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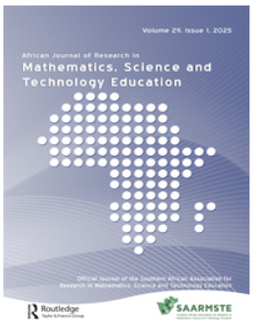
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Modeling Learners' Attitudinal Shifts in Transformation Geometry under Technology-enhanced and Conventional Van Hiele Phased Instruction

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This study compared shifts in learners' attitudes under two instructional strategies: technology-enhanced Van Hiele phased instruction (TVHPI) and conventional Van Hiele phased instruction (CVHPI). A quasi-experimental design was used with 245 learners in the CVHPI group and 238 learners in the TVHPI group. Owing to non-normal data distribution, non-parametric tests were applied. The Wilcoxon signed-rank test revealed significant improvements in attitudes from pre-test to post-test in both groups ($p < 0.001$), with CVHPI showing a strong effect ($r_{\beta} = 0.970$) and TVHPI demonstrating an even larger shift ($r_{\beta} = 0.998$). Further analysis using the Mann–Whitney *U*-test and a difference-in-differences model confirmed that TVHPI led to a greater positive change in attitudes than CVHPI. These findings extend the Van Hiele theory beyond its traditional focus on geometric reasoning by demonstrating its potential to influence learners' attitudes positively, an effect that is further amplified through integrating technology, such as GeoGebra, into phased instruction. Thereby supporting technology-enhanced, learner-centred approaches aligned with Uganda's Competency-Based Curriculum.

Keywords: *Van Hiele phased instruction; technology-enhanced instruction; transformation geometry; learner attitudes; instructional strategies; GeoGebra; competency-based; curriculum*; DiD model

Introduction

Mathematics education fosters critical thinking and problem-solving skills for students' academic success and future careers. With the global emphasis on improving learners' attitudes towards mathematics, particularly in geometry, positive attitudes are increasingly recognised as critical contributors to enhanced performance and engagement (Gunuc, 2014; Kundu, 2018; Uwurukundo et al., 2022). In Uganda, implementing the Competency-Based Curriculum (CBC) aims to develop learners' competencies and attitudes, encouraging a shift from traditional teacher-centred approaches to constructivist, learner-centred methods. This transition is particularly significant in geometry education, where the CBC emphasises understanding geometric concepts rather than rote memorisation.

Over the past few decades, teaching methods in geometry have evolved, shifting focus from memorisation to fostering conceptual understanding (Clements & Sarama, 2021; Ndungo, Balimuttajjo, et al., 2025a). Traditional teaching methods, rooted in formal deduction, have often proven inadequate for younger learners and those lacking prior knowledge of geometric concepts (Van de Walle et al., 2016). Early development of spatial thinking and visualisation skills is crucial for comprehending complex geometric ideas like transformation geometry (Sinclair & Bruce, 2015). However,

many students face challenges connecting theoretical knowledge to practical applications, especially in regions with limited access to high-quality instructional resources and teacher professional development opportunities (Zeinul & Silmi, 2022). Research by Ndungo et al. (2024) analysing trends in geometry education in Uganda highlights the importance of innovative instructional strategies that promote learners' engagement and motivation aligned with the CBC framework.

Learners' attitudes towards transformation geometry encompass several critical dimensions influencing their overall experience and performance. Positive attitudes are characterised by interest in the subject, perceived relevance, confidence and active engagement in learning activities (Mazana et al., 2018). Clapper (2014) highlights the necessity of fostering student engagement and interest, as these factors directly affect attitudes towards geometry. Moreover, recent research shows that attitudes can vary based on gender and school type, necessitating instructional strategies that account for these variables (Bora & Ahmed, 2018). The correlation between attitudes towards mathematics and achievement highlights the importance of supportive teaching practices that nurture these attitudes (Hwang & Son, 2021). Theoretical frameworks such as the theory of reasoned action and the theory of planned behaviour illuminate the relationship between attitudes, intentions and behaviours, indicating that enhancing learners' attitudes towards geometry can improve their commitment to engage with the subject (Colman, 2015; Ajzen & Fishbein, 2005; Schunk, 2012).

Various instructional strategies have been explored to improve students' geometric understanding in response to these challenges. The Van Hiele phased instruction (VHPI) model offers a structured approach to teaching geometry, guiding students through five levels of geometric understanding, from essential shape recognition to advanced reasoning about geometric transformations. Despite VHPI's success in fostering comprehension, there is a growing interest in integrating technology into this model to enhance learning outcomes further (Machisi & Feza, 2021). The current study aims to extend the Van Hiele theory by focusing on technology integration and attitude change, emphasising that positive attitudes are crucial for immediate engagement and long-term success in geometry (Bora & Ahmed, 2018; Pavlovicova & Zahorska, 2015; Uwurukundo et al., 2022; Wong & Wong, 2019). As educational advancements increasingly stress the integration of technology to boost motivation (Ndungo, Nazziwa, et al., 2025), the unique challenges and opportunities within the Ugandan context warrant a thorough examination of instructional methods like technology-enhanced Van Hiele phased instruction (TVHPI) to facilitate positive attitudinal shifts in transformation geometry.

Learners' attitudes refer to their beliefs, emotions, and dispositions towards a subject, shaping their motivation, engagement and learning experiences (Bora & Ahmed, 2018). In mathematics education, attitudes play a critical role in determining how students approach, engage with and persevere in learning geometry. Attitudes are generally classified into three key constructs: affective, behavioural and cognitive attitudes. Affective attitudes relate to students' interest, confidence and emotional responses towards geometry. Behavioral attitudes reflect their participation, effort and engagement in learning activities. Cognitive attitudes encompass their perceptions of the relevance and applicability of geometry in real-world contexts (Smith & Jones, 2020).

Studies suggest that learners' attitudes towards geometry vary widely, with some students recognising its importance while others struggle with its abstract nature (Naidoo & Kapofu, 2020). Research on gender differences presents conflicting findings: some studies report no significant differences, Sunzuma et al. (2013), while others indicate that female students exhibit more positive attitudes (Arslan et al., 2012). These inconsistencies highlight the need for further research into the factors influencing students' perceptions of geometry.

Technology, particularly GeoGebra, has been found to enhance students' affective, behavioural and cognitive attitudes towards mathematics by improving visualisation, interaction and conceptual understanding (Uwurukundo et al., 2021). However, most studies have focused on a single instructional approach, leaving gaps in understanding how different methods compare in shaping students' attitudes. Research also suggests that when students perceive geometry as relevant to real-world applications, they develop greater cognitive engagement and motivation (Smith & Jones, 2020). However, attitudinal changes are gradual, requiring instructional strategies that actively engage students across all three constructs (Albarracin & Shavitt, 2018).

While the CVHPI model is widely recognised for enhancing students' geometric reasoning, its impact on attitudes remains underexplored (Larbi, 2021; Naufal et al., 2021; Ndungo, 2024; Yalley et al., 2021; Zhou et al., 2022). Similarly, despite the potential of TVHPI to improve engagement and motivation, research on its implementation in Uganda remains limited. This study aims to address these gaps by comparing TVHPI and CVHPI, analysing their influence on learners' affective, behavioural, and cognitive attitudes towards transformation geometry.

Conventional Van Hiele Phased Instruction

Conventional Van Hiele phased instruction is a structured teaching approach based on the Van Hiele theory of geometric thought, which outlines five progressive levels of geometric understanding: Visualisation, Analysis, Abstraction, Deduction, and Rigour. This method systematically guides learners through these levels using carefully designed instructional phases, including inquiry, guided exploration and structured exercises, allowing students to develop conceptual understanding before engaging in formal proofs. Conventional Van Hiele phased instruction emphasises teacher support, discussion and hands-on activities, enabling learners to construct meaning from geometric relationships rather than relying on rote memorisation. Research has shown that CVHPI is more effective than traditional teacher-centred methods, as it fosters active engagement, critical thinking, and logical reasoning in geometry (Abdullah & Zakaria, 2013b; Jogymol & Mammen, 2018; Adeniji & Baker, 2022). However, while CVHPI enhances students' comprehension of geometric concepts, its effectiveness can be limited by the static nature of traditional teaching tools, which often lack the dynamic visualisation capabilities that modern technology can provide.

Conventional Van Hiele phased instruction is implemented through inquiry, guided exploration, verbalisation, problem-solving and integration, using graph paper, mirrors, physical models, ruler, compass and hands-on activities to develop geometric understanding before formal reasoning. These phases of instruction proposed by Van Hieles that constitute the CVHPI are illustrated in Figure 1, displaying the five sequential phases in the Van Hiele model, each phase building on the previous one, supporting the progression of geometric thinking.

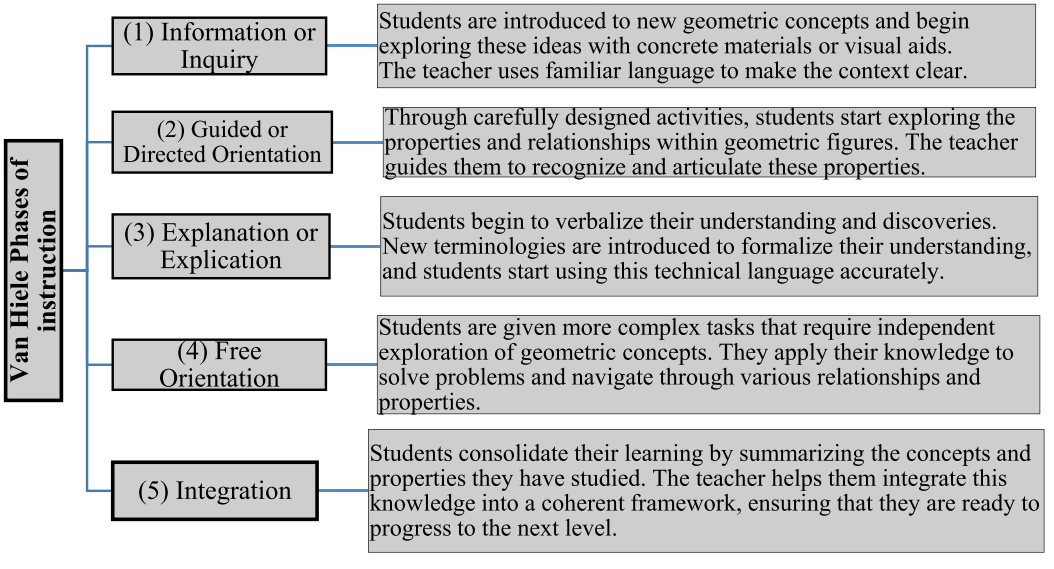


Figure 1. The five Van Hiele phases of instruction

Technology-enhanced Van Hiele Phased Instruction

Technology-enhanced Van Hiele phased instruction follows the five-phase approach of inquiry, guided exploration, verbalisation, problem-solving and integration, but integrates GeoGebra to enhance visualisation. In inquiry, students explore geometric concepts using real-world examples, supported by dynamic visualisations in GeoGebra. During guided exploration, learners manipulate geometric figures digitally, observing patterns and relationships interactively. The verbalisation phase allows them to describe their findings, while the teacher introduces formal terminology using GeoGebra demonstrations. In problem-solving, students apply transformations dynamically, reinforcing conceptual understanding. Finally, in integration, learners reflect on their understanding, solidifying geometric concepts through technology-driven exploration before progressing to formal reasoning. Figure 2 displays the GeoGebra interface with visualisations of rotation of a shape through the angle of 90°.

GeoGebra is a dynamic mathematics software that integrates geometry, algebra, calculus and statistics in a user-friendly platform. It allows for interactive visualisations and manipulations of geometric figures, making it an excellent tool for teaching and learning geometry (Adelabu et al., 2022; Bekene Bedada & Machaba, 2022; Celen, 2020; Dahal et al., 2022). With GeoGebra, learners can construct and manipulate geometric figures, which helps them visualise and understand geometric properties and relationships. It dynamically connects geometric constructions with their algebraic representations, enabling learners to see the interplay between geometry and algebra (Açıkgül, 2022; Aytekin & Isiksal-Bostan, 2019; Birgin & Acar, 2022; Zengin, 2017). Moreover, learners can apply translations, rotations, reflections and dilations to geometric figures and observe the results in real time (Ngwabe & Felix, 2020).

Theoretical Underpinning

This study is grounded in constructivist learning theory and the Van Hiele theory of geometric reasoning. Constructivism emphasises active knowledge construction through exploration and interaction, while the Van Hiele theory provides a structured model for progressing through levels of geometric

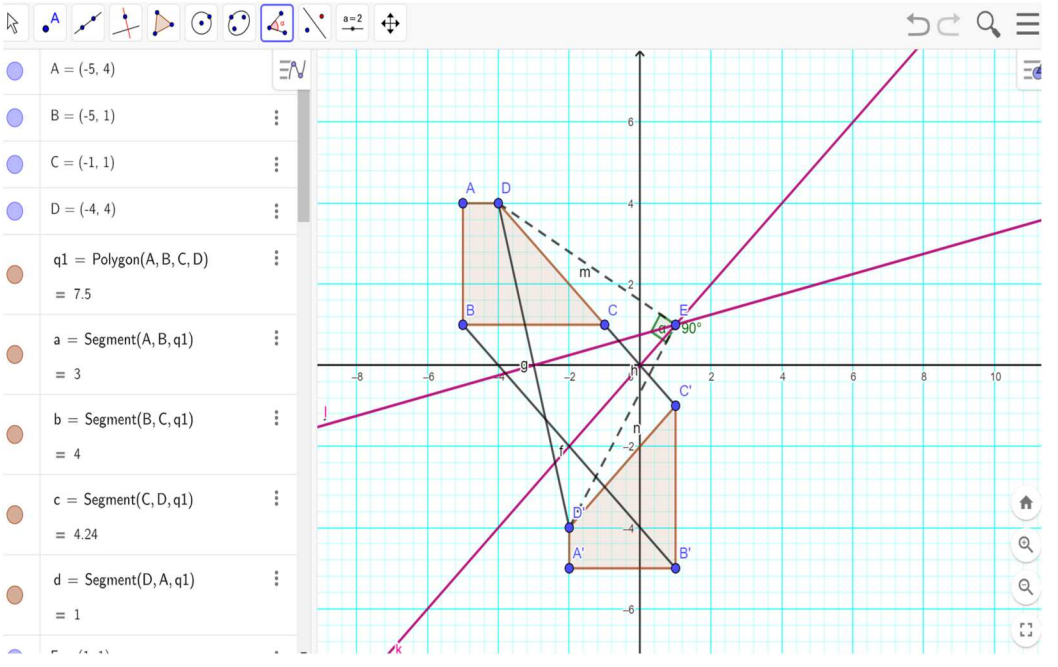


Figure 2. GeoGebra environment showing how to find the angle of rotation of a shape

reasoning. Though distinct, both frameworks complement each other; constructivism supports learner-centred engagement (Allen, 2022), while the Van Hiele model structures geometric learning through guided discovery (Sert Celik & Kaleli Yilmaz, 2022). Together, they inform the study's approach to enhancing learners' attitudes towards transformation geometry.

The current study links constructivist theory and Van Hiele theory by emphasising that both approaches support active engagement in learning. It contributes to this understanding by investigating how conventional and technology-enhanced Van Hiele phased instruction influences learners' attitudes towards transformation geometry. The aim is to identify effective strategies that enhance attitudes in Ugandan secondary schools.

Problem Statement

In Uganda, the implementation of the CBC aims to develop critical thinking and problem-solving skills among learners. However, educators face challenges transitioning from teacher-centred approaches to the constructivist methodologies emphasised by the CBC (Kidega et al., 2023). Transformation geometry, a key component of the mathematics curriculum, plays a crucial role in fostering these skills, yet its effectiveness is often undermined by students' negative attitudes, which impact engagement and learning outcomes.

While the VHPI model is recognised for enhancing students' geometric reasoning, its influence on attitude formation in transformation geometry remains underexplored (Abdullah & Zakaria, 2013a; Demir et al., 2023; Larbi, 2021). Moreover, despite growing evidence that technology can enhance engagement and motivation, the integration of TVHPI remains insufficiently researched in Uganda's mathematics education.

This study examines how TVHPI influences learners' attitudes towards transformation geometry compared with CVHPI, addressing critical gaps in understanding technology's role in fostering positive attitudes towards geometry within a competency-based framework.

Research Hypotheses

The study addresses two research hypotheses to examine the effect of conventional and technology-enhanced Van Hiele phased instruction on shifts in learners' attitudes towards transformation geometry in secondary schools. These hypotheses are:

1. H_{01}: Learners exposed to TVHPI or CVHPI will not exhibit statistically significant shifts in attitudes towards transformation geometry from pre-test to post-test.
2. H_{02}: There is no significant difference in learner attitudes between the TVHPI and CVHPI.

Significance of the Study

The significance of this study is rooted in its potential to enhance mathematics education within Uganda's CBC. By comparing the effects of TVHPI and CVHPI on learners' attitudes in transformation geometry, the research aims to identify effective instructional strategies that foster critical thinking and problem-solving skills. Furthermore, understanding how these methods influence student engagement will provide valuable insights for educators and policymakers. Ultimately, this study seeks to contribute to developing more effective teaching practices, ensuring that students gain a deeper appreciation and understanding of mathematical concepts.

Scope of the Study

The research was carried out over 6 months, from May 2024 to October 2024, in the Midwestern region of Uganda. It included three comparable secondary schools from rural and three from urban districts, targeting senior three learners. The study concentrated on transformation geometry topics, including reflection, rotation, enlargement, and transformation matrices. It assessed shifts in learners' attitudes using two instructional approaches: CVHPI and TVHPI.

Methodology

Research Paradigm and Philosophical Underpinning

The research paradigm for this study is grounded in a positivist approach, emphasising objective measurement and quantifiable outcomes. This paradigm supports the use of statistical methods to analyse the effects of different instructional strategies on learners' attitudes. The philosophical underpinning is rooted in empiricism, which asserts that knowledge is gained through observable and measurable phenomena (Siddiqui, 2019; Park et al., 2020). By employing a quantitative methodology, the study seeks to compare between the instructional methods (CVHPI and TVHPI) and changes in learners' attitudes towards transformation geometry, thereby contributing to evidence-based educational practices.

Research Design

The study employed a quasi-experimental design, utilising quantitative methods with pre-and post-tests. The arrangement of the quasi-experiment per school is illustrated in Table 1.

Table 1 illustrates the quasi-experimental design for the study. The CVHPI and TVHPI classes underwent pre-tests (O_{c1}, O_{t1}), respective treatments (x_1, x_2) and post-tests (O_{c2}, O_{t2}) to assess instructional impact.

Study Population and Sampling

The study targeted a population of 10,530 senior three (S.3) secondary school learners from one rural and one urban district of Midwestern Uganda. To ensure adequate statistical power and robust analysis, G*Power software (version 3.1.9.7) was used to calculate the minimum sample size required (Faul et al., 2007). With an effect size of 0.5, a statistical power of 0.95, and two-tailed testing, a minimum sample size of 222 learners was obtained, giving 444 learners for the two districts.

In this study, schools in two districts were purposively selected based on specific inclusion criteria: administrative flexibility, multiple streams in senior three and a computer lab with adequate resources. Three comparable groups (triples) of schools were identified in the rural district and two in the urban district, from which one triple from each district was randomly selected. Two senior three classes in each school were randomly assigned to experiment 1 (CVPHI) or experiment 2 (TVHPI) groups. Thus, CVHPI and TVHPI were implemented in the same schools to control for external variables. The critical difference was the instructional method.

Given the natural setting of the study, all learners within the selected classes were recruited. Initially, 317 learners from rural and 334 from urban schools were involved, totalling 651 participants. However, owing to dropout and missing post-test data, the final analysis included 250 learners from urban schools and 233 from rural schools, resulting in a total sample size of 483 participants. Despite the attrition, the final sample size remained above the G*Power estimate, ensuring sufficient power to detect significant differences in learners' attitudes towards transformation geometry between the two instructional strategies (Novikov & Novikov, 2013).

Data Collection Instruments

The attitude scale used in this study was developed through a rigorous validation process to ensure its reliability and suitability for assessing students' attitudes towards transformation geometry; the details of this validation process can be found in Ndungo et al. (2025b). Its development was grounded in an

Table 1. The arrangement of quasi-experiments for the study in a typical school

Group	Pre-test	Treatment	Post-test
CVHPI Class	O_{c1}	x_1	O_{c2}
TVPHI Class	O_{t1}	x_2	O_{t2}

CVHPI, Conventional Van Hiele phased instruction; TVHPI, technology-enhanced Van Hiele phased instruction.

extensive literature review, drawing insights from the works of Avcu (2015), Doz et al. (2022), Uwurukundo et al. (2021), Yea-Ling Tsao and Wei-Shin Tung (2022), Mazana et al. (2018), Opolot-Okurut, (2005) and Abdullah and Zakaria (2011). The scale initially consisted of 36 items designed to capture three key constructs: interest and confidence; learning engagement and metacognition; and the perceived relevance and applications of transformation geometry. A panel of five experts, including secondary school mathematics teachers and university mathematics lecturers, reviewed the scale for content validity.

A pilot study was then conducted with 132 Senior Three students from two secondary schools, generating data for initial validation that was analysed by the first author using Excel (CSV) and Python. Internal consistency analysis yielded a Cronbach's α of 0.85, confirming strong reliability. Exploratory factor analysis results, supported by Bartlett's test of sphericity ($\chi^2 = 891.48$, $p < 0.001$) and a Kaiser–Meyer–Olkin measure of 0.81, indicated the suitability of the data for factor analysis. Initially, a 12-factor model emerged; however, a more interpretable three-factor solution was selected based on theoretical coherence and statistical fit. Items with low factor loadings (<0.4) or poor item-total correlations were systematically removed, reducing the scale to 22 items, categorised as shown in Table 2.

Following the successful validation of the tool during the pilot study, actual data from 483 S.3 learners were analysed to confirm the structure of this attitude scale. The factor correlation matrix revealed strong interrelationships among the three attitude constructs: Affective, Behavioral, and Cognitive. Notably, Factor 1 (Affective) and Factor 2 (Behavioral) demonstrated a high correlation of 0.705, indicating a strong conceptual alignment between emotional and behavioural components of attitude. Additionally, Factor 3 (Cognitive) exhibited moderate correlations with both Factor 1 (0.500) and Factor 2 (0.529), suggesting that while the cognitive dimension is distinct, it maintains a meaningful association with both emotional and behavioural aspects. These findings reinforce the structural validity of the attitude scale, confirming that the identified factors align with the theoretical constructs of attitude as intended.

Table 2. Final attitude scale for transformation geometry

Interest, enjoyment and confidence (affective component) (α = 0.69)
A1: I find transformation geometry interesting.
A2: Exploring geometric transformations attracts my attention.
A4: The concept of transformations in geometry excites me.
A9: I find joy in discovering the connections between shapes in transformation.
A14: I feel motivated to complete transformation geometry classwork thoroughly.
A19: I am confident in my ability to understand transformation geometry concepts.
A21: I feel sure of myself when working on transformation geometry problems.
Learning engagement, effort and metacognition (behavioural component) (α = 0.66)
A5: I actively seek additional information about transformation geometry.
A6: I feel curious about the different types of transformations in geometry.
A7: I look forward to transformation geometry lessons.
A15: I seek opportunities to apply transformation geometry concepts in real-world scenarios.
A16: The variety of transformation geometry activities improves my learning experience.
A17: I take the initiative in discovering advanced transformation concepts beyond class requirements.
A22: I am confident I can explain transformation geometry concepts to others.
A26: I feel capable of exploring new transformation geometry topics independently.
Relevance, applications and importance of transformation geometry (cognitive component) (α = 0.78)
A29: Understanding transformation geometry is important for my future.
A30: I can connect transformation geometry concepts to real-world situations.
A32: Transformation geometry is useful in fields outside of mathematics.
A33: I believe transformation geometry has applications beyond the classroom.
A34: Exploring transformation geometry enhances my critical thinking skills.
A35: The knowledge of transformation geometry contributes to my overall education.
A36: I value understanding how transformations are used in various disciplines.

Procedures

The study began with a 2 day training program designed to equip teachers with the necessary skills to deliver lessons using both the TVHPI and CVHPI methods. The training covered the theoretical framework and practical application of the Van Hiele phases of instruction, focusing on how to guide students through different levels of geometric thinking. Teachers were also trained in the use of GeoGebra for teaching transformation geometry, including how to construct geometric figures, apply transformations such as reflection, rotation, translation and enlargement, and visualise geometric relationships dynamically.

To ensure consistency in lesson delivery, the first author and the teachers collaboratively developed standardised lesson plans covering all learning outcomes specified for the intervention. These plans detailed instructional content, student activities and lesson organisation, ensuring that all participating teachers followed a uniform approach. Following the training, pre-tests were administered to the participating students to establish baseline attitudes, allowing for an accurate assessment of the instructional methods' impact over time.

The intervention spanned six weeks with both groups (CVPHI and TVHPI) received four lessons of 40 minutes per week, amounting to 24 lessons by the end of the intervention delivered following the normal school timetable. To maintain consistency, the same teacher instructed both groups while the first author monitored and provided support to teachers during the intervention period to ensure fidelity. Notably, the experiment 2 group (TVHPI) received their lessons in the computer laboratory, using GeoGebra to facilitate interactive and dynamic learning experiences. The setup for GeoGebra was installed on all the computers in the school computer laboratories; the teachers used projectors to deliver lessons, while the learners used the computers to perform different transformations. This group's first lesson was designed to introduce learners to the GeoGebra software. In contrast, the experiment 1 group (CVHPI) was taught in regular classrooms without technology; the teacher used a chalkboard to illustrate transformations, while the learners used graph books/papers and mathematical set instruments to perform transformations. At the end of the intervention, post-tests were administered to all students to measure any changes in their attitudes following the 6 weeks of instruction. After the study concluded, CVHPI learners were given 1 week of access to GeoGebra for ethical considerations, ensuring equitable exposure to technology while maintaining the integrity of the instructional intervention.

Data Analysis

To gain meaningful insights into learners' attitudinal shifts, the study employed both descriptive and inferential statistical techniques. First, descriptive statistics provided an overview of pre-test and post-test mean scores and standard deviations, establishing baseline attitudes and measuring changes after instruction. To assess within-group differences, the Wilcoxon signed-rank test was applied, ensuring robust analysis given the violations of normality identified through the Shapiro–Wilk and Kolmogorov–Smirnov tests. For between-group comparisons, the Mann–Whitney *U*-test was used to determine whether the post-test differences between TVHPI and CVHPI learners were statistically significant. Furthermore, a difference-in-differences (DiD) analysis using an ordinary least squares (OLS) regression model helped isolate the interaction effect of instructional methods over time, accounting for both pre-existing variations and post-intervention shifts. Finally, rank-biserial correlation (r_β) values measured effect sizes, offering deeper insights into the strength of attitudinal changes.

Ethical Considerations

This study adhered to strict ethical standards, ensuring participant rights, data integrity and unbiased reporting. Ethical approval was secured from MUST-REC and UNCST (MUST-2024-1519 and SS2857ES), with additional clearance from district education offices and school administrators. To uphold informed consent, teachers and students provided voluntary participation, while minors required parental consent and student assent. Confidentiality and anonymity were strictly maintained through coded data storage with restricted access. To ensure data accuracy and reliability, the first

author conducted the analysis, while the second and third authors independently reviewed the Python codes, results and raw data, further validated by teachers involved in the intervention implementation. Additionally, after the study concluded, CVHPI learners were granted 1 week of access to GeoGebra, ensuring ethical fairness in technological exposure.

Results and analysis

This section outlines the main results of the study. First, descriptive statistics provide a summary of baseline attitudes for each group. Next, we report the results of hypothesis testing for within-group changes (H_{o1}) and between-group comparisons (H_{o2}). The results are supported by statistical tables and figures.

To confirm the validity of the attitude scale, we conducted both reliability analysis (Cronbach's α) and normality tests (Shapiro–Wilk and Kolmogorov–Smirnov tests) on the difference scores (post-test – pre-test). The reliability analysis indicated acceptable to good internal consistency, with Cronbach's α values of 0.76 for the affective component, 0.75 for the behavioral component, and 0.80 for the cognitive component, confirming that the attitude scale is reliable for further analysis. For normality, both the Shapiro–Wilk and Kolmogorov–Smirnov tests revealed significant deviations from normality in all individual attitude components, while the overall attitude score showed mixed results, with the Shapiro–Wilk test rejecting normality ($p = 0.000007$) but the Kolmogorov–Smirnov test failing to reject it ($p = 0.115958$). In light of these findings, non-parametric methods were employed.

Participants' Demographics and Mean Attitude Scores

With the validity of the attitude scale confirmed, we then examined descriptive statistics to provide an overview of how learner attitudes changed from pre-test to post-test under each instructional method. Table 3 illustrates the demographic distribution of the participants.

Table 3 shows that the sample is nearly balanced, with 50.7% in the CVHPI group and 49.3% in the TVHPI group, ensuring a fair instructional comparison. Gender representation is also even, with 50.9% female and 49.1% male participants, reducing gender-related bias. Additionally, 51.8% of students are from urban schools, while 48.2% are from rural schools, allowing for insights into geographical differences in learning attitudes. This balanced distribution enhances the study's reliability and generalisability.

Following the demographic distribution of participants in Table 3, Table 4 presents the mean scores and standard deviations of learners' attitudes towards transformation geometry. By summarising the baseline attitudes observed before any intervention and their subsequent shifts, this table provides a concise overview of the initial perceptions and the effects of the instructional treatments.

The data in Table 4 are categorised into pre-test and post-test phases, allowing a comparative analysis of students' attitudes before and after exposure to each instructional method.

Across all attitude items, there is a noticeable increase in mean scores from pre-test to post-test, indicating an overall improvement in students' interest, engagement, confidence and perceived relevance of transformation geometry. The improvements are more pronounced among students

Table 3. Demographic distribution of participants

Category	Count	Percentage
CVHPI	245	50.7
TVHPI	238	49.3
Female	246	50.9
Male	237	49.1
Urban	250	51.8
Rural	233	48.2

CVHPI, Conventional Van Hiele phased instruction; TVHPI, technology-enhanced Van Hiele phased instruction.

Table 4. Mean scores and standard deviations of students' attitudes towards transformation geometry

	TVHPI				CVHPI			
	Pre-test		Post-test		Pre-test		Post-test	
Items	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A1	3.10	1.15	3.89	0.91	2.86	1.19	3.65	1.07
A2	3.16	1.15	4.00	0.86	2.78	1.15	3.64	1.13
A4	2.44	1.40	3.58	1.13	2.56	1.28	2.78	1.28
A5	2.84	1.31	3.96	1.00	2.72	1.09	3.53	1.31
A6	3.11	1.19	4.05	0.87	2.98	1.17	3.51	1.13
A7	3.21	1.21	4.00	1.01	2.96	1.19	3.61	1.06
A9	3.14	1.24	3.98	0.93	3.11	1.19	3.40	1.05
A14	3.26	1.20	3.96	0.92	3.02	1.22	3.63	0.95
A15	2.96	1.27	3.85	1.03	2.57	1.15	3.44	1.04
A16	3.37	1.15	3.98	0.94	3.03	1.14	3.44	1.04
A17	2.67	1.21	3.74	1.03	2.61	1.15	3.45	1.06
A19	3.29	1.17	3.92	0.96	2.94	1.22	3.51	1.01
A21	2.76	1.27	3.71	1.03	2.71	1.17	3.33	1.02
A22	2.53	1.41	3.34	1.07	2.42	1.21	2.90	1.25
A26	2.74	1.25	3.61	1.04	2.70	1.19	3.31	1.13
A29	3.30	1.24	4.14	0.95	3.04	1.11	3.74	1.08
A30	2.84	1.20	3.77	1.05	2.92	1.20	3.49	1.02
A32	3.34	1.11	4.05	0.94	3.02	1.08	3.61	0.99
A33	3.24	1.14	3.89	1.12	3.15	1.17	3.73	1.01
A34	3.22	1.09	3.83	1.05	3.22	1.17	3.62	0.98
A35	3.18	1.12	3.83	1.05	3.18	1.13	3.60	1.01
A36	3.07	1.18	3.90	1.05	3.15	1.16	3.73	0.94

CVHPI, Conventional Van Hiele phased instruction; TVHPI, technology-enhanced Van Hiele phased instruction.

taught using TVHPI, as reflected in their consistently higher post-test means compared with those in CVHPI. This suggests that integrating technology into Van Hiele Phased instruction enhances students' engagement and motivation in learning transformation geometry.

The standard deviations show a slight decrease in post-test scores, indicating reduced variability in students' responses after instruction. This suggests that after learning through either method, students developed a more consistent perception of transformation geometry. The findings highlight the effectiveness of both instructional approaches in fostering positive attitudes but also emphasise the greater impact of TVHPI in shifting students' attitudes in transformation geometry.

While Table 4 shows the overall attitude scores, Table 5 breaks these attitudes into individual components: effective, which captures interest, enjoyment and confidence; behavioural, reflecting engagement, effort and metacognition; and cognitive, emphasising real-world relevance and

Table 5. Mean scores and standard deviations of students' attitudes towards transformation geometry

	CVHPI				TVHPI			
	Pre-test		Post-test		Pre-test		Post-test	
Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affective	2.85	1.20	3.42	1.07	3.02	1.23	3.86	0.96
Behavioral	2.75	1.16	3.40	1.13	2.93	1.25	3.82	0.99
Cognitive	3.10	1.147	3.65	1.00	3.17	1.15	3.92	1.03

CVHPI, Conventional Van Hiele phased instruction; TVHPI, technology-enhanced Van Hiele phased instruction.

application. This is to provide a better understanding of how each instructional approach impacted different aspects of student attitudes.

Table 5 reveals a clear improvement in students' attitudes towards transformation geometry across all three constructs—affective, behavioral, and cognitive—following instruction, with TVHPI consistently outperforming CVHPI.

In the affective component, both groups showed increased interest. The CVHPI learners' mean scores rose from 2.85 to 3.42, while the TVHPI learners demonstrated a sharper increase from 3.02 to 3.86, suggesting that technology-driven instruction was more effective in sparking curiosity and boosting confidence.

The behavioral component followed a similar trend. The CVHPI learners progressed from 2.75 to 3.40, whereas the TVHPI learners increased from 2.93 to 3.82. This indicates that technology integration not only encouraged active participation but also fostered deeper engagement with transformation geometry concepts.

The cognitive component showed the highest pre-test means across both groups. The CVHPI learners improved from 3.10 to 3.65, while TVHPI learners advanced from 3.17 to 3.92. These results affirm that while both methods helped students appreciate the significance of transformation geometry, TVHPI provided a stronger link between abstract concepts and real-world applications.

Beyond the rising mean scores, the decrease in standard deviations across all constructs suggests that post-test responses became more consistent, particularly in the TVHPI group. This highlights the stabilising effect of technology-enhanced instruction, making learning more engaging, structured and impactful.

Testing Attitude Shifts in CVHPI and TVHPI from Pre-test to Post-test

This section evaluates the extent of attitude shifts within each instructional group, comparing pre-test and post-test results to test whether the instructional methods led to significant changes (H_{o1}). To test this hypothesis, the Wilcoxon signed-rank test was applied separately to pre- and post-test scores within each group. Table 6 illustrates the Wilcoxon signed-rank test results.

The Wilcoxon signed-rank test results in Table 6 confirm that both CVHPI and TVHPI led to a statistically significant improvement in learner attitudes from the pre-test to the post-test. The *p*-values ($p < 0.001$) indicate that these shifts are highly unlikely to have occurred by chance.

Examining the sum of positive and negative ranks, it is evident that the number of learners whose attitudes improved far outweighs those whose attitudes declined in both groups, demonstrating that both approaches were effective in enhancing attitudes.

The rank-biserial correlation (r_β) further supports these findings, showing a very strong effect in both methods. The r_β value of 0.970 for CVHPI suggests that the majority of learners experienced a positive change, while TVHPI, with an r_β of 0.998, reflects an almost complete shift in attitude for nearly all learners.

These results provide strong evidence to reject the null hypothesis (H_{o1}) ($p < 0.001$), confirming that both instructional strategies resulted in a significant shift in learner attitudes from pre-test to post-test.

Table 6. Wilcoxon signed-rank test results

Group	Wilcoxon statistic	*p*-Value	Sum of positive ranks	Sum of negative ranks	Sum of ties	Positive change count	Negative change count	No change count	(r_β)
CVHPI	909.5	3.80×10^{-36}	49,979.5	1592.5	33	215	24	6	0.970
TVHPI	49	7.11×10^{-40}	65,058.5	200.5	22	229	5	4	0.998

CVHPI, Conventional Van Hiele phased instruction; TVHPI, technology-enhanced Van Hiele phased instruction.

The results establish that regardless of the method used, learners demonstrated a meaningful and positive change in their perceptions of transformation geometry after instruction.

Assessing the Shift Advantage of TVHPI over CVHPI

This section tests the hypothesis that TVHPI produces a significantly greater improvement in learner attitudes than CVHPI, using statistical analyses to determine the validity of this claim.

The plot in Figure 3 illustrates the differences in attitude shifts between TVHPI and CVHPI. Before the intervention, both groups are assumed to maintain consistent baseline attitudes, represented by horizontal lines. The intervention point at time = 0, indicated by a vertical dashed line, marks the beginning of distinct shifts in attitudes. After this point, the red line (TVHPI) shows a larger positive change in attitude compared to the blue line (CVHPI). The dotted green and purple lines represent hypothetical trends: the green line shows what the TVHPI group might have looked like if it followed the CVHPI trend, while the purple line shows what CVHPI might have looked like following the TVHPI pattern. Their intersection is not a measured point but a visual cue to compare hypothetical paths under the difference-in-differences framework.

To confirm the significant differences, the Mann–Whitney *U*-test revealed a statistically significant difference between the groups ($U = 89{,}837.5$, $p < 0.001$). The rank-biserial correlation ($r_\beta = 0.230$) indicated a modest effect size, with one group showing consistently higher ranks than the other. While this test confirmed that a difference existed, it did not directly show which group experienced a larger shift. To further quantify this difference, we utilised an OLS regression model framed within the DiD approach (Table 7) to account for the baseline differences, changes over time, and the combined interaction effect, providing insights into how attitudes evolved pre- and post-intervention for each group.

The estimate of the DiD model is

$$Y_{it} = 2.89 + 0.14(Group_i) + 0.59(Time_t) + 0.24(Group_i.Time_t) + \epsilon_{it}$$

where: Y_{it} represents overall attitudes; $Group_i$ is 1 if the group is TVHPI and 0 if the group is CVHPI; $Time_t$ is 1 if the time is post-test and 0 if the time is pre-test; *Intercept* is 2.89 (baseline attitude for

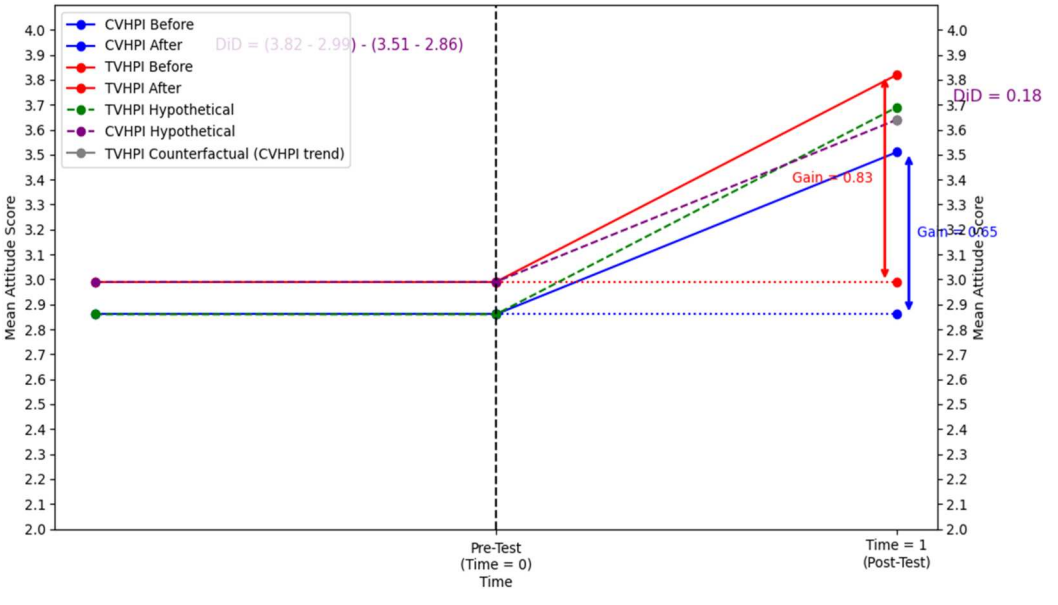


Figure 3. A difference-in-differences (DiD) analysis for learners' attitudes

Table 7. Ordinary least squares (OLS) regression model for difference-in-differences (DiD)

Effect	Coefficient	Standard error	*t*-Value	*p*-Value	95% Confidence Interval
Intercept (baseline CVHPI pre-test)	2.89	0.03	84.45	<0.001	[2.83, 2.96]
Group effect (TVHPI vs CVHPI at pre-test)	0.14	0.05	2.89	0.004	[0.05, 0.24]
Time effect (post-test vs pre-test for CVHPI)	0.59	0.05	12.19	<0.001	[0.50, 0.69
DiD effect (TVHPI post-test improvement beyond CVHPI)	0.24	0.07	3.43	0.001	[0.10, 0.37]

CVHPI, Conventional Van Hiele phased instruction; TVHPI, technology-enhanced Van Hiele phased instruction.

CVHPI at pre-test); $\beta_1 = 0.14$ represents the differences in pre-test attitudes between TVHPI and CVHPI; $\beta_2 = 0.59$ represents the change in CVHPI attitudes from pre-test to post-test; $\beta_3 = 0.24$ represents the additional attitude improvement for TVHPI beyond CVHPI from pre-test to post-test; and ϵ_{it} represents the error term, defined by $Y_{it}^{obderved} - Y_{it}^{Predicted}$ (the attitude that the model fails to explain.

Table 7 highlights the key results of the DiD analysis, showing significant improvements in attitudes for learners in TVHPI over CVHPI. The model equation reinforces these findings, as the positive and statistically significant DiD coefficient indicates that TVHPI leads to a greater positive shift in learner attitudes compared with CVHPI. These results provide strong evidence to reject the null hypothesis (H_{02}), t(d.f.) = 3.43, $p = 0.001$, with a DiD coefficient (β_3) of 0.24. This supports the alternative hypothesis that the TVHPI approach is significantly more effective in enhancing learner attitudes compared to CVHPI. Thus the TVHPI is more superior to the CVHPI in shifting learners' attitudes towards transformation geometry within the context of the study.

Discussion

This study aimed to evaluate the impact of CVHPI and TVHPI on learners' attitudes towards transformation geometry within the framework of the Van Hiele theory of geometric thought and constructivist learning theory. The results confirm that both instructional methods significantly improved students' attitudes, with TVHPI demonstrating a greater positive shift than CVHPI. These findings align with prior research on Van Hiele's instructional model and reinforce the theoretical argument that structured geometric instruction, especially when integrated with technology, enhances learner engagement, motivation, and conceptual understanding (Machisi & Feza, 2021; Uwurukundo et al., 2022).

The study's findings support the theory of reasoned action, Ajzen and Fishbein, (2005) and Colman (2015), which posits that attitudes directly influence behavioural intentions and learning outcomes. By showing a significant improvement in students' affective, behavioural, and cognitive attitudes, the results suggest that instructional strategies that foster positive attitudes towards mathematics may ultimately enhance engagement and achievement in geometry. Moreover, the findings align with constructivist perspectives Mcleod (2023), which emphasise active learner engagement in constructing mathematical knowledge. The greater effectiveness of TVHPI, as evidenced by the DiD analysis, highlights the potential of technology to mediate and accelerate the learning process through dynamic visualisation and interactive exploration.

The study confirmed that Van Hiele Phased Instruction, in both conventional and technology-enhanced forms, significantly improved learners' attitudes towards transformation geometry. The Wilcoxon signed-rank test results demonstrated that learners in both groups exhibited positive attitude shifts from pre-test to post-test, providing empirical support for the Van Hiele theory's structured approach to guiding students through progressive levels of geometric reasoning (Alex & Mammen, 2016; Clements & Sarama, 2021).

The findings further align with prior research indicating that CVHPI effectively enhances geometric comprehension through structured exploration and teacher support (Abdullah & Zakaria, 2013a; Adeniji & Baker, 2022). However, the greater effectiveness of TVHPI in fostering positive attitudes suggests that technology enhances constructivist learning experiences, making abstract geometric concepts more engaging and accessible to students. This is consistent with Uwurukundo et al. (2021) and Zengin (2017) who found that GeoGebra improves learners' motivation and engagement in mathematics by providing dynamic representations of geometric transformations.

The study's results strongly support the hypothesis that TVHPI leads to greater improvements in learners' attitudes towards transformation geometry than CVHPI. The DiD analysis ($\beta_3 = 0.24$, $p = 0.001$) confirmed that the attitude improvement in TVHPI exceeded that of CVHPI, demonstrating that integrating technology into VHPI significantly enhances student engagement, curiosity, and confidence. This finding is consistent with Bora and Ahmed (2018) and Pavlovicova & Zahorska (2015) who found that instructional strategies that integrate technology result in higher motivation and positive attitudes in mathematics.

The breakdown of attitude components further highlights the role of technology in enhancing different aspects of learner engagement. The affective component, which captures interest and confidence, showed the greatest improvement in the TVHPI group, suggesting that technology-integrated instruction makes learning more enjoyable and relatable to students (Clapper, 2014). The behavioural component, which reflects effort and engagement, also improved more significantly in TVHPI, supporting research by Susilawati et al. (2017) that suggests interactive learning environments promote active participation and self-regulated learning. Finally, the cognitive component, which focuses on perceived relevance, demonstrated that TVHPI helped students better appreciate the real-world applications of transformation geometry, reinforcing arguments by Hwang and Son (2021) and Sinclair and Bruce (2015) that students develop a stronger understanding when they can visualise and manipulate geometric concepts dynamically.

These findings align with constructivist learning theory, which posits that learners develop deeper conceptual understanding through active exploration and hands-on learning experiences (Allen, 2022). By allowing students to manipulate geometric figures in real time, TVHPI reduces cognitive load, Sweller (2011) and helps students bridge the gap between abstract concepts and concrete understanding. This supports prior studies demonstrating that technology-assisted learning fosters deeper engagement and conceptual growth in mathematics (Adelabu et al., 2022; Celen, 2020; Dahal et al., 2022).

One of the study's significant contributions is its contextual relevance to Uganda's CBC. As the CBC emphasises learner-centred instruction and conceptual understanding over memorisation, the results suggest that TVHPI aligns more effectively with these curriculum goals than CVHPI. This is particularly relevant in a setting where teachers struggle to transition from traditional teacher-centred methods to more interactive pedagogies (Kidega et al., 2023).

Limitations of the Study

While this study provides key insights into CVHPI and TVHPI's impact on learners' attitudes towards transformation geometry, certain areas warrant further exploration. First, it examined short-term attitudinal shifts, leaving room for future studies to assess long-term persistence of attitude changes. Second, teacher-related factors, such as instructional fidelity and digital competency, were not analysed but could influence outcomes. Lastly, individual differences in learning styles and prior digital exposure warrant further investigation.

Conclusions and Recommendations

This study provides strong empirical evidence that TVHPI significantly improves learners' attitudes towards transformation geometry more than CVHPI. By demonstrating that technology enhances students' interest, engagement, and appreciation of transformation geometry, the study reinforces the constructivist argument that active, interactive and technology-integrated learning environments

foster deeper conceptual understanding. These findings support the Van Hiele theory, the theory of reasoned action, and the competency-based curriculum's emphasis on learner-centred pedagogies, providing a strong case for the integration of dynamic visualisation tools such as GeoGebra in secondary school mathematics instruction.

Given the increasing emphasis on improving attitudes towards mathematics in global education, this study highlights the importance of innovative instructional approaches in shaping students' perceptions of geometry. Educational policymakers should consider scaling up technology-enhanced instruction in mathematics classrooms to enhance engagement and improve learning outcomes. Future research should explore longitudinal effects, teacher implementation strategies and equity issues related to technology access, ensuring that all learners benefit from the advantages of dynamic, interactive, and structured mathematical instruction.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Data Availability

The data that support the findings of this study are openly available and can be accessed on request.

Doctoral Research Attribution

This article is part of the first author's doctoral study, approved under clearance numbers SS2857ES and MUST-2024-1519. The study focuses on the interplay among instructional strategies, learners' geometry attitudes, and Van Hiele's geometric reasoning levels in selected Mid-Western Uganda secondary schools.

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