricula. It became compulsory in 2011 with the implementation of the Curriculum and Assessment Policy Statement (CAPS), replacing probability in Paper 1 and transformational geometry in Paper 2 (Machisi 2023). The Department of Basic Education (DBE) enhances teaching environments by promoting learner-centred methods and providing schools with advanced digital tools, such as interactive smartboards, to improve geometry learning through dynamic geometry software (DGS). GeoGebra DGS is a computer software application (app) that enables learners to create dynamic diagrams of real-time changes in objects' properties and relationships, enabling them to visualise complex geometric concepts. Geometry concepts often require visualisation strategies, such as GeoGebra, Geometer's Sketchpad and Cabri, installed on smartboards. These tools allow users to create mathematical relationships, synthesise ideas and manipulate diagrams. GeoGebra as a DGS has the potential to enhance learners' understanding of circle geometry through exploration (Nzaramyimana et al. 2021).

Literature review

Integration of information and communication technology into teaching circle geometry

To make sure there is an adjustment in the quality of education, teachers must ensure innovation and creativity are key parts of their pedagogical processes by using technology-based, learner-focussed education systems to facilitate rigorous, lively, imaginative and inventive learning that is enjoyable (Fazar & Somakin 2016; Oladele et al. 2021; Daramola, Oladele & Owolabi 2019).

Twenty-first-century digital tools allow individual learning to be independent of the system and can be more effective than traditional systems, which do not foster active engagement of learners in the learning processes (Khalaf & Mohammed Zin 2018). To enhance the teaching and acquisition of mathematical knowledge, the International Society for Technology in Education (ISTE 2016) suggests utilising digital technologies, including GeoGebra software (Ndlovu & Ndlovu 2020; Ndlovu, Wessels & De Villiers 2013). The researchers considered using GeoGebra during lessons on circle geometry in this study. Das (2021) promotes the integration of technology to give learners an extensive educational setting, but neither the high school mathematics curriculum nor the assessment processes have widely adopted GeoGebra software.

The case for Euclidean geometry

For mathematicians and learners to recognise and comprehend the space, shape or orientation of various bodies and objects within our universe, geometry is a necessary branch of mathematics (Jin et al. 2021). In the spatial domain, geometry is a branch of mathematics (Ansong, Wiafe & Amankwah 2021) and is seen as increasingly important in STEM fields (Moral-Sánchez, Sánchez-Compaña & Romero 2022). The study of geometrical figures and shapes based on different axioms is known as Euclidean geometry (statements that are assumed to be true but require proof) and theorems that are typically taught in secondary schools. It offers a method for precisely measuring and forecasting the physical qualities of objects, which is essential for many fields of science, technology and engineering (León 2021; Minkowski 2011).

Mathematicians and mathematics learners can grasp circular space, shape and orientation in this world (Badu-Domfeh 2020), because of the circle theorems found in geometry. Circle theorems are thought to be among geometry's most challenging topics, which impair the performance of learners in mathematics (Kwadwo & Asomani 2021). One of the hardest topics to learn in geometry is circle theorems, which contributes to poor student performance in the final NSC (Nxumalo, Chibisa & Mabusela 2022). For instance, the mathematics learner performance of the NSC decreased by 5.6% nationally when geometry was reinstated as a required topic taught in South Africa's educational curriculum in 2014 Department of Basic Education, and it dropped below 50% in 2015 for the first time in quite a while (DBE 2015; Reddy et al. 2022). The total number of learners who took the mathematics examination in 2016 was the largest ever, totalling 265 810 candidates.

Affordances of GeoGebra

GeoGebra is an acronym that combines algebra and geometry. To fulfil their learners' requirements, teachers can create or adapt education experiences using freely available open-source software such as GeoGebra (Hohenwarter, Jarvis & Lavicza 2009; Majerek 2014). GeoGebra's software is very useful as a teaching tool for mathematics, in general, and Euclidean geometry, in particular, helping to make mathematics more meaningful and visual for the learners.

GeoGebra promotes visual and practical learning through multi-representational examinations, helps both teachers and learners handle numerical concepts through problem-solving and gives users the ability to visualise, think critically and draw influences to enhance education (Bansilal 2015; Chigona, Chigona & Davids 2014; Steffen & Winsor 2021). It can effectively portray spatial objects by displaying objects (focuses, lines and areas in space) from various angles. GeoGebra is a software for solving algebra, calculus, geometry and space design problems, aiding active learning and discovery through interactive resources provided by teachers. Mahmudi (2010) highlights the advantages of using GeoGebra, including quick, complete artwork, lucid visual experiences, accurate assessment and easy examination of mathematical objects, unlike traditional tools like pencils, rulers or compasses. Learners are expected to independently explore GeoGebra software and can review their learning through video instruction, allowing them to explore their abilities without formal teaching.

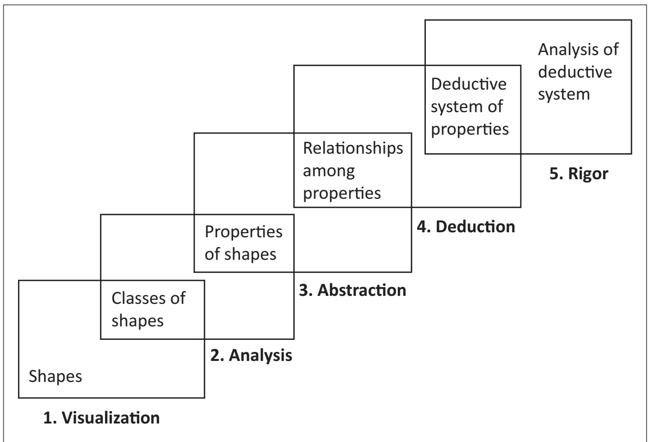
GeoGebra use in teaching circle geometry

GeoGebra software is enhancing mathematics courses by integrating learning models and allowing learners to clearly understand abstract ideas, promoting better communication and deeper comprehension (Babbie 2010; Badu-Domfeh 2020). In the 21st century, effectively trained teachers are empowered to incorporate innovation such as dynamic software and Software Wingeom 2D and 3D, among others, into learning circles geometry (Adelabu et al. 2022; Prieto-González & Gutiérrez-Araujo 2024; Supu & Herlina 2023). This helps to enhance student understanding and expose them to new numerical concepts, aligning with National Council of Teachers of Mathematics (NCTM) (2024) standards and benchmarks (Baffoe & Mereku 2010). Technological learning software (DGSs) such as GeoGebra are essential tools for geometry education as they assist learners in generalising concepts across a wide range of figures and shapes (Sunzuma 2023). These DGSs enable learners and teachers to create figurative, functional and relational models, promoting higher-level deductive thinking, problem-solving abilities and a deeper understanding of two-dimensional shapes (Battista 2002; Bokosmaty, Mavilidi & Paas 2017; Steffen & Winsor 2021).

Theoretical frameworks

Theoretical framework for understanding student performance in circle geometry

Van Hiele's theory of learner comprehension of geometry to evaluate performance in circle geometry was employed for this study (Figure 1). The theory outlines five levels of development (Van Hiele 1986): visualisation, analysis, informal deduction, deduction and rigour. Instruction plays a crucial role in these phases, with each level represented by a unique vocabulary and language (Alex & Mamme 2012; Van Hiele 1986).



Source: Van Hiele, P.M., 1986, *Structure and insight: A theory of mathematics education*, Academic Press, viewed n.d., from https://cir.nii.ac.jp/crid/1130000795426623744

FIGURE 1: The Van Hiele theory.

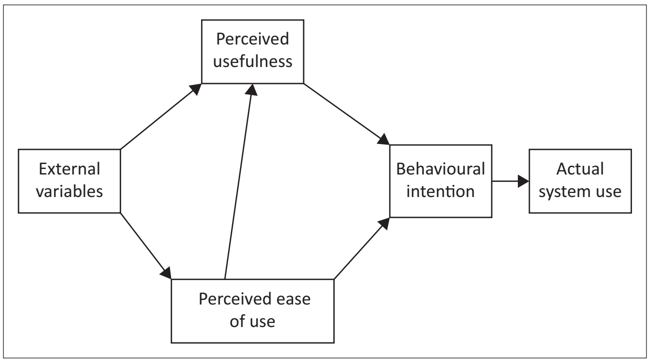
The study implemented the five phases of instruction of Van Hiele's theory. In the visualisation phase: (1), learners were reminded of Grade 10 Euclidean geometry and introduced to the GeoGebra software, which enables a dynamic visualisation approach that is beneficial to students for learning Euclidean geometry. In the analysis phase (2), GeoGebra software was used to teach circle theorems, and learners explored tasks by breaking down complex aspects of circle theorems into their key components to aid in comparing and contrasting differences. In the abstraction phase (3), learners were introduced to real-world figures using the software and asked to draw similar diagrams. In the deduction phase (4), learners were given tasks with diagrams to solve using multiple theorems. In the rigour phase 5, learners who had acquired an overview of the subject were asked to summarise the properties of a geometric shape (Ndlovu & Ndlovu 2020; Ndlovu et al. 2013).

Theoretical framework for investigating learners' experiences of using GeoGebra when learning circle geometry

Davis (1985) developed the first technology acceptance model (TAM) model, stating that an individual's mentality significantly influences their choice to use the tool (Figure 2). The TAM was employed to study learners' experiences with GeoGebra in a mathematics classroom (Davis 1989). The TAM is a theoretical framework that predicts computer use behaviour and technology acceptance. It focusses on an individual's perception (Lala 2014) of a tool's usefulness and ease of use, which affects their use (Bandura 1982).

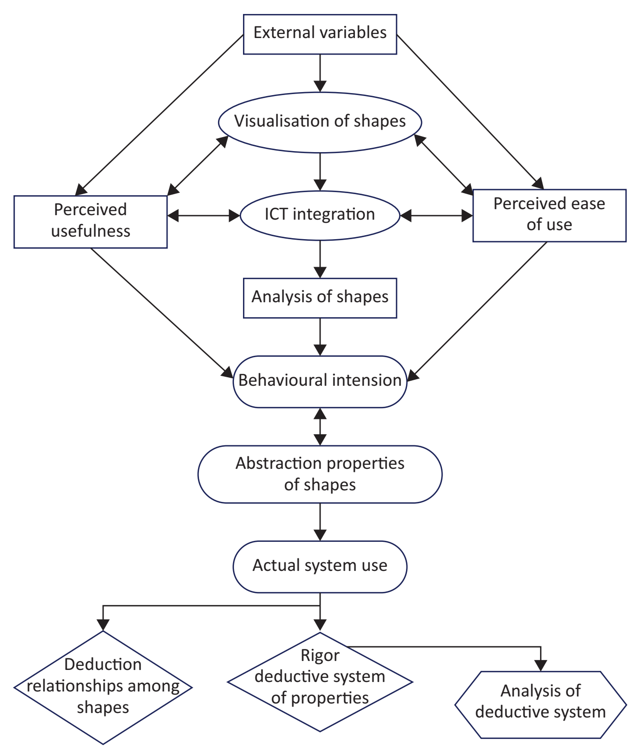
Conceptual framework

The Van Hiele theory and the TAM framework were used in this study, with learners, the classroom setting and ICT resources such as laptops and GeoGebra serving as external variables (Figure 3). GeoGebra, laptops and smartboards were used to illustrate and explain circle geometry theorems, which learners then analysed, discussed and applied to solve problems.



Source: Davis, F.D., 1989, 'Technology acceptance model: TAM', *Al-Suqri, MN, Al-Aufi, AS: Information Seeking Behavior and Technology Adoption* 205, 219, viewed n.d., from https://quod.lib.umich.edu/b/busadwp/images/b/1/4/b1409190.0001.001.pdf

FIGURE 2: Technology acceptance model framework.



ICT, information and communication technology.

FIGURE 3: Combined model – The Van Hiele theory and technology acceptance model frameworks.

The combination of these two theories is germane considering that the GeoGebra is a software suite for learning and teaching science, technology, engineering and mathematics from primary school up to the university level. While teaching with GeoGebra covers the cognitive and the psychomotor aspects of learning supported by the Van Hiele theory, the TAM framework catered for the affective domains of learning. Assessing the three domains while evaluating achievement is germane, as studies have shown that academic performance could be affected by various affective constructs (Acosta-Gonzaga & Ramirez-Arellano 2021; Nazamud-Din, Zaini & Jamil 2020). Considering that GeoGebra is highly technological (Zhang et al. 2023), the extent to which students accept and use this technology (affective constructs) may also impact achievement. Therefore, combining the two frameworks ensures that all three learning domains are effectively covered in this study.

Purpose of the study

The purpose of this study was to research how learners' performance in mathematics circle geometry can be enhanced through the utilisation of ICT tools such as GeoGebra compared to the traditional method of teaching whereby a teacher uses a chalkboard and textbook to teach learners. Furthermore, the researchers aimed to explore the experiences related to the integration of GeoGebra in mathematics education.

Research questions and hypotheses

1. *What are the effects of using GeoGebra on Grade 11 learners' problem-solving competence in circle geometry?*

To address this research question, the following four two-tailed null sub-hypotheses were used:

- **H_{01}:** $\mu_1 = \mu_3$, (There is no difference between the pre-test mean scores of the experimental and control groups).
- **H_{02}:** $\mu_1 = \mu_2$, (There is no difference between the experimental group's mean scores in the pre-and post-test).
- **H_{03}:** $\mu_3 = \mu_4$, (There is no difference between the control group's mean scores in the pre- and post-tests).
- **H_{04}:** $\mu_2 = \mu_4$, (There is no difference between the experimental and control group's post-test mean scores).

The pre-test mean score for the experimental group is denoted by μ_1, the post-test mean score by μ_2, the pre-test mean score by μ_3 for the control group and the post-test mean by μ_4 for the control group:

2. *What are Grade 11 learners' experiences of engaging with DGS when learning circle geometry in a mathematics classroom?*

Methodology

A mixed methods approach was used by the researchers in this study using the convergent parallel design. This type of mixed-method research design involves collecting and analysing quantitative data, followed by the collection and analysis of qualitative data to use the qualitative findings to explain or triangulate the quantitative results (Creswell 2009, 2017). This mixed methods approach was deployed by collecting quantitative data (using pre-and post-tests quasi-experimental design), followed by qualitative data (using focus group discussions). Both data were triangulated conceptually and analytically that helped us to gain a more comprehensive understanding of the effectiveness of using GeoGebra on Grade 11 learners' problem-solving competence in circle geometry. The intervention components were created by extracting the experiences of individuals in the environments where the strategies were being used, which made it easier for interventions to move along the translational continuum. Because the researchers conducted focus group discussions and the pre-and post-tests, this allowed them to theoretically and statistically integrate qualitative research and quantitative data.

The study was conducted in one public high school in Alexandra, Johannesburg East District, Gauteng province in South Africa. The target group was Grade 11 learners who were doing mathematics. The researchers worked with female and male learners aged 16–20, 40 learners (20 males and 20 females) for the experimental group and 40 (20 males and 20 females) learners for the control group out of 164 in one of Alexandra Township's high schools. Stratified simple random sampling was employed. Firstly, the students were stratified based on gender, after which the dip heart method was used to draw 40 males and females who were equally distributed into the control (taught circle geometry using traditional instructional methods) and experimental groups (taught using GeoGebra software instructional method). This research involved 80 Grade 11 learners from 164 school learners, using teaching experiment methodology to observe their mathematical learning and reasoning (Steffe & Thompson 2000). Both groups comprised almost half of the Grade 11 learners doing mathematics. Learners only interacted with GeoGebra by observing transformations in the interactive smartboard because they were not allowed to come to school with cell phones, but they were given a chance to try and do it on their own on the smartboard.

Face and content validity in a study is determined by examining the standardised pre-and post-tests and carefully evaluating its appropriateness for assessing the impact of GeoGebra on learners' performance during circle geometry lessons. To ascertain the reliability of the instrument, the pre- and post-tests were subjected to parallel forms of reliability for repeatability and consistency in measuring phenomena (Taherdoost 2016). Also, the researchers ensured consistent question phrases, clear instructions for responses, uniform conditions and equal attendance of all learners in the group for pre-test and post-test sessions, ensuring consistent results. Data were collected for the quantitative aspects using pre- and post-tests to assess knowledge of circle geometry (Oladele 2024). GeoGebra was introduced to learners, and a post-test was conducted to assess its effect on understanding. Focus group discussions were conducted to understand learners' perspectives on GeoGebra's use.

Trustworthiness in a study is determined by its credibility, transferability, confirmability and dependability (Connelly 2016). The researcher used methodological triangulation to gather perspectives on the research problem, enhancing credibility and validity. Confirmability was ensured through participant interviews and audit records, while transferability was demonstrated through relevant data interpretation. These components contributed to the overall quality and reliability of the mixed methods research design employed in this study.

Data analysis

The quantitative data collected during the research study through pre- and post-tests were analysed using the *t*-test (Motseki & Jojo 2022), and the qualitative data collected during the research through interviews were analysed using thematic analysis. To ascertain whether the learners' performance had increased, decreased or remained unchanged, the researchers employed the paired samples *t*-test to analyse the data gathered from the pre-and post-tests. The researcher used both the independent samples *t*-test and the dependent samples *t*-test. An answer to the question of whether an instrument is effective was provided by the *t*-test, which assessed the practical significance of the instruments, while the dependent *t*-test assessed the significance of the generated study hypotheses (to determine whether the learners' performance had increased, or decreased or remained unchanged). The independent sample *t*-test was used to analyse the learners' pre-and post-test scores for the control group and the experimental group. The learners took a geometry test on circles.

The qualitative analysis was conducted using Van Heile's theory and the TAM (Liao & Landry 2000). To analyse the data gathered from the focus group discussion, the researcher used thematic analysis. It calls for the identification and analysis of patterns of meaning or 'themes' in qualitative data as well as interpretation. Saldaña (2013) described thematic analysis as a deliberate decision, along with the main questions, objectives, conceptual framework and literature review. It is similar to coding. To identify processes, tensions, explanations, causes, consequences and/or conclusions, themes should be introduced as straightforward examples of something in the first analysis cycle and then interwoven in subsequent cycles (Bandura 1982). To find common themes, such as topics, ideas and patterns of meaning that had been repeated, data were carefully examined by the researchers.

Ethical considerations

The research project was approved by the Education Research Ethics Committee (REC) of the University of Johannesburg on Research Involving Humans with Ethical Clearance Number: SEM 2-2023-012. To align with the approval given, only volunteers participated in the research.

Results

Research Question 1: What are the effects of using GeoGebra on Grade 11 learners' problem-solving competence in circle geometry?

To answer Research Question 1, the collected data were subjected to quantitative analysis using descriptive statistical analysis of the mean to examine the mean scores of the pre- and post-tests for both the control and the experimental groups, as shown in Table 1.

As shown in Table 1, the mean score for the control group learners' post-tests climbed by 5.67 (from the pre-test mean of 8.48 to the post-test mean of 14.15), while in the experimental group increased by 11.3 (from 10.52 to 21.52). As a result, there was a 7.67-mark difference in the post-test averages for the two groups.

Research Question 1 was further translated to corresponding hypotheses one to four, which were tested for significance using *t*-test inferential statistics.

TABLE 1: Mean scores for the pre-tests and the post-tests.

Mean	Pre-test (mean)	Post-test (mean)
Control group	8.48	14.15
Experimental group	10.52	21.82

TABLE 2: Independent and dependent sample results.

Hypothesis	Sample group	Mean	SD	SEM	Coefficient of variation	No. of participants	*p*	*t*
H_{01}	Pre-test control group	8.48	6.318	0.64	0.935740744	40	0.268663	1.11409
	Pre-test experimental group	10.52	7.226	0.68	0.794355948	40	-	-
H_{02}	Pre-test experimental group	10.52	7.226	0.68	0.794355948	40	< 0.00001	-6.4814
	Post-test experimental group	21.82	4.933	0.61	0.371318473	40	-	-
H_{03}	Pre-test control group	8.48	6.318	0.64	0.935740744	40	0.03812	4.1762
	Post-test control group	14.15	8.577	0.74	0.60422464	40	-	-
H_{04}	Post-test control group	14.15	8.577	0.74	0.60422464	40	0.000077	4.1762
	Post-test experimental group	21.82	4.933	0.61	0.371318473	40	-	-

Note: The result is significant at $p < 0.05$.
SEM, standard error of measurement; SD, standard deviation; No., number.

To test each hypothesis, the researchers conducted both dependent (paired) and independent samples *t*-tests using SPSS to determine the significance of within-group and between-group differences in the pre-test and post-test mean scores. In the hypotheses below, μ_1 is the experimental group pre-test mean score; μ_2 is the experimental group post-test mean score; μ_3 is the control group pre-test mean score and μ_4 is the control group post-test mean score. The results of the significance testing are shown in Table 2.

The first hypothesis, H_{01}: There is no difference in the pre-test mean scores of the experimental and control groups, that is $\mu_1 = \mu_3$ (independent samples *t*-test for the pre-test scores). The 40 participants who wrote the pre-test in the experimental group got (*M* = 10.52, standard deviation [SD] = 7.226) compared to the 40 participants in the control group who got (M = 8.48, SD = 6.318), and this demonstrated that no group was better than the other, $t = 1.11409$, $p = 0.268663$. This meant that there was a negligible difference in prior knowledge between the two groups. This indicated that before the GeoGebra intervention, both groups' circle geometry problem-solving abilities were comparable to each other.

The second hypothesis, H_{02}: There is no difference between the pre-and post-test mean scores of the experimental group, that is $\mu_1 = \mu_2$ (dependent or paired samples *t*-test). The 40 participants who wrote the pre-test in the experimental group got (M = 10.52, SD = 7.226) compared to the participants' post-test results, who demonstrated significantly better marks (M = 21.82, SD = 4.933). The two-tailed *p*-value is less than 0.00001, $t = –5.9764$. By regular models, this distinction is viewed as extremely statistically significant. Cohen's $d = 1.826$, which showed an effect size because it is higher than Cohen's (2013) threshold of 0.8 for a large effect. This implied a large effect size in the experimental group, which connoted an improvement in the students' performance in circle geometry. This showed that the experimental group had made considerable progress in their circle geometry problem-solving skills. The difference between the means of the pre-test (μ_1) and the post-test (μ_2) was 11.3. The learners' answers to the questions and scores demonstrate that the learners in the experimental group achieved higher scores overall, especially in Levels 1 to 3 of van Hiele's theory development. These levels were addressed in Questions 1 to 3 of the post-test. According to these results, it is evident that learners who have access to laptops or tablets would have improved their geometric thinking skills even on Levels 4 and 5. This is because they would have had more time to practice and engage thoughtfully with GeoGebra. Consequently, they would have gained a deeper understanding of circle theorems.

The third hypothesis, H_{03}: There is no difference between the pre-and post-test mean scores of the control group, that is $\mu_3 = \mu_4$ (dependent or paired samples *t*-test). The 40 participants who wrote the pre-test in the control group got (M = 8.48, SD = 6.138) compared to the participants' post-test results, thus demonstrating significantly better marks (M = 14.15, SD = 8.577). The two-tailed $p = 0.03812$ and $t = –2.98507$. This difference meets the standard criteria for statistical significance. Because Cohen's $d = 0.761$ is less than Cohen's (1988) cut-off of 0.8, this suggests a trivial effect size. This means that although the traditional teaching method (whereby a teacher uses a chalkboard and textbook to teach learners) was effective, it was not as effective as that of the experimental group (GeoGebra lessons). The effectiveness was measured using the quasi-experimental design deployed in the quantitative part of the study, which revealed a significant difference through which effectiveness was measured.

Fourth hypothesis, H_{04}: There is no difference in the post-test mean scores of the experimental and control groups, that is $\mu_2 = \mu_4$ (independent samples *t*-test). The 40 participants who wrote the post-test in the experimental group got (M = 21.82, SD = 4.933) compared to the 40 participants in the control group who got (M = 14.15, SD = 8.577). This demonstrated statistically significantly better marks, $t = 4.1762$, $p = 0.000077$. Cohen's $d = 1.096277$ was an enormous impact as it is more noteworthy than the 0.8 threshold (Cohen 1988). That is, learners who used the GeoGebra programme in the classroom improved significantly more in their capacity to solve circle geometry problems when compared to the control group, which used more conventional pen and paper techniques. This indicates that Van Heile's theory of geometric thought development level of the experimental group was practically significantly better than the marks of the control group.

Research Question 2: What are Grade 11 learners' experiences of engaging with GeoGebra when learning about circle geometry in a mathematics classroom?

Research Question 2 was answered qualitatively using thematic analysis aligned to the Van Heile theory as an interpretive lens of geometric thought development to examine how the learners' reason using the properties of circle theorems and their relationships as learners' experiences before and after the exposure to the GeoGebra software under the subthemes of visualisation, analysis, deduction, abstraction and rigour.

In terms of visualisation, a learner in the control group indicated that:

> 'When the circle geometry questions are presented in my test, I become scared because it consists of many theorems, and I find it hard keeping track of all of them and making sure that I don't forget, so I become very scared and nervous.' (Learner 1, control group)

Besides, learner in the control group reported that:

> 'When the circle geometry questions are presented in my test, I become totally confused because there are many circles and lines there. Circle geometry is not my thing at all.' (Learner 6, control group)

One learner claimed that:

> 'When the circle geometry questions are presented to me, I usually feel confused because in the diagrams, there are many things happening, and it is hard to keep track of all the theorems. Sometimes, you don't know which theorems to apply in that question, so I really get confused.' (Learner 4, control group)

Another learner also from the control group, asserted that:

> 'When the circle geometry questions are presented in my test, I suddenly feel nervous and confused because, for me, circle geometry is hard. Remembering all the theorems is challenging because they are too many, so I do not know how to analyse all of them.' (Learner 7, control group)

However, a learner from the experimental group shared that:

> 'When the circle geometry questions are presented in my test, I feel a bit of excitement because I get to analyse the diagram and see what I am given and what I am supposed to deal with. I love circle geometry.' (Learner 3, experimental group)

A learner further explained that:

> 'My experience learning circle geometry with GeoGebra was fun because I understood that the circles and lines are not just drawn, they have a meaning, and you can also measure them to see what the theorems mean. It showed me that circle geometry does not come just anywhere, it comes as real theorems.' (Learner 3, experimental group)

At the analysis stage, a learner in the control group shared that:

> 'When the circle geometry questions are presented in my test, I really feel devastated. I strongly believe that I am not really good at approaching and attempting analytical questions. I believe that circle geometry requires analytical thinking. So, I don't really feel good about that.' (Learner 2, control group)

Worthy of note is the perception held by this student, who believes he showed a deficiency in approaching and attempting analytical questions.

The aforementioned were the experiences with the group taught using the traditional method. However, a learner in the experimental group hinted that:

> 'My experience in learning circle geometry using GeoGebra was very exciting because it was a new way in which I could learn circle geometry. I actually learnt a lot because right now I am able to keep up with the theorems and I almost know all of them.' (Learner 1, control group)

Another learner also in the experimental group, reported that:

> 'Using GeoGebra when learning circle geometry, for me it was actually amazing since I am really bad at drawing circles and lines. So, I believe that it was much more helpful since when you are able to draw accurate diagrams, you can also measure the correct measurements. So, the experience was amazing.' (Learner 2, experimental group)

Similarly, a learner in the experimental group taught with the Geogebra software indicated that:

> 'When geometry questions are presented to me, the first thing that comes to my mind is to check which theorems are presented on the question and try to come up with questions which can suit the theorems. I then analyse the statement to see which information I am given so that I can be able to apply the information to the questions.' (Learner 5, experimental group)

The learner further clarified that:

> 'My experience with using GeoGebra for circle geometry was exciting because it helped me understand and see exactly what is going on rather than being told that angles are equal without really seeing that they are equal. When you are using your hand to draw, you will not draw the diagrams accurately, as you might make mistakes. So, when you are using GeoGebra, everything becomes simpler and more understandable and this was aided by its visualisation capability.' (Learner 5, experimental group)

In the same vein, another learner indicated that:

> 'Learning using GeoGebra was a really nice experience, especially for visual learners because they can really see what is happening. How are the theorems formed, and you can keep up with knowing the theorems since you have seen them visually.' (Learner 4, control group)

Also, Learner 6 had a fun experience using GeoGebra because they were able to perform measurements on the diagrams and see all the equal angles and lines. This was unlike when the angles and lines were drawn on the board without a scale.

To further answer Research Question 2, learners' experiences were examined using the technology acceptance model to ascertain the usefulness of incorporating GeoGebra as a technological tool for learning circle geometry. The transcripts were categorised based on scholarly motivation, participation, content proficiency, enjoyment, focus and self-confidence.

In terms of scholarly motivation, Learner 1 indicated an interest in incorporating technology when being taught circle geometry because it is a requirement of the modern world, where technology is now dominant. The learner stressed that:

> 'I enjoy being taught visually. I am interested in being taught using technology; it would be really helpful.' (Learner 1, control group)

The use of GeoGebra also enhanced participation as indicated by the contributions from a learner who stated that:

> 'I really do have an interest in incorporating technological tools when I am being taught circle geometry.' (Learner 2, control group)

Learner added that:

> 'I believe that some of the teachers are not really able to draw, and that really contradicts everything if you are learning circle geometry and the drawings are not accurate.' (Learner 2, control group)

Based on these submissions, the one learner concluded that:

> 'I believe that if we learn geometry using technological tools it will be very much better.' (Learner 2, control group)

The focus group discussion also revealed that using GeoGebra enhanced learners' content proficiency, as Learner 3 explained that the software was very helpful especially when teachers and even the textbooks are unable to explain everything but in the learners' words: 'smart boards can actually help us with more information when teachers research more about circle geometry just like using YouTube videos to explain certain concepts in circle geometry'.

Still, on content proficiency, some learner expressed interest in using technology tools because they make it easier for us to understand what teachers struggle to explain to learners. In the learner's words:

> '[*W*]hen we use the technology tools, we will learn more better. It will also help us to be more visual and not only use the textbook content proficiency.' (Learner 7, control group)

Learner 8 further stressed the usefulness of GeoGebra for enhancing content proficiency, positing that it provides a bigger picture and broader vision of the circles required for solving problems in circle geometry with different perspectives. Furthermore, on content proficiency, a learner clarified that:

> 'We can also use GeoGebra to draw and measure the angles and distance correctly.' (Learner 5, experimental group)

On the subtheme of enjoyment, a learner explained that:

> 'I think teaching using technological tools will be a very good idea since we live in the modern world. YouTube videos explain a lot better if a learner does not understand something taught by the teacher. Some learners are visual learners, so if they see something, they can understand it better. Using technological tools when teaching will be very beneficial to the learners.' (Learner 4, control group)

In terms of focus, a learner believes that using technology resources makes it much easier to understand. In his own words, he pointed out that:

> 'It is possible that when the teacher explains, some learners do not understand, but when we use, for example, YouTube videos, it becomes much easier to see what is going on.' (Learner 5, experimental group)

The learners also expressed the usefulness of GeoGebra in boasting self-confidence as expressed by Learner 6, who indicated that its use during classes revealed more information about circle geometry and aided in drawing proper measures for the diagrams. In the learner's words:

> 'If we use technological tools, we will never go wrong.' (Learner 6, control group)

Discussion

The findings of this study demonstrated that the mean post-test scores for the experimental and control groups differed statistically significantly. This was captured in learners' answers in the pre- and post-tests. In the pre-test, the learners in the experimental group answered similarly to the learners in the control group; they were not able to differentiate between the theorems, or they would know the size of the angle but not the theorem and the reason. This was supported by their answers in their post-test. It was confirmed by the statistical significance of all five motivation attributes that the experimental group's use of GeoGebra motivated learners more than the control group's use of the traditional method during lessons (Chalaune & Subedi 2020). These results are in line with those of preceding research (Adelabu et al. 2022), which showed that learners who had been subjected to a GeoGebra-mediated environment were able to achieve significantly higher scores in problem-solving. These results align with the conclusions of the previous study (Adelabu et al. 2022), which showed that learners who were exposed to a GeoGebra-mediated environment could attain noticeably better problem-solving scores. According to Ogbonna and Chimuka (2020), there was a discernible academic gap between the learners who trained in Grades 1 and 2 using GeoGebra according to Van Hiele's geometrical understanding theory. According to this study, GeoGebra is a suitable tool for raising learner performance. From the results of the post-test of the experimental group, it was observed that most learners improved and got better marks in Questions 1, 2 and 3, which had the questions on Levels 1 (visualisation), 2 (analysis) and 3 (informal deduction) of Van Heile's theory (Oladele 2024).

The qualitative findings showed a positive experience difference in their understanding of circle theorems. This finding revealed that learners found GeoGebra useful for learning circle geometry, as it simplifies the understanding and application of circle theorems. It also aids in analysing and determining relationships among theorems, demonstrating Level 4 development in mathematical problem-solving and enhancing their self-confidence. This finding showed that GeoGebra promotes visual learning, aligning with Van Heile's levels of geometric thought development. It provides comprehensive information about circle geometry theorems, enabling analysis and differentiation of properties, particularly for visual learners. Learners' perceptions of circle geometry questions in tests vary, with most finding them challenging to remember. Some found them useful, while others judged questions based on the visualisation of shapes. Also, the learners were confident; they participated during the lessons, which portrays focus and enjoyment, which can be alluded to why their content proficiency in circle geometry theorems also improved.

The perceived usefulness and ease of use of the GeoGebra software were also examined in line with the technology acceptance model. The study explored the use of ICT in teaching circle geometry, revealing its perceived usefulness and ease of use. In this regard, learners expressed interest in using technology tools for a broader understanding of circle geometry theorems, providing comprehensive information, and aiding in visual learning beyond textbooks which enhanced participation. It highlights the benefits of visual and practical learning, including participation, concentration, enjoyment, self-confidence and content proficiency, which aids in solving problems in circle geometry. These results are in line with earlier research that showed how using GeoGebra software to teach and learn improved learners' cognitive comprehension, visualisation and accomplishment in mathematics classes, particularly in circle geometry. These results are significant because they demonstrate that learners learn best when they are doing independent research and getting their hands dirty rather than when teachers are lecturing them.

This finding is in line with Nxumalo et al. (2022), who found that early career teachers' favourable views on IT integration into education, particularly mathematics education, are crucial for the successful implementation of learning programmes. Erebakyere and Adegyei's (2022) study on teaching circle theorems using dynamic Autograph technology found that each method significantly improved learners' ability to learn the circle theorems. Adelabu et al.'s (2022) research shows that using GeoGebra software in Grade 11 circles improves academic achievement compared to traditional methods, suggesting teachers should incorporate it into teaching. Both findings from the qualitative and quantitative analysis show that it has a beneficial impact on learners' ability to understand circle geometry by integrating GeoGebra into their classrooms.

Conclusion

The primary goal of this research was to investigate how learners' experiences with this intervention were affected by using GeoGebra and how much of an impact it had on their performance. Eighty learners in Grade 11 mathematics participated in the research, which was carried out in one of Alexandra's high schools. This study combined an experimental design with a mixed methods approach. Eighty learners participated in focus groups to discuss their experiences using GeoGebra during a circle geometry lesson. Pre- and post-tests were given to the learners to gauge the impact of using GeoGebra on their performance in the circle geometry.

Based on the research study's findings, learners' performance is positively impacted when GeoGebra is integrated into mathematics classes and when teaching circle geometry. It also enhances learners' geometric thinking at some of Van Hiele's levels (Levels 1 and 2). The researchers suggest using GeoGebra-assisted lessons in geometry for educational purposes, following the research's findings. Gauteng Department of Education needs to train more teachers on integrating ICT into their classes and provide schools with enough technological tools, such as laptops to learners and teachers with GeoGebra software to help them improve performance in geometry. Because inspiration is the primary factor influencing learner performance, any approach to educational instruction that inspires learners to learn will help resolve the issue of low performance in mathematics and geometry. It was therefore recommended that teachers use GeoGebra software when teaching geometry, especially circles.

Acknowledgements

The authors acknowledge the contribution of all the study participants and, particularly, those in the experimental group.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

S.C.N., M.N., and J.I.O. all contributed equally to this research article.

Funding information

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Data availability

The data that support the findings of this study are available upon reasonable request from the corresponding author, J.I.O.

Disclaimer

The views and opinions expressed in this article are those of the authors and are the product of professional research. It does not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher. The authors are responsible for this article's results, findings and content.

References

Acosta-Gonzaga, E. & Ramirez-Arellano, A., 2021, 'The influence of motivation, emotions, cognition, and metacognition on students' learning performance: A comparative study in higher education in blended and traditional contexts', *Sage Open* 11(2), 21582440211027561. https://doi.org/10.1177/21582440211027561

Adelabu, F.M., Marange, R.Y. & Jogymol, A., 2022, 'GeoGebra software to teach and learn circle geometry academic achievement of grade 11 students', *Mathematics Teaching Research Journal Golden Fall* 14(3), viewed 19 February 2024, from https://www.researchgate.net/publication/364714727_GeoGebra_software_toTeach_and_Learn_Circle_Geometry.

Alex, J.K. & Mammen, K.J., 2012, 'A survey of South African grade 10 learners' geometric thinking levels in terms of the Van Hiele theory', *The Anthropologist* 14(2), 123–129. https://doi.org/10.1080/09720073.2012.11891229

Ansong, E.K., Wiafe, D.A. & Amankwah R., 2021, 'Application of GeoGebra to improve academic performance of students in geometry', *International Journal of Computer Applications* 183(29). https://doi.org/10.5120/ijca2021921671

Babbie, E.R., 2010, *The practice of social research*, 12th edn.,Wadsworth Cengage, viewed n.d., from https://archive.org/details/isbn_9780495598428.

Badu-Domfeh, A.K., 2020, *Incorporating GeoGebra software in the teaching of circle theorem and its effect on the performance of students*, University of Cape Coast Institutional Repository, viewed n.d., from http://hdl.handle.net/123456789/4630.

Baffoe, E.M.M.A.N.U.E.L. & Mereku, D.K., 2010, 'The van hiele levels of understanding of students entering senior high school in Ghana', *African Journal of Educational Studies in Mathematics and Sciences* 8, 51–62.

Bandura, A., 1982, 'Self-efficacy mechanism in human agency', *American Psychologist* 37(2), 122–147. https://doi.org/10.1037/0003-066X.37.2.122

Bansilal, S., 2015, 'Exploring student teachers' perceptions of the influence of technology in learning and teaching mathematics', *South African Journal of Education* 35(4), 1–8. https://doi.org/10.15700/saje.v35n4a1217

Battista, M.T., 2002, 'Learning geometry in a dynamic computer environment', *Teaching Children Mathematics* 8(6), 333–339. https://doi.org/10.5951/TCM.8.6.0333

Bokosmaty, S., Mavilidi, M.F. & Paas, F., 2017, 'Making versus observing manipulations of geometric properties of triangles to learn geometry using dynamic geometry software', *Computers & Education* 113, 313–326. https://doi.org/10.1016/j.compedu.2017.06.008

Boonmoh, A., Jumpakate, T. & Karpklon, S., 2021, 'Teachers' perceptions and experience in using technology for the classroom', *Computer-Assisted Language Learning Electronic Journal* 22(1), 1–24, viewed n.d., from https://old.callej.org/journal/22-1/Boonmoh-Jumpakate-Karpklon2021.pdf.

Bikić, N., Maričić, S.M. & Pikula, M., 2016, 'The effects of differentiation of content in problem-solving in learning geometry in secondary school', *Eurasia Journal of Mathematics, Science & Technology Education* 12(11), 2783–2795. https://doi.org/10.12973/eurasia.2016.02304a

Chalaune, B.B. & Subedi, A., 2020, 'Effectiveness of GeoGebra in teaching school mathematics', *Contemporary Research: An Interdisciplinary Academic Journal* 41(1), 46–58. https://doi.org/10.3126/craiaj.v4i1.32729

Chigona, A., Chigona, W. & Davids, Z., 2014, 'Educators' motivation on integration of ICTs into pedagogy: Case of disadvantaged areas', *South African Journal of Education* 34(3), 1–8. https://doi.org/10.15700/201409161051

Cohen, J., 1988, *Statistical power analysis for the behavioral sciences,* 2nd edn., Routledge, New York.

Connelly, L.M., 2016, 'Trustworthiness in qualitative research', *Medsurg nursing* 25(6), 435.

Creswell, J.W., 2009, *Research design: Qualitative, quantitative, and mixed methods approaches*, 3rd edn., Sage, viewed n.d., from https://psycnet.apa.org/record/2008-13604-000.

Creswell, J.W. & Clark, V.L.P., 2017, *Designing and conducting mixed methods research*, Sage Publications, Thousand Oaks.

Daramola, D.S., Oladele, J.I. & Owolabi, H.O., 2019, 'Effect of assessment for learning strategy on children's learning outcomes in mathematics in Private-Owned ECCE Centers in Ilorin South Local Government Area, Kwara State', *International Journal of Psychology and Education* 3(3), viewed n.d., from https://journals.uew.edu.gh/index.php/ijope/article/view/26.

Das, K., 2021, 'İntegrating e-learning & technology in mathematics education', *Journal of Information and Computational Science* 11(1), 310–319.

Davis, F., 1985, 'A technology acceptance model for empirically testing new end-user information systems: Theory and results', Doctoral dissertation, Massachusetts Institute of Technology, MIT Sloan School of Management, viewed n.d., from http://hdl.handle.net/1721.1/15192.

Davis, F.D., 1989, 'Technology acceptance model: TAM', *Al-Suqri, MN, Al-Aufi, AS: Information Seeking Behavior and Technology Adoption* 205, 219, viewed n.d., from https://quod.lib.umich.edu/b/busadwp/images/b/1/4/b1409190.0001.001.pdf.

Department of Basic Education, 2015, *The South African National Curriculum Framework for children from Birth to Four*, viewed n.d., from https://bit.ly/3RomsDn.

Erebakyere, J. & Agyei, D.D., 2022, 'Teaching and learning circle theorems with Dynamic Autograph technology: Should we employ the social-interaction or the self-exploration strategy?', *African Journal of Educational Studies in Mathematics and Sciences* 18(1), 49–67.

Fazar, I. & Somakin, Z., 2016, 'Pengembangan Bahan Ajar Program Linear Menggunakan Aplikasi Geogebra Berbantuan Android di Sekolah Menengah Atas', *JPPM* 9(1), 6–11, viewed n.d., from https://jurnal.untirta.ac.id/index.php/JPPM/article/viewFile/974/3511.

Giannakopoulos, A., 2017, 'An alternative way of solving geometry riders in grade 12: Back toto synthesis and analysis', *Proceedings of the 23rd Annual National Congress of the Association for Mathematics Education of South Africa* 2, 3–7, viewed n.d., from https://amesa.org.za/AMESA2017/Volume2.pdf#page=29.

Hohenwarter, M., Jarvis, D. & Lavicza, Z., 2009, 'Linking geometry, algebra, and mathematics teachers: GeoGebra software and the establishment of the international GeoGebra institute', *International Journal for Technology in Mathematics Education* 16(2), 15, viewed n.d., from https://bit.ly/3TaIB9z.

Jin, G., Zou, L., Jiang, Y., Zong, Z. & Sun, Z., 2021, 'A circle theorem technique to handle 2-D flows around arbitrary cylinders in discrete vortex method', *Journal of Wind Engineering and Industrial Aerodynamics* 209, 104496. https://doi.org/10.1016/j.jweia.2020.104496

Khalaf, B.K. & Mohammed Zin, Z.B., 2018, 'Traditional and inquiry-based learning pedagogy: A systematic critical review', *International Journal of Instruction* 11(4), 545–564. https://doi.org/10.12973/iji.2018.11434a

Kwadwo, A.E. & Asomani, W.D., 2021, 'Investigating colleges of education students' difficulty in understanding circle geometry', *ADRRI Journal of Physical and Natural Sciences* 4, 1–27, viewed n.d., from https://journals.adrri.org/index.php/adrrijpns/article/view/750.

Lala, G., 2014, 'The emergence and development of the technology acceptance model (TAM)', *Marketing from Information to Decision* 7, 149–160, viewed n.d., from https://www.ceeol.com/search/article-detail?id=48800.

León, A., 2021, *New elements of Euclidean geometry*, viewed n.d., from https://www.researchgate.net/publication/355042152_New_Elements_of_Euclidean_Geometry.

Liao, Z. & Landry, R., 2000, 'An empirical study on organizational acceptance of new information systems in commercial bank environment', *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, Maui, HI, 07 January 2000. https://doi.org/10.1109/HICSS.2000.926665

Machisi, E., 2023, 'Secondary mathematics education in South Africa and Zimbabwe: Learning from one another', *Contemporary Mathematics and Science Education* 4(1), ep23007. https://doi.org/10.30935/conmaths/12812

Mahmudi, A., 2010, 'Membelajarkan geometri dengan program GeoGebra', in *Proceedings of National Seminar on Mathematics and Mathematics Education 2010*, viewed n.d., from https://eprints.uny.ac.id/10483/.

Majerek, D., 2014, 'Application of Geogebra for teaching mathematics', *Advances in Science and Technology Research Journal* 8(24), 51–54. https://doi.org/10.12913/22998624/567

Minkowski, H., 2011, *Basics of Euclidean geometry*. *Geometric Methods and Applications*, viewed n.d., from https://www.cis.upenn.edu/~cis6100/geombchap6.pdf.

Mokotjo, M. & Mokhele-Makgalwaa, N., 2021, 'Mathematics teachers' perceptions of the value of GeoGebra integration in South African high schools', *African Perspectives of Research in Teaching & Learning* 5(1), viewed n.d., from http://hdl.handle.net/10386/3295.

Moral-Sánchez, S.N., Sánchez-Compaña, M.T. & Romero, I., 2022, 'Geometry with a STEM and gamification approach: A didactic experience in secondary education', *Mathematics* 10(18), 3252. https://doi.org/10.3390/math10183252

Motseki, P. & Jojo, Z., 2022, 'The effectiveness of using the geometer's sketchpad to enhance TVET college level 4 students' understanding of circle geometry', *Progressio* 43(1), 1–17, viewed n.d., from https://hdl.handle.net/10520/ejc-progress-v43-n1-a5.

National Council of Teachers of Mathematics (NCTM), 2024, *NCTM standards for teacher preparation programs*, viewed n.d., from https://www.nctm.org/Standards-and-Positions/CAEP-Standards/.

Ndlovu, L. & Ndlovu, M., 2020, 'The effect of graphing calculator use on learners' achievement and strategies in quadratic inequality problem solving', *Pythagoas* 41(1), a552. https://doi.org/10.4102/pythagoras.v41i1.552

Ndlovu, M., Wessels, D. & De Villiers, M., 2013, 'Competencies in using sketchpad in geometry teaching and learning: Experiences of preservice teachers', *African Journal of Research in Mathematics, Science and Technology Education* 17(3), 231–243. https://doi.org/10.1080/10288457.2013.848536

Nazamud-Din, A., Zaini, M.H. & Jamil, N.H.M., 2020, 'The relationship of affective, behavioral and cognitive engagements in ESL higher learning classroom', *English Language Teaching and Linguistics Studies* 2(4), 48–64. https://doi.org/10.22158/eltls.v2n4p48

Nxumalo, M.P., Chibisa, A. & Mabusela, M.S., 2022, 'Acceptance of the GeoGebra application in learning circle theorems', *International Journal of Learning, Teaching and Educational Research* 21(12), 1–20. https://doi.org/10.26803/ijlter.21.12.1

Nzaramyimana, E., Mukandayambaje, E., Iyamuremye, L., Hakizumuremyi, V. & Ukobizaba, F., 2021, 'Effectiveness of GeoGebra towards students' active learning, performance and interest to learn mathematics', *International Journal of Mathematics and Computer Research* 9(10), 2423–2430. https://doi.org/10.47191/ijmcr/v9i10.05

Oladele, J.I., 2024, *Appendix F-Pre_Post-test and Memorandum*, viewed n.d., from https://osf.io/jze64.

Oladele, J.I., Ndlovu, M. & Ayanwale, M.A., 2022, 'Implementing assessment as learning with computer adaptive learning for enhancing STEM education in Africa: A Fourth Industrial Revolution possibility', in B. Chirinda, K. Luneta & A. Uworwabayeho (eds.), *The Fourth Industrial Revolution (4IR) and mathematics education in Africa*, Springer, viewed n.d., from https://link.springer.com/chapter/10.1007/978-3-031-13927-7_8.

Oladele, J. I., Koledafe, O. S. & Daramola, D. S., 2021, 'Prospects for online instructional delivery using google classrooms: Implications for higher education in sub-Sahara Africa', *Journal of Digital Learning and Education* 1(3), 92–108. https://doi.org/10.52562/jdle.v1i3.227

Ogbonna, U.I. & Alfred, C., 2020, *The impact of using GeoGebra to teach circle geometry on grade 11 students' achievement*, viewed n.d., from https://bit.ly/3OX4XsV.

ISTE, 2016, *Standards for students*, viewed n.d., from http://www.iste.org/standards/iste-standards/standards-for-students.

Perienen, A., 2019, *Frameworks for ICT integration in mathematics education – A teacher's perspective*, Open University of Mauritius.

Prieto-González, J.L. & Gutiérrez-Araujo, R.E., 2024, 'Geometry learning with dynamic software in pre-service mathematics teacher education: A systematic review', *Education and Information Technologies* 1–21. https://doi.org/10.1007/s10639-024-12756-2

Reddy, V., Winnaar, L., Arends, F., Juan, A., Harvey, J., Hannan, S. & Isdale, K., 2022, *The South African TIMSS 2019 Grade 9 results: Building achievement and bridging achievement gaps*, viewed n.d., from https://www.timss-sa.org/wp-content/uploads/2022/08/Gauteng-TIMSS-Gr9-FINAL-report.pdf.

Saldaña, J., 2013, *The coding manual for qualitative researchers*, 4th edn., Sage, viewed n.d., from https://us.sagepub.com/en-us/nam/the-coding-manual-for-qualitative-researchers/book273583.

Smith, C.R., Julie, C. & Gierdien, F., 2020, 'The integration of semiotic resources and modalities in the teaching of geometry in a grade 9 class in a South African high school: The four cases of congruency', *South African Journal of Education* 40(2), 1682. https://doi.org/10.15700/saje.v40n2a1682

Steffe, L.P. & Thompson, P.W., 2000, *Teaching experiment methodology: Underlying principles and essential elements in Research design in mathematics and science education*, pp. 267–307, Erlbaum, Hillsdale, NJ.

Steffen, K.A. & Winsor, M.S., 2021, 'Improving high school students' understanding of quadrilaterals by using pre-constructed diagrams on GeoGebra', *Journal of Teacher Action Research* 7(2), viewed n.d., from https://bit.ly/48u1qJp.

Sunzuma, G., 2023, 'Technology Integration in Geometry Teaching and Learning: A Systematic Review (2010-2022)', *LUMAT: International Journal on Math, Science and Technology Education* 11(3), 1–18. https://doi.org/10.31129/LUMAT.11.3.1938

Sunzuma, G. & Maharaj, A., 2019, 'In-service teachers' geometry content knowledge: Implications for how geometry is taught in teacher training institutions', *International Electronic Journal of Mathematics Education* 14(3), 633–646. https://doi.org/10.29333/iejme/5776

Taherdoost, H., 2016, 'Validity and reliability of the research instrument; how to test the validation of a questionnaire/survey in a research', *International Journal of Academic Research in Management* 5(3), 28–36. https://doi.org/10.2139/ssrn.3205040

Uygun, T., 2020, 'An inquiry-based design research for teaching geometric transformations by developing mathematical practices in dynamic geometry environment', *Mathematics Education Research Journal*. https://doi.org/10.1007/s13394-020-00314-1

Van Hiele, P.M., 1986, *Structure and insight: A theory of mathematics education*, Academic Press, viewed n.d., from https://cir.nii.ac.jp/crid/1130000795426623744.

Victor-Akinyemi, H.B., Uyanne, E.O., Udeoji, A.N. & Oladele, J.I., 2021, 'Teaching strategy preferences in upper basic schools in Ilorin west local government area, Kwara state, Nigeria', *Journal of Educational Research in Developing Areas* 2(1), 1–12. https://doi.org/10.47434/JEREDA.2.1.2021.1

Zhang, Y., Wang, P., Jia, W., Zhang, A. & Chen, G., 2023, ,Dynamic visualization by GeoGebra for mathematics learning: A meta-analysis of 20 years of research', *Journal of Research on Technology in Education* 1–22. https://doi.org/10.1080/15391523.2023.2250886