



Differential Effects of Gender on Students' Academic Performance in Three-Dimensional Geometry under Innovative and Traditional Teaching Methods in Public Day Secondary Schools in Musanze District, Rwanda

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Abstract: *Persistent gender disparities in mathematics achievement, particularly in three-dimensional geometry, continue to raise concerns about the effectiveness of instructional approaches used in secondary schools. This study examined the differential effects of gender on students' academic performance in three-dimensional geometry under innovative and traditional teaching methods in public day secondary schools in Musanze District, Rwanda. The study was guided by Constructivist Learning Theory and Cognitive Load Theory and employed a quasi-experimental research design. Multi-stage sampling techniques were used to select a sample of 269 students from public day secondary schools in Musanze District. Data were collected using Mathematics Achievement Tests and analyzed using descriptive statistics and Two-Way Analysis of Covariance (ANCOVA). The findings revealed that gender had no statistically significant effect on students' academic performance in three-dimensional geometry after controlling for prior mathematical knowledge. The interaction effect between gender and instructional method was also not statistically significant, indicating that innovative teaching methods benefited both male and female students equally. However, students taught using innovative teaching methods achieved significantly higher academic performance than those taught using traditional instructional approaches. The findings provide empirical evidence that innovative teaching methods can improve students' achievement while promoting gender equity in mathematics learning. The study therefore supports the adoption of learner-centered instructional approaches to enhance academic performance in three-dimensional geometry across secondary schools.*

Keywords: *Gender, Academic Performance, Three-Dimensional Geometry, Innovative Teaching Methods, Mathematics Instruction.*

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1. Introduction

Mathematics plays a fundamental role in the development of logical reasoning, critical thinking, problem-solving abilities, and analytical skills that are essential for

academic success and participation in science, technology, engineering, and mathematics (STEM) disciplines. As economies increasingly rely on scientific innovation and technological advancement, mathematics education has become a key driver of national

development and human capital formation. According to the Organisation for Economic Co-operation and Development (OECD, 2021), mathematical literacy is among the most important competencies required for effective participation in modern society and the global economy. Consequently, improving students' achievement in mathematics remains a major priority for educational systems worldwide. Despite its importance, mathematics continues to be one of the subjects in which students experience considerable learning difficulties. International assessments have consistently shown that many learners fail to attain expected proficiency levels in mathematics. For example, the Programme for International Student Assessment (PISA) reported that approximately 69% of students across participating countries failed to reach advanced proficiency levels in mathematics, indicating persistent challenges in mathematical understanding and application (OECD, 2021). These challenges are particularly evident in geometry, where students are required to visualize, manipulate, and reason about abstract spatial relationships. Among the various topics taught in secondary school mathematics, three-dimensional geometry remains one of the most challenging areas for learners because it demands advanced spatial reasoning, visualization, and analytical skills that many students struggle to develop effectively. Battista (2019) notes that geometry learning requires learners to construct mental representations of geometric objects and relationships, making it cognitively demanding. Similarly, Uttal, Miller, and Newcombe (2022) reported that weaknesses in spatial thinking significantly affect students' performance in geometry and related STEM subjects. As a result, three-dimensional geometry continues to record relatively lower achievement levels than other mathematics topics in many educational systems worldwide (Martin, 2023).

To address these challenges, educational systems around the world have increasingly adopted innovative teaching methods aimed at improving conceptual understanding and learner engagement. These methods include inquiry-based learning, guided discovery learning, collaborative learning, and technology-supported instruction. Research indicates that innovative teaching approaches significantly improve students' understanding of abstract mathematical concepts by promoting active participation and experiential learning (Van der Graaf, Segers, & Verhoeven, 2022). Furthermore, Yoon, Liu, and Schott (2023) found that the integration of digital technologies and interactive learning environments increased student engagement by more than 20% and contributed to improved academic outcomes in geometry instruction. Despite the growing use of innovative instructional approaches, concerns regarding gender differences in mathematics achievement remain a subject of considerable debate. Historically, mathematics has often

been viewed as a male-dominated field, leading to questions regarding whether male and female students benefit equally from educational interventions. Globally, studies have reported mixed findings regarding gender differences in mathematics achievement. While some studies indicate slight performance advantages among male students, others report minimal or no significant differences when learners are provided with supportive and learner-centered instructional environments (Dweck, 2020; Hattie, 2023). Simonsmeier, Flaig, and Schneider (2022) found that inquiry-based learning significantly reduced achievement gaps between male and female learners by promoting equal participation and engagement during instruction.

In Africa, mathematics achievement remains a major educational concern despite substantial investments in curriculum reforms and educational technology. According to the African Union (2020), less than 40% of secondary school students in many African countries achieve the minimum expected proficiency levels in mathematics. Research conducted in East Africa has revealed that geometry is among the weakest-performing mathematics topics due to difficulties associated with visualization and spatial reasoning (Mutonyi & Norton, 2021). Adu-Gyamfi and Brenya (2019) further reported that traditional teacher-centered instructional approaches continue to dominate many African classrooms, limiting opportunities for learners to actively engage with mathematical concepts. Consequently, educational stakeholders have increasingly advocated for innovative teaching methods as a means of improving mathematics achievement across the continent. In Rwanda, mathematics occupies a central position in the country's educational and economic development agenda. The Government of Rwanda recognizes mathematics education as essential for achieving the objectives of the National Strategy for Transformation (NST1) and the vision of becoming a knowledge-based economy (Ministry of Finance and Economic Planning, 2017). However, national examination reports continue to indicate challenges in mathematics performance. According to the Rwanda Basic Education Board (REB, 2022), geometry-related questions consistently record some of the lowest mean scores in Ordinary Level national examinations. Nzabonimpa and Uwizeyimana (2023) reported that students' performance in three-dimensional geometry remained below expected competency levels, with many learners experiencing difficulties in interpreting geometric representations and solving spatial problems. To improve mathematics learning outcomes, Rwanda has implemented several educational reforms, including the adoption of a competency-based curriculum, increased use of learner-centered pedagogies, and integration of information and communication technologies in education (MINEDUC,

2022). Studies conducted in Rwanda indicate that technology-supported and learner-centered instructional approaches enhance student engagement and conceptual understanding in mathematics (Nkuyubwatsi, Rwampyemana, & Uwizeyimana, 2022). Nevertheless, evidence regarding whether male and female students benefit equally from such innovative instructional interventions remains limited. Uwurukundo, Niyigena, and Habimana (2022) observed that although digital learning initiatives are expanding in Rwandan schools, little empirical research has examined the interaction between gender and innovative teaching methods in determining students' academic performance in mathematics.

In Musanze District, public day secondary schools continue to face challenges associated with mathematics achievement, particularly in geometry-related topics. While schools have increasingly adopted learner-centered and technology-supported instructional approaches, limited empirical evidence exists regarding the extent to which these methods influence male and female students differently. Understanding whether innovative teaching methods promote equitable learning outcomes across gender groups is essential for informing instructional practices and educational policy decisions. The present study therefore sought to determine the differential effects of gender on students' academic performance in three-dimensional geometry under innovative and traditional teaching methods in public day secondary schools in Musanze District, Rwanda. Specifically, the study examined whether gender significantly influences students' academic performance when innovative instructional approaches are employed and whether such methods provide equitable learning opportunities for both male and female learners. The findings contribute to the growing body of knowledge on mathematics education and provide evidence to support the implementation of effective and inclusive instructional practices in secondary schools.

1.2. Problem statement

Despite efforts to improve mathematics education in Rwanda, students continue to experience difficulties in understanding three-dimensional (3D) geometry. The Rwanda Basic Education Board (REB, 2022) reported that only 31.4% of students correctly answered 3D geometry questions in the national Ordinary Level Mathematics examinations. These difficulties are particularly related to spatial visualization, conceptual understanding, interpretation of three-dimensional objects, and application of geometric principles. In public day secondary schools in Musanze District, the continued use of traditional teacher-centred approaches may provide

limited opportunities for students to actively explore, visualize, manipulate, and construct knowledge of 3D geometry. Although innovative teaching methods provide opportunities for active participation and deeper understanding, there is insufficient evidence on whether their effects on students' academic performance differ according to gender. This creates a need to determine whether male and female students benefit differently when taught using innovative teaching methods compared with traditional teaching methods in 3D geometry.

The problem is further complicated by differences in students' prior mathematical knowledge. Students enter geometry lessons with different levels of understanding of prerequisite mathematical concepts, and such differences may influence their subsequent academic performance regardless of the teaching method received. Consequently, comparing the performance of male and female students or comparing students taught through innovative and traditional approaches without considering their initial level of knowledge may produce misleading conclusions about the effectiveness of the instructional methods. A Mathematics Pre-test is therefore necessary to establish students' prior knowledge before the intervention and to control for these baseline differences when examining post-test academic performance. The study consequently sought to determine the differential effects of gender on academic performance among students taught using innovative teaching methods and those taught using traditional teaching methods in 3D geometry, while controlling for prior knowledge measured through the Mathematics Pre-test.

Although previous studies have reported positive effects of innovative teaching approaches on mathematics learning, limited empirical evidence has established whether the effectiveness of these approaches differs between male and female students specifically in 3D geometry in public day secondary schools in Musanze District. In particular, it remains unclear whether any differences in post-intervention academic performance are attributable to gender, instructional method, or students' existing mathematical knowledge. This gap necessitates a comparison of students exposed to innovative teaching methods with those receiving traditional instruction while taking gender and prior mathematical knowledge into account. Therefore, the study employed a quasi-experimental approach using pre-test and post-test assessments and examined the main effects of gender and instructional method, as well as their interaction, while controlling for students' prior mathematical knowledge. This approach was intended to provide clearer evidence on whether innovative teaching methods offer similar or different academic benefits to male and female students in 3D geometry

1.3.1. General Objective

To investigate the effect of innovative teaching methods on student performance in 3-dimensional Geometry in public day secondary schools in rural areas of Musanze District, Rwanda

1.3.2. Specific Objectives

- i. To determine the differential effects of gender on academic performance among students taught using innovative teaching methods and those taught using traditional teaching methods in 3D geometry, while controlling for prior knowledge (Mathematics pretest).

2. Literature Review

2.1. Innovative Teaching Methods in Mathematics Education

Innovative teaching methods encompass contemporary, research-based strategies that move beyond traditional lecture-based instruction to actively engage students, enhance understanding, and improve learning outcomes (Hattie, 2023). These methods are particularly effective in mathematics, where abstract concepts like 3D geometry often require visualization, exploration, and problem-solving skills (Mayer, 2022). Key approaches include technology integration, guided discovery learning, and inquiry-based learning, each of which supports conceptual understanding, retention, and higher-order thinking (Anderson & Krathwohl, 2021).

Technology-enhanced instruction is particularly relevant to three-dimensional geometry because digital environments can provide dynamic representations that allow students to explore geometric objects and relationships. GeoGebra, for example, can support dynamic visualization and mathematical exploration. A meta-analysis of 14 studies involving 1,334 participants found a positive medium-to-large effect of GeoGebra on mathematics achievement, with geometry among the areas in which the software showed particularly useful effects (Zhang et al., 2023). Therefore, innovative mathematics instruction should be understood as a broad framework incorporating different learner-centred and technology-supported approaches rather than being restricted to guided discovery and inquiry-based learning. In the present study, these approaches are considered in relation to students' academic performance and mathematics self-efficacy in three-dimensional geometry

2.1.1. Technology Integration

Technology integration involves the purposeful use of digital tools and platforms to support learning. In 3D geometry, software like GeoGebra 3D and SketchUp allows students to manipulate shapes dynamically, explore spatial relationships, and visualize abstract concepts in real time (Martin, 2023; Tinker & Krajcik, 2021). Research shows that frequent and meaningful use of these tools improves problem-solving accuracy, conceptual understanding, and spatial reasoning (Mayer, 2022). However, findings are mixed. Some studies indicate that technology alone does not guarantee improved performance; its effectiveness depends on teacher expertise, scaffolding, and student engagement (Deubel, 2019; Hinojosa et al., 2024). In rural contexts, limited access to digital devices and infrastructure may constrain the benefits of technology integration, highlighting the need for context-specific strategies. Tool usage frequency, accuracy in visualizing 3D shapes, and solution accuracy are key indicators of effectiveness: These measures capture how students interact with technology and translate digital manipulation into learning outcomes (Hattie, 2023).

2.1.2. Guided Discovery Learning

Guided discovery learning (GDL) is a structured, student-centered approach where learners actively explore concepts with teacher scaffolding (Brusilovsky & Millán, 2022). Students engage with tasks, experiment, and uncover patterns, which promotes deep conceptual understanding and retention (Mayer, 2022).

Guided discovery learning enhances problem-solving skills, metacognition, and motivation (Ajda, 2022). Yet, its effectiveness relies heavily on teacher facilitation quality. Poorly designed tasks or insufficient guidance can lead to confusion or incomplete learning, particularly in resource-constrained schools where teachers may lack professional development opportunities (Lee & Hannafin, 2016). Indicators of effectiveness include active participation, depth of explanations, and problem-solving performance. Active participation reflects the extent to which students engage with tasks and interact with peers and learning materials. Depth of explanations captures how well students articulate their reasoning and connect concepts to underlying principles, demonstrating conceptual understanding. Problem-solving performance measures students' ability to apply knowledge to novel or complex tasks, showing whether they have internalized geometric principles rather than merely memorizing formulas (Almulla, 2023).

2.1.3. Inquiry-Based Learning

Inquiry-Based Learning (IBL) emphasizes student-driven investigation, where learners actively pose questions, explore problems, and construct knowledge independently (Bell, Smetana, & Binns, 2022). In the context of 3D geometry, IBL tasks may involve analyzing how the dimensions of shapes affect volume or surface area, encouraging higher-order reasoning, critical thinking, and the ability to transfer knowledge to new problems (Edelson et al., 2019). By placing students at the center of the learning process, IBL fosters autonomy, curiosity, and active engagement with complex geometric concepts.

However, effective IBL requires careful teacher scaffolding to ensure students remain supported and do not become frustrated or disengaged (Belland et al., 2017). Evidence shows that when implemented well, IBL enhances concept retention, problem-solving skills, and learner confidence (National Academies of Sciences, 2018). Key indicators of IBL effectiveness include students' success in solving problems, appropriate utilization of teacher support, and long-term retention of concepts, capturing both the development of skills and depth of understanding.

2.1.4. Collaborative/Cooperative Learning

Collaborative or cooperative learning is an instructional approach in which students work together in small groups to achieve shared learning objectives while contributing individually to the learning process. Unlike conventional teacher-centred instruction, cooperative learning encourages students to discuss ideas, explain mathematical procedures to peers, solve problems collectively, and provide feedback to one another. These interactions can support conceptual understanding and mathematical reasoning because learners are required to communicate and justify their thinking. A meta-analysis of cooperative learning in mathematics found a positive and significant effect on students' mathematics achievement, with cooperative learning producing better achievement outcomes than traditional instruction (Capar & Tarim, 2015). More recent evidence also indicates that cooperative learning can positively influence academic achievement and higher-order thinking, although its effectiveness may vary according to the instructional technique, subject area, and learning context (Güngör et al., 2026).

Collaborative learning is particularly relevant to three-dimensional geometry because students can work together to interpret geometric diagrams, construct and manipulate models, visualize three-dimensional objects, and solve problems involving surface area, volume, and spatial

relationships. Through group discussion and peer explanation, students can compare different approaches to geometric problems and correct misconceptions through interaction with classmates. Evidence from research involving mathematics learners aged 11–16 years also indicates that cooperative learning can improve mathematics attainment, although outcomes may differ across educational and student contexts (Hampson, 2026). In the context of the present study, collaborative learning is therefore considered one of the innovative approaches that can complement guided discovery, inquiry-based learning, and technology-supported instruction by promoting active participation, peer interaction, and problem-solving during three-dimensional geometry lessons.

2.1.5. Technology-Enhanced/ICT-Based Learning

Technology-enhanced or ICT-based learning refers to the integration of digital technologies, software, and electronic resources into teaching and learning to support students' understanding and active engagement with subject content. In mathematics education, ICT can provide dynamic representations, interactive activities, visualization, and opportunities for learners to explore mathematical relationships. This is particularly important in geometry, where students are required to understand spatial relationships and visualize objects that may be difficult to represent using static diagrams. A systematic review by Yohannes and Chen (2023) found that GeoGebra has been widely used in mathematics education, particularly in geometry, and that many studies have examined its influence on students' learning performance, higher-order thinking, attitudes, and perceptions. Similarly, Ng and Rosli (2023), in a systematic review of studies published between 2018 and 2022, found that GeoGebra was increasingly used to support geometry learning through dynamic mathematical representations.

Technology-enhanced learning is particularly relevant to three-dimensional geometry because digital tools can enable learners to visualize, manipulate, rotate, and investigate geometric objects dynamically. GeoGebra, for example, can be used to represent mathematical relationships and provide learners with opportunities to explore concepts rather than relying solely on teacher explanations. Evidence from a meta-analysis of 29 studies involving 2,111 students showed a positive overall effect of GeoGebra-supported learning on students' mathematical abilities, while another meta-analysis of 14 studies involving 1,334 participants found a positive medium-to-large effect of GeoGebra as a dynamic visualization tool on mathematics achievement, with particularly positive effects reported in geometry-related

learning. Furthermore, research examining problem-based learning supported by GeoGebra and Cabri 3D reported a moderate positive effect on students' understanding of geometrical concepts. However, effective ICT integration depends on adequate equipment, teacher preparedness, appropriate instructional design, and opportunities for students to interact meaningfully with the technology. In the present study, technology-enhanced learning is therefore considered an important component of innovative teaching for supporting visualization, conceptual understanding, and academic performance in three-dimensional geometry

2.1.6. Traditional Teaching Methods

Traditional teaching methods are characterized by teacher-centered instruction, reliance on rote learning, and limited use of instructional aids (Hattie, 2023). In this approach, the teacher dominates classroom activities, while students play a passive role, mainly listening, taking notes, and memorizing formulas (Mayer, 2022). While these methods can support the acquisition of procedural knowledge and efficient syllabus coverage, they often limit student engagement and hinder the development of conceptual understanding and higher-order thinking skills (Bransford, Brown, & Cocking, 2000).

Several empirical studies have shown that students taught using traditional methods tend to perform well in routine calculations but struggle with complex problem-solving and spatial reasoning tasks, particularly in topics such as three-dimensional geometry (Schoenfeld, 1985; National Research Council, 2001). This limitation arises because traditional methods provide limited opportunities for visualization, interaction, and exploration of geometric concepts (Vygotsky, 1978). However, despite these weaknesses, traditional teaching methods remain widely used in many educational contexts, especially in resource-constrained environments, due to their simplicity and minimal reliance on instructional materials (UNESCO, 2021; World Bank, 2020).

2.2. Theoretical Framework

This study was guided by Constructivist Learning Theory, which was developed by Piaget (1973) and later expanded by Vygotsky (1978). The theory posits that learners actively construct knowledge through interaction with their environment rather than passively receiving information from teachers. According to Piaget (1973), learning occurs when individuals build new knowledge based on their prior experiences and existing cognitive structures through the processes of assimilation and accommodation. Constructivist theorists maintain that meaningful learning takes place when learners engage actively in exploration, inquiry, experimentation, and

problem-solving activities that enable them to construct their own understanding of concepts.

The theory emphasizes learner-centered instructional approaches in which students participate actively in the learning process. Vygotsky (1978) argues that learning is socially constructed and that interaction with peers, teachers, and learning resources plays a critical role in knowledge development. Through collaboration, discussion, and guided support, learners are able to achieve higher levels of understanding than they would attain individually. Consequently, learning environments that encourage active engagement, exploration, and interaction are more likely to promote meaningful learning and academic achievement

Constructivist Learning Theory is particularly relevant to the teaching and learning of three-dimensional geometry because the topic requires learners to understand abstract concepts, visualize spatial relationships, and manipulate geometric structures mentally. Battista (2019) notes that geometry learning is most effective when students are provided with opportunities to explore geometric relationships and construct meaning through active engagement with mathematical tasks. Similarly, Uttal, Miller, and Newcombe (2022) emphasize that spatial reasoning skills develop more effectively when learners interact directly with visual and manipulative representations of geometric concepts.

The theory is closely aligned with the innovative teaching methods employed in the current study. Inquiry-based learning, guided discovery learning, and technology-supported instruction using GeoGebra and SketchUp create opportunities for students to explore, investigate, and construct mathematical knowledge independently. According to Van der Graaf, Segers, and Verhoeven (2022), inquiry-based instructional approaches promote deeper conceptual understanding by engaging learners in the process of discovering relationships and generating solutions to problems. Likewise, Putri and Musdi (2024) observed that guided inquiry approaches improve students' mathematical understanding by encouraging active participation and independent reasoning during the learning process.

The theory is also relevant to the gender dimension of the present study. Constructivist learning environments emphasize equal participation, collaboration, and active engagement among learners irrespective of gender. Through learner-centered instructional approaches, both male and female students are provided with opportunities to construct knowledge, share ideas, and solve problems collaboratively. Consequently, Constructivist Learning Theory provides an appropriate framework for explaining how innovative teaching methods may influence

academic performance in three-dimensional geometry among both male and female students.

3. Methodology

The study adopted a mixed-methods research approach, with the quantitative component employing a quasi-experimental non-equivalent control group design. Under this design, students were exposed to two different instructional conditions. The experimental group was taught 3D geometry using innovative teaching methods, while the control group was taught using traditional teaching methods. The use of pre-test and post-test assessments enabled the researcher to establish students' level of prior knowledge before the intervention and assess their academic performance after the instructional period. This design was considered appropriate because the objective required a comparison of students' achievement across instructional methods while also examining whether gender influenced or modified the effectiveness of the teaching approaches.

The study was conducted in selected public day secondary schools in Musanze District, Rwanda. The target population comprised students and mathematics teachers from the selected schools. The student participants were selected using appropriate sampling procedures, including proportional allocation and simple random sampling, to ensure that students from the participating schools were adequately represented. The existing classes were retained in order to maintain the natural school setting and facilitate the implementation of the quasi-experimental design. The study therefore compared students who received innovative teaching methods with those who received traditional teaching methods within the selected schools. Gender was considered an important student characteristic in the analysis because the first objective specifically sought to establish whether male and female students responded differently to the two instructional approaches in the learning of 3D geometry.

Data for this objective were collected using mathematics achievement tests administered at two stages of the study. The Mathematics Pre-test was administered before the instructional intervention to assess students' existing mathematical knowledge and establish their baseline level of understanding. The pre-test information was important because students may enter an instructional intervention with different levels of prior knowledge, which can influence their subsequent academic performance. After the instructional intervention, a Mathematics Post-test was administered to assess students' achievement in 3D geometry. The same assessment framework was used to provide a basis for determining changes in students' performance following the instructional intervention. In

the analysis, gender and instructional method were treated as the main explanatory factors, prior mathematical knowledge measured through the pre-test was treated as a covariate, and students' post-test achievement in 3D geometry was treated as the dependent variable.

The quantitative data collected from the achievement tests were analysed using both descriptive and inferential statistical techniques. Descriptive statistics were first used to summarise students' academic performance according to gender and instructional group. This provided an initial description of how male and female students performed under innovative and traditional teaching conditions. For inferential analysis, a Two-Way Analysis of Covariance (ANCOVA) was employed. The statistical technique was used to examine the main effect of gender and the main effect of instructional method on students' post-test academic performance while controlling for prior mathematical knowledge. It was also used to examine the interaction between gender and instructional method. The interaction analysis was particularly important for the first objective because it helped determine whether the effect of innovative teaching methods compared with traditional teaching methods differed between male and female students. Controlling for prior mathematical knowledge also helped ensure that the comparison of post-test performance took students' initial mathematical knowledge into consideration.

Before the Two-Way ANCOVA was conducted, the relevant assumptions of the statistical analysis were examined. The normality of the data was assessed using Q-Q plots to determine whether the distribution of the achievement scores was reasonably appropriate for the intended analysis. The assumption of homogeneity of error variances was assessed using Levene's test. These diagnostic procedures were conducted to establish whether the data satisfied the assumptions required for the application of ANCOVA. The results of the assumption tests were considered when interpreting the findings, particularly where an assumption was not fully satisfied. This procedure strengthened the methodological rigour of the analysis and provided a basis for making appropriate interpretations of the statistical results.

Ethical considerations were observed throughout the research process. Before data collection, the researcher obtained the necessary permission from the relevant authorities and the participating schools. The purpose and procedures of the study were explained to the participants, and the required consent procedures were followed, particularly because the study involved secondary school students. Participation was treated as voluntary, and participants were informed that the information they provided would be used for academic research purposes.

Confidentiality and anonymity were maintained throughout the process by protecting participants' personal information and ensuring that the data were handled appropriately. The researcher also ensured that the instructional activities and data collection procedures were conducted in a manner that respected the rights and welfare of the participating students.

4. Results and Discussion

This section presents and discusses the findings related to the differential effects of gender on students' academic performance in 3D geometry under innovative and traditional teaching methods. The findings are presented based on the data collected through the Mathematics Pre-test and Post-test and analysed using descriptive statistics and Two-Way ANCOVA. The discussion relates the findings to the study objective and explains the implications of gender, instructional method, and prior mathematical knowledge for students' achievement in 3D geometry.'

4.1. Findings

4.1.1. Response Rate

The study involved 269 students who provided complete data for the analysis of the first objective, comprising 143 male students and 126 female students. The participants were drawn from both the experimental and control groups and completed the Mathematics Pre-test and Post-test used to assess their prior mathematical knowledge and academic performance in 3D geometry. The completed assessments provided the data required to examine the differential effects of gender and instructional method on students' academic performance while controlling for prior knowledge. Therefore, the responses from the 269 students were included in the subsequent descriptive and inferential analyses

To determine the differential effects of gender on academic performance among students taught using innovative teaching methods and those taught using traditional teaching methods in three-dimensional geometry while controlling for prior mathematical knowledge, descriptive statistics and a Two-Way Analysis of Covariance (ANCOVA) were conducted. Descriptive statistics were first computed to establish students' academic performance across gender and instructional groups before conducting inferential analysis. The results are presented in Table 1.

Table 1: Descriptive Statistics for Academic Performance by Gender and Treatment Group

Student's Gender	Treatment Group	Mean	Std. Deviation	N
Male	Experimental Group	13.60	2.465	73
	Control Group	12.53	1.800	70
	Total	13.08	2.224	143
Female	Experimental Group	14.10	2.032	59
	Control Group	12.24	1.835	67
	Total	13.11	2.136	126
Total	Experimental Group	13.83	2.287	132
	Control Group	12.39	1.816	137
	Total	13.09	2.179	269

Source: Field data, 2026

Table 1 provides information on students' academic performance in three-dimensional geometry according to gender and treatment group. The results indicate that students in the experimental group achieved higher mean scores than students in the control group. Female students in the experimental group obtained the highest mean score (14.10), while female students in the control group obtained the lowest mean score (12.24). These findings

suggest that innovative teaching methods enhanced students' academic performance in three-dimensional geometry among both male and female students. However, descriptive statistics alone cannot determine whether the observed differences were statistically significant. Therefore, inferential analysis was conducted using ANCOVA while controlling for prior mathematical knowledge

Table 2: Between Subjects Factors According to Gender and Treatment Group

		Value Label	N
Student's Gender	1	Male	143
	2	Female	126
Treatment Group	1	Experimental Group	132
	2	Control Group	137

Source: Field data, 2026

Table 2 presents the between-subjects factors used in the analysis. The respondents were categorized according to gender and treatment group. The findings indicate that 143 respondents were male, while 126 were female. Similarly, 132 students belonged to the experimental group, whereas 137 students were in the control group. These groupings were used to determine the differential effects of gender and instructional methods on students'

academic performance in three-dimensional geometry while controlling for prior mathematical knowledge.

To determine whether statistically significant differences existed in students' academic performance based on gender and instructional method after controlling for prior mathematical knowledge, a Two-Way Analysis of Covariance (ANCOVA) was conducted. The results are presented in Table 3

Table 3: Inferential Analysis of Student Achievement: The ANCOVA Model Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Squared	Eta
Corrected Model	301.514 ^a	4	75.379	20.491	.000	.237	
Intercept	841.244	1	841.244	228.683	.000	.464	
MATPRE	151.329	1	151.329	41.137	.000	.135	
GENDER	1.132	1	1.132	.308	.579	.001	
GROUP	74.211	1	74.211	20.173	.000	.071	
GENDER * GROUP	5.732	1	5.732	1.558	.213	.006	
Error	971.162	264	3.679				
Total	47386.000	269					
Corrected Total	1272.677	268					

a. R Squared = .237 (Adjusted R Squared = .225)

The Analysis of Covariance (ANCOVA) revealed that the overall model was statistically significant, $F(4, 264) = 20.49$, $p < .001$, $\eta^2 = .237$, indicating that the model explained a significant proportion of the variance in students' academic performance in three-dimensional geometry after controlling for prior mathematical knowledge. Prior mathematical knowledge had a statistically significant effect on students' academic performance, $F(1, 264) = 41.14$, $p < .001$, $\eta^2 = .135$. Similarly, instructional method significantly influenced students' academic performance, $F(1, 264) = 20.17$, $p < .001$, $\eta^2 = .071$, indicating that students taught using innovative teaching methods achieved significantly higher academic performance than those taught using traditional instructional approaches.

Gender did not have a statistically significant effect on students' academic performance, $F(1, 264) = 0.31$, $p = .579$, $\eta^2 = .001$. Likewise, the interaction between gender and instructional method was not statistically significant, $F(1, 264) = 1.56$, $p = .213$, $\eta^2 = .006$. Therefore, the null hypothesis was retained, indicating that the effectiveness of innovative teaching methods did not differ significantly between male and female students. These findings suggest

that both male and female students benefited equally from the instructional intervention.

4.2. Discussion of Findings

The present study found that gender did not have a statistically significant effect on students' academic performance in three-dimensional geometry under innovative and traditional teaching methods. This finding suggests that male and female students achieved comparable learning outcomes when exposed to similar instructional approaches, indicating that academic performance in three-dimensional geometry depends more on the quality of instruction than on gender. The non-significant interaction between gender and instructional method further indicates that innovative teaching methods benefited both male and female students equally. These findings suggest that inquiry-based learning, guided discovery learning, and technology-supported instruction through GeoGebra and SketchUp created inclusive learning environments that promoted equitable participation and achievement among learners. The findings are consistent with those of Uttal et al. (2022),

who reported that gender differences in geometry achievement diminish when learners receive appropriate instructional support and opportunities to develop spatial reasoning skills. Similarly, Zuze and Hu (2019) found that equitable learning environments contribute to comparable academic outcomes among male and female learners, while Adu-Gyamfi and Brenya (2019) observed that learner-centered instructional approaches reduce gender disparities in mathematics achievement.

Instructional method had a statistically significant effect on students' academic performance in three-dimensional geometry, with students taught using innovative teaching methods achieving significantly higher academic performance than those taught using traditional instructional approaches. This finding indicates that learner-centered instructional approaches promote deeper conceptual understanding by actively engaging students in inquiry, collaboration, exploration, and visualization of geometric concepts. The use of GeoGebra and SketchUp enabled students to manipulate three-dimensional objects, visualize spatial relationships, and solve geometry problems more effectively than conventional teaching approaches. These findings are consistent with those of Putri and Musdi (2024), who found that guided inquiry significantly improves students' mathematical understanding and achievement. Likewise, Van der Graaf et al. (2022) reported that inquiry-based learning enhances students' conceptual understanding and academic performance by actively involving learners in the construction of mathematical knowledge.

Prior mathematical knowledge also had a statistically significant influence on students' academic performance, indicating that students with stronger mathematical foundations achieved better learning outcomes than those with weaker prior knowledge. This finding suggests that successful learning in three-dimensional geometry depends on learners' ability to build on previously acquired mathematical concepts and skills. Similar observations were reported by Anderson and Krathwohl (2021), who argued that meaningful learning occurs when new knowledge is connected to learners' existing cognitive structures. The findings further support Constructivist Learning Theory, which posits that learners actively construct knowledge through interaction with learning experiences, teachers, peers, and instructional resources. Through inquiry-based learning, guided discovery learning, and technology-supported activities, students were actively engaged in exploring, discussing, and constructing understanding of three-dimensional geometry concepts. Consequently, the findings demonstrate that innovative teaching methods enhance students' academic performance while providing equitable learning opportunities for both male and female students.

5. Conclusion and Recommendations

This section presents the study's main conclusion and recommendations based on the findings on gender, instructional methods, and students' performance in 3D geometry.

5.1. Conclusion

The study concludes that innovative teaching methods, including inquiry-based learning, guided discovery learning, and technology-supported instruction, can enhance students' academic performance in three-dimensional geometry compared with traditional teaching methods. The findings further indicate that gender did not significantly influence students' academic performance or significantly change the effect of instructional methods, suggesting that innovative teaching approaches can benefit both male and female students. The study also concludes that prior mathematical knowledge plays an important role in students' achievement, as students' existing mathematical foundations influence their ability to understand and apply new geometric concepts. Therefore, strengthening foundational mathematical knowledge while promoting learner-centred and technology-supported instructional practices can contribute to improved achievement in 3D geometry and more equitable learning opportunities among secondary school students.

5.2. Recommendations

Based on the study findings and conclusions, the following recommendations are proposed to improve the teaching and learning of 3D geometry in secondary schools;

- 1) Mathematics teachers should increase the use of innovative teaching methods such as inquiry-based learning, guided discovery learning, and technology-supported instruction when teaching three-dimensional geometry. These approaches should provide students with opportunities to actively explore, discuss, visualize, and solve geometric problems rather than relying mainly on traditional teacher-centred instruction.
- 2) Schools should strengthen the integration of educational technologies in mathematics teaching. School administrators should facilitate access to appropriate digital tools and resources, including geometry software such as GeoGebra and SketchUp, and ensure that mathematics teachers receive adequate support and training to use these technologies effectively in teaching 3D geometry.
- 3) Mathematics teachers should assess and strengthen students' prior mathematical

knowledge before introducing advanced geometry concepts. Teachers should use diagnostic assessments and remedial activities to identify learning gaps and provide opportunities for students to revise prerequisite mathematical concepts. This can help students develop the foundation required to understand more complex three-dimensional geometry concepts.

- 4) Schools and education stakeholders should promote gender-inclusive instructional practices rather than relying on gender-specific teaching approaches. Since innovative teaching methods can support both male and female students, teachers should provide equal opportunities for participation, collaboration, exploration, and use of learning technologies, while ensuring that all students are actively engaged in mathematics learning.

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