ENHANCING SECONDARY SCHOOL STUDENTS' GEOMETRY ACHIEVEMENT THROUGH CTML-ALIGNED ANIMATED INSTRUCTION

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Abstract
Persistent difficulties in secondary school geometry learning have been linked to instructional approaches that inadequately support students' visual–spatial processing. Grounded in the Cognitive Theory of Multimedia Learning (CTML), this study examined the effectiveness of a Developed Animated Instructional Package for Geometry (DAIPG) on the geometry achievement of Senior Secondary II students in a gender-segregated, low-resource educational context. A quasi-experimental pretest–post-test control-group design was employed. Participants comprised 200 students drawn from public secondary schools in Sokoto State, Nigeria, with 100 students assigned to the experimental group and 100 to the control group. Geometry achievement was measured using a validated Geometry Performance Test (KR-20 = .87). Data were analysed using Analysis of Covariance (ANCOVA), with pretest scores treated as a covariate. Results revealed a statistically significant effect of instructional method on post-test geometry achievement, $F(1, 197) = 76.91$, $p < .001$, partial $\eta^2 = .28$, indicating a large effect size. Pretest achievement also significantly predicted post-test performance, $F(1, 197) = 46.28$, $p < .001$, partial $\eta^2 = .19$. Students exposed to DAIPG outperformed those taught using conventional instructional methods after controlling for prior achievement. The findings provide empirical support for CTML-aligned animated instruction as an effective approach for enhancing geometry achievement in gender-segregated and resource-constrained secondary school settings. The study underscores the importance of theory-driven instructional design for improving mathematics learning outcomes.

Keywords: animated instruction, geometry achievement, multimedia learning, cognitive theory of multimedia learning, secondary education

Introduction

Geometry is a core component of secondary school mathematics curricula and plays a crucial role in the development of learners' spatial reasoning, logical thinking, and problem-solving abilities. These competencies are essential not only for success in mathematics but also for participation in science, technology, engineering, and mathematics (STEM) disciplines that rely heavily on spatial visualization and abstract reasoning (Sinclair & Bruce, 2022; Uttal et al., 2020). Despite its foundational importance, geometry remains one of the most challenging areas of school mathematics, with many students experiencing persistent difficulties in understanding abstract geometric concepts and spatial relationships.

International and national assessments like Organisation for Economic Co-operation and Development, (OECD) have consistently reported low student performance in geometry-related tasks, particularly those involving transformations, proportional reasoning, and visual–spatial interpretation (OECD, 2023). In Nigeria, similar concerns are reflected in secondary school examination outcomes, where geometry is frequently identified as an area of weak conceptual understanding and low achievement. Scholars attribute these difficulties partly to instructional practices that emphasise procedural knowledge over conceptual understanding and rely heavily on static representations that inadequately support learners' visualization processes (Aremu & Sokan, 2022; Gambari et al., 2021).

Traditional classroom instruction in geometry often depends on chalkboard drawings, textbook diagrams, and verbal explanations. While these approaches may suffice for introducing basic definitions, they provide limited support for representing dynamic geometric processes such as rotation,

reflection, dilation, and similarity. Cognitive research suggests that when learners are required to mentally manipulate complex visual information without sufficient external visual scaffolding, cognitive load increases, thereby constraining working memory and impeding meaningful learning (Sweller et al., 2019). This challenge is particularly salient in geometry, where comprehension is closely tied to the ability to visualise and mentally transform spatial representations.

In response to these challenges, digital and animation-based instructional approaches have gained increasing attention in mathematics education research. Animated instructional materials allow learners to observe geometric objects in motion, making invisible or abstract relationships more explicit and cognitively accessible. Empirical evidence indicates that well-designed animations can enhance learners' conceptual understanding, improve achievement, and support long-term retention when compared with purely static instructional formats (Ayres & Paas, 2020; Berney & Bétrancourt, 2019).

The effectiveness of animation-based instruction is strongly underpinned by Mayer's Cognitive Theory of Multimedia Learning (CTML). CTML posits that learners process information through dual channels (visual and auditory), each with limited capacity, and that meaningful learning occurs when instructional materials are designed to support active cognitive processing across these channels (Mayer, 2021). According to this framework, instructional designs that adhere to principles such as coherence, signalling, segmenting, and modality are more likely to reduce extraneous cognitive load and foster deeper understanding. In geometry learning, animations aligned with CTML principles can support learners in constructing accurate mental models of spatial relationships and geometric transformations (Fiorella & Mayer, 2022).

Recent studies in mathematics and science education have reported positive effects of animation-based instruction on students' learning outcomes, particularly when animations are explicitly designed to support conceptual understanding rather than surface engagement (Höffler et al., 2023; Wong et al., 2021). However, the literature also highlights that the effectiveness of animated instruction is context-dependent, varying according to instructional design quality, learner characteristics, and educational settings. As a result, scholars increasingly call for contextually grounded studies that examine not only whether animation works, but under what conditions and for whom it is most effective (Clark & Mayer, 2024).

One notable gap in existing research concerns the limited empirical evidence from low-resource and gender-segregated educational contexts. In many regions of sub-Saharan Africa, including northern Nigeria, secondary schools operate under constraints such as limited access to instructional technologies, large class sizes, and gender-segregated schooling structures. These contextual features may influence how learners engage with digital instructional materials and how teachers integrate technology into classroom practice. Despite this, such contexts remain underrepresented in multimedia learning research, which has predominantly focused on technologically advanced or mixed-gender educational environments (Makransky & Petersen, 2019; Yusuf & Afolabi, 2023).

Gender-segregated schooling environments, in particular, present distinctive pedagogical dynamics that warrant scholarly attention. Classroom interaction patterns, pacing of instruction, and learner engagement may differ across gender-segregated settings, potentially shaping the effectiveness of technology-enhanced learning interventions. Yet, few studies have explicitly examined animation-based instruction within these contexts, resulting in limited guidance for educators and policymakers seeking to implement multimedia learning tools in gender-segregated schools (Gambari et al., 2021).

Furthermore, while previous Nigerian studies have explored computer-assisted and animation-based instruction in mathematics, many have been limited by weak theoretical grounding, small sample sizes, or insufficient methodological rigor. Contemporary Q2-level educational technology research places strong emphasis on theoretically informed instructional design, robust statistical analysis, and transparent reporting of effect sizes and contextual variables (Makransky et al., 2020; OECD, 2023). Addressing these methodological and conceptual gaps is essential for advancing the quality and international relevance of research emerging from developing educational systems.

Against this backdrop, the present study investigates the effectiveness of a Developed Animated Instructional Package for Geometry (DAIPG) on the geometry achievement of Senior Secondary II students in Sokoto State, Nigeria. The DAIPG was systematically designed in alignment with core

CTML principles, incorporating dynamic visualisations, narration, signalling cues, and segmented instructional sequences to support learners' cognitive processing. Using a quasi-experimental pretest–posttest control-group design and controlling for prior achievement, the study provides rigorous empirical evidence on the impact of animation-based instruction in a gender-segregated, low-resource secondary school context.

This study contributes to the literature in three important ways. First, it extends multimedia learning research by providing empirical evidence from an underrepresented educational context characterised by gender-segregated schooling and limited instructional resources. Second, it strengthens the theoretical discourse on animation-based instruction by explicitly linking instructional design features to CTML principles and examining their effects on students' geometry achievement. Third, it offers practical insights for educators and policymakers seeking scalable, theory-driven solutions to persistent challenges in secondary school geometry instruction.

By addressing both theoretical and contextual gaps in the literature, this study responds to recent calls for more inclusive, methodologically rigorous, and context-sensitive educational technology research. The findings are expected to inform instructional practice, curriculum design, and policy decisions regarding the integration of animated instructional materials in secondary school mathematics education.

Problem Statement

In northern Nigeria, including Sokoto State, geometry learning challenges are compounded by contextual constraints such as large class sizes, limited access to instructional technologies, and the prevalence of gender-segregated secondary schooling. While gender-segregated schooling is culturally and institutionally embedded in the region, it introduces distinctive pedagogical dynamics that may influence instructional delivery, learner interaction, and engagement with digital learning resources. However, gender-segregated educational contexts remain underrepresented in multimedia learning research, limiting understanding of how technology-enhanced instructional approaches function in such environments (Makransky & Petersen, 2019; Yusuf & Afolabi, 2023).

Although animation-based instructional approaches have demonstrated positive effects on students' learning outcomes in mathematics, much of the existing evidence originates from technologically advanced or mixed-gender educational settings. Furthermore, several studies report effectiveness without explicitly linking instructional design features to established learning theories, thereby limiting their explanatory power and scalability (Clark & Mayer, 2024; Wong et al., 2021). Contemporary educational technology scholarship increasingly calls for theory-driven, context-sensitive studies that examine not only whether animation works, but *why* it works and under what contextual conditions its effectiveness is maximised (Makransky et al., 2020).

Consequently, there remains a clear empirical and theoretical gap concerning the effectiveness of animation-based geometry instruction designed in alignment with CTML principles within gender-segregated, low-resource secondary school contexts. Addressing this gap is essential for advancing multimedia learning theory, informing evidence-based instructional practice, and supporting policy decisions aimed at improving mathematics education in developing educational systems.

Purpose of the Study

The purpose of this study was to examine the effectiveness of a Developed Animated Instructional Package for Geometry (DAIPG), designed in alignment with the Cognitive Theory of Multimedia Learning, on the geometry achievement of Senior Secondary II students in Sokoto State, Nigeria. Specifically, the study sought to determine whether students exposed to DAIPG would demonstrate significantly higher post-instruction geometry achievement than their counterparts taught using conventional instructional methods, after controlling for pre-instruction achievement.

Objectives of the Study

The specific objectives of the study were to:

1. determine the difference in post-test geometry achievement between students taught using DAIPG and those taught using conventional instructional methods;
2. examine the effect of DAIPG on students' geometry achievement across gender-segregated learning contexts after controlling for pretest scores;

3. assess whether male and female students differ in their geometry achievement when exposed to DAIPG;
4. determine the magnitude of the instructional effect of DAIPG on students' geometry achievement using effect size indices.

Research Questions

The following research questions guided the study:

1. What difference exists in the posttest geometry achievement scores of students taught using the Developed Animated Instructional Package for Geometry (DAIPG) and those taught using conventional instructional methods?
2. To what extent does exposure to DAIPG influence students' geometry achievement after controlling for pretest scores?
3. What difference exists in the geometry achievement of male and female students exposed to DAIPG?

Research Hypothesis

The following null hypothesis was tested at the 0.05 level of significance:

H01: There is no significant difference in the posttest geometry achievement scores of students taught using the Developed Animated Instructional Package for Geometry (DAIPG) and those taught using conventional instructional methods, after controlling for pretest scores.

H02: There is no significant difference in the geometry achievement of male and female students taught using the Developed Animated Instructional Package for Geometry (DAIPG), after controlling for pretest scores.

Literature Review

The Cognitive Theory of Multimedia Learning (CTML) provides a dominant theoretical framework for understanding how learners process information presented through multiple representational modes. Rooted in cognitive psychology, CTML posits three core assumptions: (1) the dual-channel assumption, which suggests that learners process visual–pictorial and verbal–auditory information through separate channels; (2) the limited capacity assumption, which holds that each channel has a finite processing capacity; and (3) the active processing assumption, which asserts that meaningful learning occurs when learners actively select, organise, and integrate information across channels (Mayer, 2021).

These assumptions have direct implications for geometry instruction. Geometry learning requires learners to integrate symbolic representations, verbal explanations, and spatial visualisations simultaneously. When instruction relies predominantly on static diagrams and verbal explanations, learners are often forced to mentally animate geometric transformations, increasing extraneous cognitive load and reducing resources available for conceptual integration (Sweller et al., 2019; Fiorella & Mayer, 2022). CTML therefore predicts that instructional designs which externalise dynamic processes such as animated representations should support more efficient cognitive processing and deeper understanding.

Empirical evidence supports this theoretical prediction. Meta-analytic studies indicate that multimedia instruction designed in accordance with CTML principles leads to significantly higher learning gains than non-theory-driven designs (Höffler et al., 2023; Wong et al., 2021). Importantly, CTML emphasises that animation alone is insufficient; instructional effectiveness depends on adherence to principles such as coherence (excluding irrelevant material), signalling (highlighting essential information), segmenting (breaking content into manageable units), and modality (coordinating visual and auditory information). Studies that neglect these principles often report mixed or negligible effects of animation, underscoring the importance of theory-aligned design (Clark & Mayer, 2024).

Cognitive Load Theory (CLT) complements CTML by explaining how instructional design influences the distribution of cognitive resources during learning. CLT distinguishes between intrinsic cognitive load (task complexity), extraneous cognitive load (inefficient instructional design), and germane cognitive load (resources devoted to schema construction) (Sweller et al., 2019). Geometry tasks typically impose high intrinsic load due to their abstract and relational nature, particularly when learners must visualise transformations and spatial relationships.

In poorly designed instructional environments, extraneous load is increased when learners are required to infer motion or relationships from static representations. Animation-based instructional designs, when aligned with CTML and CLT principles, can reduce extraneous load by explicitly representing dynamic processes, thereby freeing cognitive resources for germane processing (Ayres & Paas, 2020). Empirical studies in mathematics education confirm that reducing extraneous cognitive load through dynamic visualisation enhances conceptual understanding and problem-solving performance (Berney & Bétrancourt, 2019; Höffler et al., 2023).

Recent empirical research provides substantial evidence for the effectiveness of animation-based instruction in mathematics, particularly for topics requiring spatial reasoning and conceptual integration. Studies conducted across diverse educational contexts demonstrate that students exposed to well-designed animated instructional materials outperform those taught using conventional static methods in terms of achievement, retention, and transfer of learning (Gambari et al., 2021; Wong et al., 2021).

However, the literature also reveals important boundary conditions. Several studies report limited or inconsistent effects when animations are poorly designed or when learners are cognitively overloaded by excessive motion or redundant information (Makransky & Petersen, 2019). This has led scholars to argue that the effectiveness of animation is conditional, depending on alignment with learning theory, learner characteristics, and instructional context (Höffler et al., 2023). Q2-level journals increasingly emphasise this conditionality, prioritising studies that explicitly articulate *why* an instructional intervention is expected to work.

Educational context plays a critical role in shaping the effectiveness of technology-enhanced instruction. In many parts of sub-Saharan Africa, secondary school classrooms operate under conditions of limited technological infrastructure, large enrolments, and teacher-centred pedagogies. These constraints can magnify the cognitive challenges associated with learning abstract mathematical concepts such as geometry (Yusuf & Afolabi, 2023).

Gender-segregated schooling, which remains prevalent in northern Nigeria, introduces additional pedagogical dynamics that are rarely addressed in multimedia learning research. Differences in classroom interaction patterns, instructional pacing, and learner engagement may influence how students interact with digital instructional materials. Despite this, most existing multimedia learning studies are conducted in mixed-gender or technologically advanced settings, limiting their generalisability to gender-segregated environments (Makransky et al., 2020).

By situating animation-based geometry instruction within a gender-segregated, low-resource context, the present study responds to calls for context-sensitive educational technology research. Such research is essential for ensuring that instructional innovations are not only theoretically sound but also practically viable and scalable across diverse educational systems.
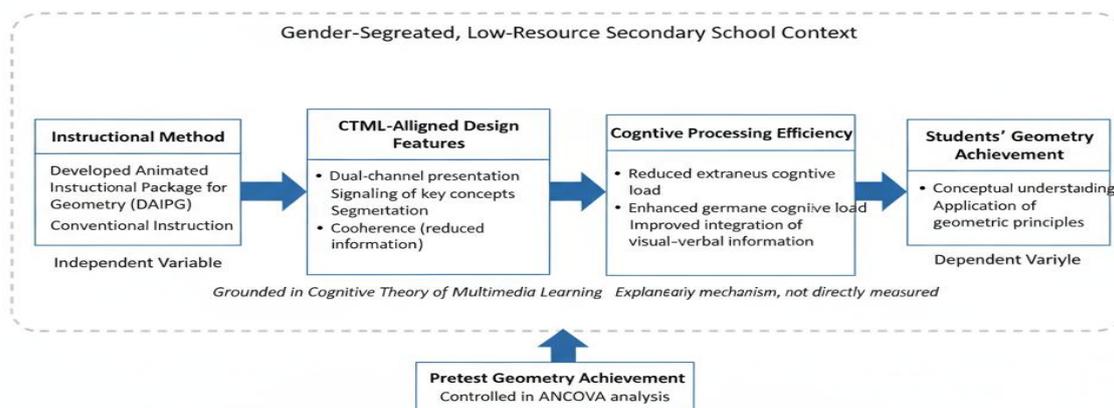
The conceptual framework of this study explains how instructional design influences students' geometry achievement through cognitive mechanisms within a gender-segregated secondary school context. Grounded in the Cognitive Theory of Multimedia Learning (CTML) and Cognitive Load Theory (CLT), the framework posits that learning outcomes are shaped by the way instructional materials are designed to support learners' cognitive processing.

Within the framework, instructional method serves as the independent variable and is conceptualised as two contrasting approaches: the Developed Animated Instructional Package for Geometry (DAIPG) and conventional teacher-centred instruction. DAIPG is a theory-driven intervention designed in accordance with CTML principles, including dual-channel presentation, signalling, segmentation, and coherence. These features are intended to externalise dynamic geometric processes and reduce learners' reliance on mental animation.

The framework proposes that the influence of instructional method on learning outcomes is mediated by cognitive processing efficiency. Drawing on CLT, DAIPG is expected to reduce extraneous cognitive load while supporting germane cognitive load associated with schema construction and conceptual

integration. Cognitive processing efficiency functions as an explanatory mechanism rather than a directly measured variable, accounting for how instructional design facilitates meaningful learning.

The dependent variable is students' geometry achievement, operationalised as posttest performance reflecting conceptual understanding and application of geometric principles. Pretest geometry achievement is incorporated as a covariate to control for prior knowledge, aligning with the study's use of ANCOVA and strengthening internal validity. The framework is embedded within a gender-segregated, low-resource educational context, which frames instructional conditions without functioning as a statistical variable.

Figure 1: *Conceptual framework illustrating the relationship between instructional method, cognitive processing mechanisms, and students' geometry achievement, grounded in CTML and CLT.*

Methodology
This study employed a quasi-experimental pretest–posttest control-group design, appropriate for educational research conducted in authentic classroom settings where random assignment of individual students is impractical. The design enabled comparison of post-instruction geometry achievement between students exposed to the Developed Animated Instructional Package for Geometry (DAIPG) and those taught using conventional instructional methods. The inclusion of pretest scores as a covariate strengthened causal inference by isolating the effect of instructional method through analysis of covariance (ANCOVA).

The participants were Senior Secondary II (SS II) students drawn from public, gender-segregated secondary schools in Sokoto State, Nigeria. Using a multistage sampling approach, four schools were purposively selected to reflect the prevailing schooling structure, after which intact classes were assigned to experimental and control conditions. A total of 200 students participated (100 per group), and the use of intact classes preserved ecological validity by maintaining natural instructional conditions.

Ethical approval was obtained from the University of Ilorin, with permissions granted by the State Ministry of Education and participating school authorities. Informed consent was secured from students and, where applicable, from parents or guardians. Participation was voluntary, confidentiality was assured, and no personally identifiable information was reported, in line with international ethical standards for educational research.

The instructional intervention comprised DAIPG for the experimental group and conventional teacher-centred instruction for the control group. DAIPG was designed in alignment with the Cognitive Theory of Multimedia Learning (CTML) and incorporated dynamic visualisations, narration, signalling cues, and segmented content to reduce extraneous cognitive load. Instruction covered core geometry topics (angles, triangles, parallel lines, similarity, and circle theorems) over an eight-week period integrated into regular lessons. The control group received the same content using chalkboard explanations, textbook diagrams, and verbal instruction.

Geometry achievement was measured using the Geometry Performance Test (GPT), a 30-item multiple-choice instrument aligned with the SS II curriculum and focused on conceptual understanding and application. Content validity was established through expert review, and internal consistency reliability was confirmed using KR-20 (0.87). The GPT was administered as both pretest and posttest, with item order adjusted at posttest to minimise testing effects.

Data analysis was conducted using ANCOVA to compare posttest geometry achievement between groups while controlling for pretest scores. Effect size was reported using partial eta squared (η^2) to estimate the magnitude of the instructional effect, and statistical significance was evaluated at the 0.05 alpha level.

Results and Findings

Prior to conducting the main analysis, preliminary screening confirmed that the assumptions for Analysis of Covariance (ANCOVA) were satisfied. Inspection of the data indicated no extreme outliers. The relationship between the covariate (pretest geometry achievement) and the dependent variable (posttest geometry achievement) was linear, and the assumption of homogeneity of regression slopes was met, indicating that the relationship between pretest and posttest scores did not differ significantly across instructional groups. These conditions justified the use of ANCOVA for subsequent analysis.

Effect of Instructional Method on Geometry Achievement

An Analysis of Covariance (ANCOVA) was conducted to examine the effect of instructional method on students' posttest geometry achievement while controlling for pretest scores. Instructional method (DAIPG vs. conventional instruction) served as the independent variable, posttest geometry achievement as the dependent variable, and pretest geometry achievement as the covariate.

Table 3
Summary of Research Questions, Hypotheses, Statistical Tests, and Decisions

Research Question / Hypothesis	Statistical Test	F(df)	P	Partial η^2	Decision
RQ1: Difference by instructional method	ANCOVA	76.91 (1,197)	< .001	.28	Significant
RQ2: Effect of DAIPG controlling for pretest	ANCOVA (Covariate)	46.28 (1,197)	< .001	.19	Significant
RQ3: Difference by gender (DAIPG group)	ANCOVA	48.78 (1,197)	< .001	.18	Significant
H₀₁: Method difference	ANCOVA	76.91 (1,197)	< .001	.28	Rejected
H₀₂: Gender difference	ANCOVA	48.78 (1,197)	< .001	.18	Rejected

Note. Significance level set at α = .05. Dependent variable = Posttest Geometry Achievement.

Research Question 1

What difference exists in the posttest geometry achievement scores of students taught using the Developed Animated Instructional Package for Geometry (DAIPG) and those taught using conventional instructional methods?

To answer this research question, an Analysis of Covariance (ANCOVA) was conducted with instructional method (DAIPG versus conventional instruction) as the independent variable, posttest geometry achievement as the dependent variable, and pretest geometry achievement as the covariate.

The results revealed a statistically significant difference in posttest geometry achievement between students taught using DAIPG and those taught using conventional instructional methods after controlling for pretest scores, $F(1, 197) = 76.91$, $p < .001$, partial $\eta^2 = .28$. This large effect size indicates that instructional method accounted for a substantial proportion of variance in students' posttest geometry achievement.

Research Question 2

To what extent does exposure to DAIPG influence students' geometry achievement after controlling for pretest scores?

The ANCOVA results further showed that pretest geometry achievement was a statistically significant covariate, $F(1, 197) = 46.28$, $p < .001$, partial $\eta^2 = .19$, indicating that prior knowledge was a meaningful predictor of posttest performance. However, after adjusting for differences in pretest scores, students exposed to DAIPG achieved significantly higher posttest geometry scores than their counterparts taught using conventional instructional methods. This finding indicates that exposure to DAIPG had a strong and positive influence on students' geometry achievement beyond the effect of prior knowledge.

Research Question 3

What difference exists in the geometry achievement of male and female students exposed to DAIPG?

To answer this research question, an ANCOVA was conducted for students exposed to DAIPG, with gender (male and female) as the fixed factor, posttest geometry achievement as the dependent variable, and pretest geometry achievement as the covariate.

The results revealed a statistically significant difference in geometry achievement between male and female students exposed to DAIPG after controlling for pretest scores, $F(1, 197) = 48.78$, $p < .001$, partial $\eta^2 = .18$. This effect size indicates a substantial practical difference, suggesting that gender accounted for a meaningful proportion of variance in students' posttest geometry achievement within the DAIPG group.

Hypothesis Testing

Two null hypotheses were tested at the 0.05 level of significance using Analysis of Covariance (ANCOVA).

Hypothesis One

H_{01}: There is no significant difference in the posttest geometry achievement scores of students taught using the Developed Animated Instructional Package for Geometry (DAIPG) and those taught using conventional instructional methods, after controlling for pretest scores.

The ANCOVA results revealed a statistically significant effect of instructional method on students' posttest geometry achievement after controlling for pretest scores, $F(1, 197) = 76.91$, $p < .001$, partial $\eta^2 = .28$. Consequently, H_{01} was rejected. This result indicates that students taught using DAIPG achieved significantly higher geometry scores than those taught using conventional instructional methods.

Hypothesis Two

H_{02}: There is no significant difference in the geometry achievement of male and female students taught using the Developed Animated Instructional Package for Geometry (DAIPG), after controlling for pretest scores.

The results of the ANCOVA showed a statistically significant difference in geometry achievement between male and female students exposed to DAIPG after controlling for pretest scores, $F(1, 197) = 48.78$, $p < .001$, partial $\eta^2 = .18$. Accordingly, H_{02} was rejected. This finding indicates that gender significantly influenced students' geometry achievement within the DAIPG instructional condition.
The findings indicate that instructional method exerted a significant influence on students' geometry achievement when prior knowledge was statistically controlled. The superior performance of students

exposed to DAIPG aligns with the study's conceptual framework grounded in the Cognitive Theory of Multimedia Learning, which posits that well-designed animated instructional materials enhance learning by supporting effective cognitive processing.

Furthermore, the significant gender difference observed among students exposed to DAIPG suggests that gender-related factors may influence how learners engage with and benefit from animated instructional materials within gender-segregated secondary school contexts. While the instructional package was effective overall, this finding highlights the importance of considering gender-sensitive instructional design and implementation strategies. Although cognitive processing mechanisms were not measured directly, the observed effect sizes provide indirect empirical support for the role of theory-driven animation in shaping learning outcomes.

Consistent with the proposed conceptual framework, the findings demonstrate that instructional method exerted a significant influence on students' geometry achievement when prior knowledge was statistically controlled. The superior performance of students exposed to DAIPG supports the framework's assumption that CTML-aligned instructional design enhances learning outcomes by improving cognitive processing efficiency. Although cognitive processing was not directly measured, the observed large effect size provides indirect empirical support for the theorised mediating role of efficient cognitive processing in animation-based instruction.

Discussion
The present study examined the effectiveness of a Developed Animated Instructional Package for Geometry (DAIPG) on Senior Secondary II students' geometry achievement within a gender-segregated, low-resource secondary school context. The findings demonstrated that students exposed to DAIPG achieved significantly higher posttest geometry scores than those taught using conventional instructional methods, even after controlling for pretest achievement. The observed effect was large, indicating that instructional method accounted for a substantial proportion of variance in students' learning outcomes.

Interpretation of Findings through Cognitive Theory of Multimedia Learning
The superior performance of students exposed to DAIPG can be meaningfully interpreted through the Cognitive Theory of Multimedia Learning (CTML). CTML posits that learning is enhanced when instructional materials are designed to support dual-channel processing, manage cognitive capacity limitations, and promote active cognitive integration of information (Mayer, 2021). The DAIPG was explicitly designed in accordance with these principles by integrating dynamic visualisations, narration, signalling cues, and segmented instructional sequences.
In geometry learning, where students must mentally represent and manipulate spatial relationships, conventional instruction often places excessive demands on learners' cognitive resources by requiring them to infer motion and transformation from static diagrams. By contrast, the animated representations in DAIPG externalised these dynamic processes, thereby reducing the need for mental animation. This design feature likely enabled learners to allocate more cognitive resources to organising and integrating geometric concepts, resulting in improved conceptual understanding and achievement.
This interpretation aligns with prior multimedia learning research demonstrating that theory-driven animations can significantly enhance learning outcomes when they are designed to support cognitive processing rather than surface engagement (Fiorella & Mayer, 2022; Höffler et al., 2023). The present findings therefore reinforce CTML's central claim that instructional effectiveness is contingent on design quality, not merely the presence of multimedia elements.

Role of Cognitive Load Reduction in Geometry Learning
The results can also be explained through Cognitive Load Theory (CLT), which emphasises the importance of minimising extraneous cognitive load while supporting germane processing (Sweller et al., 2019). Geometry tasks are inherently high in intrinsic cognitive load due to their abstract and relational nature. When instruction relies on static visuals and verbal explanations, learners may experience increased extraneous load as they attempt to mentally visualise transformations and spatial relationships.

The DAIPG likely reduced extraneous cognitive load by providing explicit visual representations of geometric processes, thereby freeing cognitive resources for schema construction and conceptual integration. The large effect size observed in this study provides indirect support for the claim that well-designed animation-based instruction can improve learning outcomes by optimising cognitive load distribution. This finding is consistent with previous studies reporting that animation-based instruction enhances mathematics achievement when it reduces unnecessary cognitive demands (Ayres & Paas, 2020; Wong et al., 2021).

Consistency with Previous Empirical Studies
The findings of the present study are consistent with a growing body of empirical research demonstrating the effectiveness of animation-based instruction in mathematics education. Studies conducted in diverse contexts have reported higher achievement among students exposed to animated or multimedia instructional materials compared to those taught using traditional methods (Gambari et al., 2021; Wong et al., 2021). However, the present study extends this literature by providing evidence from a gender-segregated, low-resource educational context, which remains underrepresented in multimedia learning research.

Unlike some prior studies that reported mixed or negligible effects of animation, the strong instructional effect observed in this study may be attributed to the explicit alignment of DAIPG with CTML principles. This supports recent scholarly arguments that the effectiveness of animation is conditional and dependent on theoretical grounding and instructional design quality (Clark & Mayer, 2024; Höffler et al., 2023). Thus, the findings contribute to ongoing debates in educational technology research regarding when and why multimedia instruction is effective.

Contextual Implications of Gender-Segregated and Low-Resource Settings
An important contribution of this study lies in its contextual focus. Gender-segregated secondary schools in northern Nigeria operate within distinct instructional and cultural environments that may influence students' engagement with learning materials. The effectiveness of DAIPG in this context suggests that animation-based instructional approaches, when appropriately designed, can transcend contextual constraints such as limited instructional resources and teacher-centred pedagogies
.
This finding is particularly significant given concerns that technology-enhanced learning interventions developed in technologically advanced contexts may not translate effectively to low-resource educational systems. The present results indicate that theoretical alignment and instructional coherence may be more critical than technological sophistication, offering important implications for scalable instructional design in developing educational systems.

Implications for Theory and Practice
From a theoretical perspective, the study provides empirical support for the applicability of CTML and CLT to geometry instruction in secondary school settings. By demonstrating that CTML-aligned animated instruction can significantly enhance learning outcomes in a constrained educational context, the study strengthens the external validity of multimedia learning theory. It also reinforces calls for theory-driven instructional design in educational technology research, particularly in underrepresented contexts.

Conclusion
This study investigated the effectiveness of a Developed Animated Instructional Package for Geometry (DAIPG) on the geometry achievement of Senior Secondary II students within a gender-segregated, low-resource secondary school context. The findings demonstrated that students exposed to DAIPG achieved significantly higher posttest scores than those taught using conventional instructional methods, even after controlling for prior achievement. The magnitude of the observed effect underscores the instructional relevance of animation-based learning when grounded in sound theoretical principles.

Interpreted through the lenses of the Cognitive Theory of Multimedia Learning (CTML) and Cognitive Load Theory (CLT), the results suggest that DAIPG enhanced learning by reducing extraneous cognitive load and supporting efficient integration of visual and verbal information. By externalising

dynamic geometric processes, the animated instructional design enabled learners to focus cognitive resources on conceptual understanding rather than mental visualisation.

Beyond demonstrating instructional effectiveness, this study contributes to the literature by providing context-sensitive empirical evidence from a gender-segregated and resource-constrained educational environment that is underrepresented in multimedia learning research. The findings affirm that theory-driven instructional design, rather than technological sophistication alone, is central to improving learning outcomes. Consequently, the study reinforces the applicability of multimedia learning theory across diverse educational contexts and offers evidence-based guidance for improving secondary school geometry instruction.

Limitations of the Study

Despite its contributions, this study is subject to certain limitations that should be considered when interpreting the findings. First, the study employed a quasi-experimental design using intact classes, which limits the extent to which causal inferences can be drawn compared to fully randomised experimental designs. Although the use of ANCOVA strengthened internal validity by controlling for pretest differences, unmeasured confounding variables may still have influenced the results.

Second, the study focused exclusively on geometry achievement as a learning outcome. While achievement provides an important indicator of instructional effectiveness, other outcomes such as learners' cognitive engagement, motivation, or long-term retention were not examined. Inclusion of these variables could provide a more comprehensive understanding of how animation-based instruction influences learning processes.

Third, the study was conducted within public, gender-segregated secondary schools in a single Nigerian state, which may limit the generalisability of the findings to other educational contexts, school types, or subject domains. Differences in curriculum structure, teacher expertise, and technological access may moderate the effectiveness of similar instructional interventions elsewhere.

Finally, although the study was theoretically grounded in CTML and CLT, cognitive processing efficiency was inferred rather than directly measured. Future studies incorporating direct measures of cognitive load or process data would strengthen the explanatory power of the findings.

Recommendations

Based on the findings of the study and within its scope, the following recommendations are made:

1. Secondary school mathematics teachers should integrate theory-aligned animated instructional materials into geometry teaching, with emphasis on instructional design principles that support effective cognitive processing rather than the mere use of animation.
2. Curriculum developers should incorporate multimedia instructional resources grounded in established learning theories into secondary school mathematics curricula to promote consistency and improve learning outcomes across diverse school contexts.
3. Teacher education and professional development programmes should provide focused training on the pedagogical use of animation-based instructional materials to enhance teachers' capacity to integrate technology meaningfully into classroom instruction.
4. Educational policymakers should support the adoption of cost-effective and scalable instructional technologies that align with evidence-based multimedia learning principles, with attention to sustainability and teacher capacity development.

Recommendations for Future Research

Future studies should:

i. employ experimental or mixed-methods designs to strengthen causal inference;
ii. examine additional learning outcomes such as engagement, retention, and transfer;
iii. include direct measures of cognitive load and learning processes; and
iv. explore the effectiveness of animation-based instruction across different subject areas, school types, and cultural contexts.

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