Innovation
2025, Vol. 6, No. 3, pp. 86-98
https://doi.org/10.11648/j.innov.20250603.16

Research Article

Effectiveness of Simulation-Based Instruction (SBI) in Improving Algebraic Achievement and Interest in Nigerian Secondary Schools

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Abstract

This study explored the effectiveness of through simulation-based instruction in improving algebraic achievement and interest in Nigerian Secondary Schools. Adopting a quasi-experimental pre-test, post-test non-equivalent control group design, the study was guided by four research questions and six hypotheses. The population comprised 4,893 SS II mathematics students, from which 205 students (121 experimental, 84 control) were sampled through purposive and random techniques. The experimental group (51 males, 70 females) was taught using simulation-based tools GeoGebra and interactive group tasks over a four-week instructional period, while the control group (44 males, 40 females) received conventional lecture-based instruction. Data were collected using Algebraic Achievement Test (KR-20 = 0.86) and the Algebraic Interest Scale ($\alpha = 0.84$). Mean and standard deviation were used to answer research questions, while ANCOVA tested hypotheses at a 0.05 significance level. Results showed a statistically significant effect of simulation-based instruction on students' achievement ($F(1,200) = 110.239$, $p < .001$, partial $\eta^2 = .355$) and interest ($F(1,200) = 47.655$, $p < .001$, partial $\eta^2 = .192$), indicating large effect sizes. Gender and interaction effects were not significant (partial $\eta^2 < .015$). The study recommended that mathematics teachers should integrate simulation-based strategies to foster deeper understanding in other to improve students' achievement and interest in algebra.

Keywords

Simulation-Based Instruction, Algebra, Mathematics Achievement, Student Interest, Senior Secondary School

1. Introduction

Mathematics is a universal language of logic and structure, fundamental to understanding the world and solving real-life problems. It serves as the bedrock of disciplines such as science, engineering, technology, finance, and data analysis. Through mathematics, learners develop critical skills in reasoning, computation, abstraction, and analytical thinking. Among the various strands of mathematics, algebra plays a particularly pivotal role. It involves the use of symbols, expressions, and equations to represent and solve problems, thereby fostering abstract thinking and generalization. Algebra helps students transition from concrete arithmetic to more advanced levels of mathematical thought, making it a

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Received: 25 May 2025; **Accepted:** 30 June 2025; **Published:** 13 August 2025

vital component of a learner's mathematical development.

In the Nigerian educational context, mathematics—including algebra—is a core subject, compulsory at all levels of primary and secondary schooling. The Federal Ministry of Education [8] recognizes mathematics as essential for personal and national development, as it contributes significantly to scientific innovation, technological advancement, and economic productivity. Specifically, algebra serves as a gateway to learning higher mathematics and STEM-related courses such as engineering, computer science, and physics. It empowers students with the ability to model and solve complex problems, thereby playing a central role in the country's pursuit of sustainable development through science and technology [12].

Despite the acknowledged significance of mathematics and algebra, students' performance in these subjects has remained consistently poor across many Nigerian secondary schools. Data from the West African Examinations Council (WAEC) between 2018 and 2023 reveal low credit pass rates in mathematics, with algebraic questions ranking among the most poorly attempted by candidates [16]. This underachievement is often linked to a combination of factors such as lack of motivation, anxiety, abstract content, and insufficient instructional support. A major contributing factor, however, is the continued dominance of conventional lecture-based methods, which emphasize teacher talk and passive learning. These methods tend to ignore individual learning differences and fail to stimulate the interest and participation necessary for mastering abstract mathematical concepts like algebra [7, 14].

Several educational researchers have highlighted the limitations of the conventional teaching approach, arguing that it neither supports active learning nor fosters deep conceptual understanding. According to [9], the lecture method promotes rote memorization at the expense of problem-solving and logical reasoning skills. Similarly, [2] maintain that teacher-centered strategies contribute to students' disinterest in mathematics and hinder their performance. These findings underscore the urgent need to adopt innovative instructional models that engage learners actively, personalize instruction, and enhance learning outcomes. One such promising approach is the Simulation-Based Instruction (SBI) model, which has shown potential in addressing many of the shortcomings associated with traditional teaching practices.

Simulation-Based Instruction is a learner-centered teaching approach that utilizes digital tools, visual models, and real-life scenarios to create interactive learning environments. It is based on the constructivist theory of learning, which posits that students construct knowledge more effectively when they engage in meaningful, hands-on activities. SBI integrates manipulatives, software like GeoGebra, and visual simulations to help students grasp abstract algebraic concepts by allowing them to explore patterns, test hypotheses, and receive instant feedback. These features not only simplify complex ideas but also enhance motivation, interest, and retention. According to [3], simulation-based learning fosters deeper conceptual understanding, while [5, 17] report significant improvements in students' mathematics achievement and interest following its implementation.

An equally important dimension in instructional effectiveness is the influence of gender on academic achievement. For decades, gender disparities in mathematics performance have sparked debates among educators and policymakers. In some contexts, male students tend to outperform females in mathematical subjects, often due to entrenched gender stereotypes, self-efficacy beliefs, and teacher biases. However, recent studies [10, 11] suggest that such disparities can be minimized—or even eliminated—through the use of inclusive, engaging, and evidence-based instructional strategies like Simulation-Based Instruction. Despite this promising evidence, there is a need for context-specific empirical investigations to determine whether SBI can promote equitable academic outcomes for both male and female students, particularly in algebra.

Given the persistent challenges in algebra instruction and the growing advocacy for learner-centered approaches, this study explores the effectiveness of simulation-based instruction in improving algebraic achievement and interest in Nigerian secondary schools. The research aims not only to assess the instructional impact of SBI but also to examine its ability to bridge gender performance gaps. Findings from this study are expected to provide valuable insights that can inform teaching practices, curriculum development, and policy implementation in mathematics education.

1.1. Statement of the Problem

Despite the central role of algebra in secondary school mathematics and its importance for STEM careers, students in Nigerian secondary schools continue to perform poorly in this area. The WAEC Chief Examiners' Reports (2019-2024) consistently highlight students' weaknesses in algebraic concepts such as factorization, equation solving, and interpretation of word problems. These recurring patterns of underperformance have raised concerns among stakeholders about students' academic preparedness and their ability to engage meaningfully in science- and technology-related fields.

Research has identified one of the major causes of this persistent underachievement as the continued reliance on teacher-centered instructional approaches, particularly the conventional lecture method. This method often emphasizes memorization over understanding and fails to address the abstract nature of algebra in a way that engages students. Scholars such as [2, 7] argue that conventional strategies hinder learners' conceptual development and contribute to declining interest and poor academic outcomes in mathematics. Consequently, there is a growing demand for innovative, student-centered teaching methods that promote active learning and conceptual clarity.

One such method is Simulation-Based Instruction (SBI), which incorporates interactive and visual tools to help students explore and understand algebraic concepts in real-life contexts. Although global research shows that SBI can improve students' achievement and interest in mathematics, there is a lack of empirical evidence within the Nigerian context, especially at the senior secondary level. Moreover, the influence of gender on students' responses to such instructional innovations remains unclear. Therefore, this study aims to determine whether SBI can enhance students' achievement and interest in algebra and whether gender moderates its effectiveness in Nigerian secondary schools.

1.2. Objective of the Study

The objective of this study was Improving Algebraic Achievement and Interest through Simulation-Based Instruction in Nigerian Secondary Schools. Specifically, the study sought to determine the:

1) Difference in the mean achievement scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).
2) Difference in the mean achievement scores of male and female students taught Algebra using SMI and LM.
3) Difference in the mean interest rating scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).
4) Difference in the mean interest rating scores of male and female students taught Algebra using SMI and LM.
5) Interaction effect of Instructional Models (SMI & LM) and gender on students' achievement in Algebra.
6) Interaction effect of Instructional Models (SMI & LM) and gender on students' interest rating scores in Algebra.

1.3. Research Questions

The study was guided by the following research questions:

1) What is the difference in the mean achievement scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?
2) What is the difference in the mean achievement scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?
3) What is the difference in the mean interest rating scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?
4) What is the difference in the mean interest rating scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?

1.4. Null Hypotheses

The following null hypotheses guided the study and were tested at 0.05 level of significance:

H_{O1}: There was no significant difference between the mean achievement scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).

H_{O2}: There was no significant difference between the mean achievement scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).

H_{O3}: There was no significant difference between the mean interest rating scores of students taught Algebra using SMI and those taught using LM.

H_{O4}: There was no significant difference between the mean interest rating scores of male and female students taught Algebra using SMI and those taught using LM.

H_{O5}: There was no interaction effect of teaching methods (SMI & LM) and gender on students' achievement in Algebra.

H_{O6}: There was no interaction effect between teaching methods (SMI & LM) and gender on students' interest rating scores in Algebra.

1.5. Significance of the Study

This study provides robust evidence supporting the effectiveness of Simulation-Based Instruction (SBI) in enhancing students' achievement and interest in algebra. The findings hold considerable implications for various stakeholders within the educational landscape, including teachers, students, curriculum developers, policymakers, school administrators, researchers, and instructional material designers. For teachers, the study offers practical insights into how simulation-based strategies can be integrated into classroom practice to foster greater student engagement and deeper conceptual understanding. The shift from traditional teacher-centered methods to more interactive, student-centered approaches aligns with global calls for innovative pedagogy in mathematics education.

Students emerged as the primary beneficiaries of the SMI approach, with notable improvements in both academic performance and interest in algebra. The dynamic and hands-on nature of the simulation activities made abstract concepts more tangible, thereby enhancing comprehension and fostering a more positive attitude toward mathematics learning. For curriculum developers, the study provides empirical justification for incorporating simulation-based strategies into future curriculum revisions. It demonstrates the potential of SMI to promote critical thinking, problem-solving, and active learning—competencies that are essential in 21st-century education.

The implications for policymakers are equally significant. The data presented can guide educational reforms aimed at improving instructional quality through the adoption of evidence-based teaching practices. In particular, the study highlights the need for targeted investments in teacher training and instructional technology to support the effective implementation of SMI. School administrators are encouraged to embrace the use of simulation strategies as a means of addressing persistent challenges in student performance, especially in mathematics. The study emphasizes that administrative support is crucial in creating an enabling environment for pedagogical innovation.

From a research perspective, the findings contribute meaningfully to the literature on active learning in mathematics education. The study provides a replicable model that future researchers can adopt or adapt to explore the effects of innovative instructional strategies across different contexts and subject areas. It also opens avenues for longitudinal and comparative studies to assess the long-term impact of simulation-based instruction. Furthermore, textbook authors and instructional material developers can draw on the findings to create learning resources that align with simulation-based pedagogy. By incorporating interactive examples, real-life scenarios, and engaging exercises, such resources can enhance student motivation and learning outcomes.

The results of this research are documented and made accessible through the Nnamdi Azikiwe University repository, academic libraries, and peer-reviewed journals. To ensure wide dissemination and application, summaries of the study are also intended for presentation at academic conferences, professional seminars, and teacher workshops. In sum, this study makes a significant contribution to the advancement of mathematics education by demonstrating that the Simulation Model of Instruction is an effective tool for improving students' achievement and interest in algebra, thereby offering a viable pathway toward enhanced teaching and learning outcomes in secondary school mathematics.

2. Literature Review

2.1. Conceptual Framework

2.1.1. The Concept of Mathematics and Algebra

Mathematics is a discipline that involves the study of patterns, structures, numbers, and logical reasoning. It is vital for scientific, technological, and societal development. Within mathematics, algebra plays a crucial role by providing a bridge between arithmetic and advanced mathematical thinking. It deals with symbols and rules for manipulating these symbols, enabling learners to generalize mathematical relationships and solve real-life problems. Algebraic thinking is foundational to success in STEM fields, yet it remains one of the most challenging areas for secondary school students due to its abstract nature.

2.1.2. Students' Achievement in Algebra

Student achievement in algebra reflects their ability to understand, apply, and manipulate algebraic concepts to solve problems. In Nigeria, reports from WAEC Chief Examiners (2019-2024) have consistently identified algebra as a weak point in students' mathematics performance. These reports cite challenges such as poor symbolic manipulation skills, misunderstanding of equations, and lack of foundational knowledge. According to [12], these difficulties are further aggravated by traditional teaching methods that fail to promote deep understanding and problem-solving abilities.

2.1.3. Students' Interest in Mathematics

Interest is a significant affective factor influencing students' engagement and success in mathematics. When students are interested, they are more likely to participate actively, persist through challenges, and develop a positive attitude toward learning. However, studies [14] reveal a steady decline in students' interest in algebra due to its perceived difficulty and the uninspiring nature of lecture-based instruction. Enhancing students' interest requires instructional strategies that make mathematics more meaningful, interactive, and relevant.

2.1.4. Simulation-Based Instruction (SBI)

Simulation-Based Instruction is an innovative teaching strategy that uses interactive tools and real-life scenarios to represent complex concepts visually and experientially. In mathematics education, SBI enables learners to explore abstract ideas such as algebra through dynamic simulations, manipulatives, and digital platforms like GeoGebra. This model supports the constructivist view that learners construct knowledge best through active engagement and meaningful contexts [3]. Studies by [5, 17] show that SBI significantly improves students' academic achievement and interest by allowing them to visualize problems, test solutions, and receive immediate feedback.

2.2. Theoretical Framework

This study is anchored on Constructivist Learning Theory [15]; Piaget, as cited in [1] and Cognitive Load Theory [13]. Constructivism posits that learners construct knowledge through active participation, interaction, and reflection, emphasizing the importance of scaffolding and social learning. SBI aligns with this theory by providing students with manipulatives and interactive environments that facilitate personal meaning-making. Cognitive Load Theory suggests that complex concepts should be broken into manageable parts to avoid overwhelming working memory. SBI supports this by using simulations to present content in structured, visual formats, thereby reducing cognitive overload and enhancing comprehension.

3. Methodology

3.1. Research Design

This study adopted a quasi-experimental research design, specifically the pre-test, post-test non-equivalent control group design. This design was appropriate because it involved two groups - an experimental group exposed to simulation-based instruction and a control group taught using the conventional lecture method—without random assignment. Both groups were pre-tested and post-tested using the same instruments to assess the effect of the treatment on achievement and interest in algebra.

3.2. Area of the Study

The study was conducted in Ebonyi North Education Zone of Ebonyi State, Nigeria. The zone comprises four Local Government Areas: Abakaliki, Ebonyi, Izzi, and Ohaukwu. The area was chosen due to persistent reports of low student performance in mathematics, especially in algebra, as reflected in WAEC Chief Examiners' Reports and local school records.

3.3. Population of the Study

The population consisted of 4,893 Senior Secondary II (SS2) students offering mathematics across 70 public secondary schools in the zone. The students had comparable exposure to mathematics curriculum content and were preparing for their senior school certificate examinations.

3.4. Sample and Sampling Technique

A total of 205 students (95 males and 110 females) were selected from four intact SS2 classes across four schools using a combination of purposive and simple random sampling techniques. Two schools were assigned to the experimental group (n = 121) and two to the control group (n = 84). Intact classes were used to avoid disrupting school schedules.

3.5. Instrumentation

Two validated instruments were used for data collection: Algebraic Achievement Test (AAT) developed by the researcher based on specific algebraic concepts drawn from the Senior Secondary School Two (SS II) mathematics curriculum and Algebraic Interest Scale (AIS) adopted from [4]. AAT is a 25-item multiple-choice test covering algebraic topics (linear equations, parallel and perpendicular lines, quadratic equations and inequalities). The instrument was validated by 3 experts and yielded a KR-20 reliability coefficient of 0.86. AIS is a 20-item 4-point Likert scale measuring students' interest in algebra. It yielded a Cronbach's Alpha coefficient of 0.84 after pilot testing.

3.6. Treatment Procedure

The intervention lasted for six weeks (12 lessons of 80 minutes each for double period), aligned with the SS2 algebra syllabus. The treatment was implemented as follows:

Experimental Group (Simulation-Based Instruction): Students in the experimental group were taught using Simulation-Based Instruction (SBI) involving digital tools and interactive activities. GeoGebra is the simulation tools/software employed. GeoGebra is used for graphing linear equations, manipulating algebraic expressions, and exploring functions visually.

Sample Lesson Flow (Experimental Group)

A sample of simulation-based lesson plan is stated below:

LESSON PLAN

Subject: Mathematics

Topic: Linear Equations

Class: SS2

Duration: 80 minutes (Double Period)

Teaching Method: Simulation Approach

Learning Objectives: By the end of this lesson, students will be able to:

a) Understand the concept of a linear equation
b) Plot a graph of a linear equation both manually and using the simulation software.
c) Explore the relationship between the slope and intercept in the equation of a line.

Instructional Materials:

a) Graph paper
b) Rulers
c) Computer or tablet with access to graphing simulation software (e.g., Desmos, GeoGebra)
d) Projector for teacher demonstration

Instructional Procedures**:**

1) Introduction (15 minutes):

a) Briefly introduce the concept of a linear equation in the form y=mx+c, where m is the slope and c is the intercept on y-axis.
b) Discuss real-life examples where linear equations might be used (e.g., calculating cost, distance over time).

2) Direct Instruction (20 minutes):

a) Demonstrate how to plot a simple linear equation on graph paper, starting with y=2x+1.
b) Explain how the slope m=2 determines the steepness of the line and how the intercept c=1 determines where the line crosses the y-axis.

3) Guided Practice with Simulation (20 minutes):

a) Have students use graphing simulation software on their devices.
b) Instruct students to input different values for m and c to see how the graph changes.
c) Ask students to explore questions like:

1. What happens when m is positive or negative?
2. How does changing c move the line up or down?

4) Group Activity (15 minutes):

a) In small groups, students are given different linear equations to plot using the simulation.

b) Each group presents their equation and graph to the class, explaining the relationship between the slope and intercept.

5) Closure and Assessment (10 minutes):

a) Summarize the key concepts learned in the lesson.

b) Assign homework where students plot linear equations both manually and using the simulation software.

Control Group (Lecture Method): Students in the control group were taught the same algebra content using the traditional chalk-and-talk approach. Lessons followed the standard format: definition, explanation, example on the board, and note copying.

3.7. Method of Data Collection

Pre-tests (AAT and AIS) were administered to both groups before the intervention. At the end of the four-week instructional period, post-tests were administered using the same instruments. Both the administration and scoring adhered strictly to standardized procedures to ensure reliability.

3.8. Method of Data Analysis

The research questions were answered using mean and standard deviation to determine performance and interest levels. The hypotheses were tested using Analysis of Covariance (ANCOVA) at a 0.05 level of significance to control for initial differences between the groups.

4. Results

Research Question One: What are the mean achievement scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?

Table 1. *Mean achievement scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).*

Group	N	Pre-Test		Post-Test		Gained Mean
		Mean	SD	Mean	SD	
Experimental	121	35.45	8.96	71.20	7.39	35.75
Control	84	35.42	8.92	60.60	7.30	25.18
Mean Difference		0.03		10.60		10.57

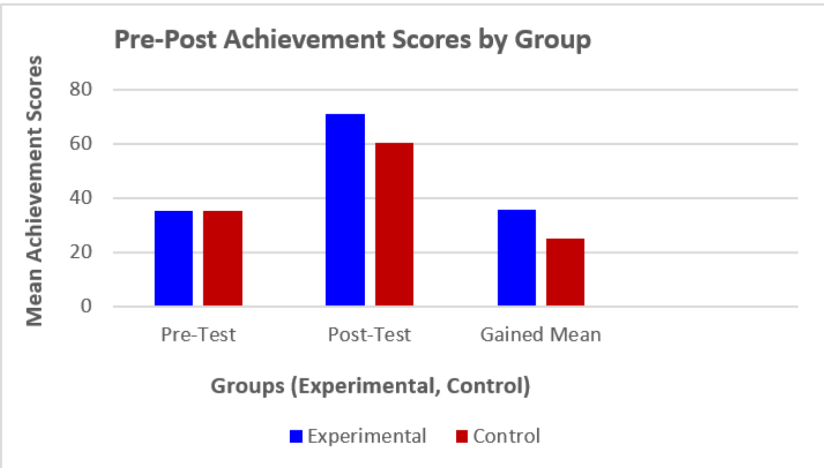

Figure 1. *The effect of simulation-based instruction on students' achievement in algebra.*

Table 1 reveals that the students taught Algebra using Simulation Model of Instruction (SMI) has pre-test mean achievement score of 35.45 and post-test mean achievement score of 71.20 with gained mean achievement score of 35.75, while those in the control group taught with lecture method has pre-test mean achievement s score of 35.42 and post-test mean score of 60.60 with gained mean 25.18. Students taught Algebra using SMI had a less homogeneous scores in their post-test (7.39) than those taught using LM (7.30). The difference between the gained mean achievement scores of the students is 10.57 in favour of SMI.

Research Question Two: What are the mean achievement scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?

Table 2. *Mean achievement scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).*

Group	Gender	N	Pre-Test		Post-Test		Gained Mean
			Mean	SD	Mean	SD	
Experimental	Male	51	35.59	8.81	72.25	7.70	36.66
	Female	70	35.36	9.10	70.43	7.11	35.03
Mean Difference			0.23		1.82		1.63
Control	Male	44	35.34	8.92	61.36	7.10	26.02
	Female	40	35.50	9.04	59.75	7.51	24.25
Mean Difference			0.16		1.61		1.77

Table 2 reveals that the male students taught Algebra using SMI has pre-test mean achievement score of 35.59 and post-test mean achievement score of 72.25 with a gain in mean scores of 30.66 while the female students had pre-test mean achievement score of 35.36 and post-test mean achievement score of 70.43 with a gain in mean scores of 35.03. The difference in mean achievement scores of the male and female students is 1.63 with male students having higher achievement scores than the female students. Table 2 also reveals that the male students taught algebra using LM has pre-test mean achievement score of 35.34 and post-test mean achievement score of 61.36 with a gain in mean scores of 26.02 while the female students had pre-test mean achievement score of 35.50 and post-test mean achievement score of 59.75 with a gain in mean scores of 24.25. The difference in gained mean achievement scores of the male and female students is 1.77 with male students having higher achievement scores than the female students.

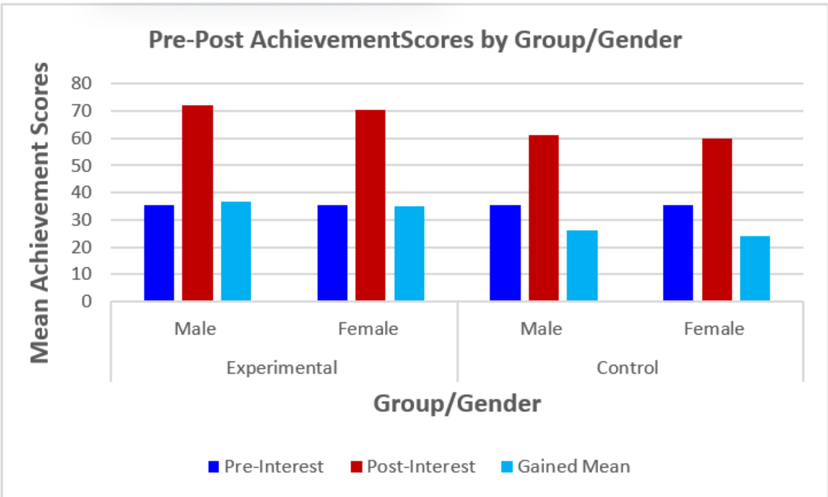

Figure 2. *The effect of simulation-based instruction on students' achievement in algebra based on gender.*

Research Question Three: What are the mean interest rating scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?

Table 3. *Mean interest scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).*

Group	N	Pre-Interest		Post-Interest		Gained Mean
		Mean	SD	Mean	SD	
Experimental	121	2.68	.199	3.12	.26	0.44
Control	84	2.61	.198	2.88	.23	0.27
Mean Difference		0.07		0.24		0.17

Table 3 reveals that the students taught Algebra using Simulation Model of Instruction (SMI) has pre-Interest mean score of 2.68 and post-Interest mean score of 3.12 with gained mean Interest score of 0.44, while those in the control group taught with lecture method had pre-Interest mean score of 2.61 and post-test mean score of 2.88 with gained mean of 0.27. Students taught Algebra using SMI had a less homogeneous scores in their post-test (.26) than those taught using LM (.23). The difference between the gained mean interest scores of the students is 0.17 in favour of SMI.

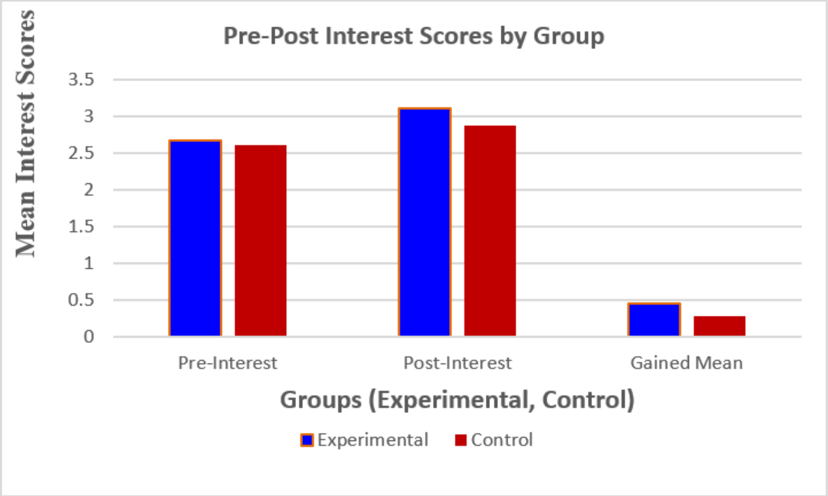

Figure 3. *The effect of simulation-based instruction on students' interest in algebra.*

Research Question Four: What are the mean interest rating scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM)?

Table 4. *Mean interest rating scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).*

Group	Gender	N	Pre-Interest		Post-Interest		Gained Mean
			Mean	SD	Mean	SD	
Experimental	Male	51	2.61	.19	3.13	.26	0.52

Group	Gender	N	Pre-Interest		Post-Interest		Gained Mean
			Mean	SD	Mean	SD	
	Female	70	2.60	.20	3.12	.25	0.52
Control	Male	44	2.62	.19	2.89	.23	0.27
	Female	40	2.61	.20	2.87	.22	0.26

Table 4 reveals that the male students taught Algebra using SMI had pre-interest mean score of 2.61 and post-interest mean score of 3.13 with a gain in interest scores of 0.52, while the female students had pre-interest mean score of 2.60 and post-interest mean score of 3.12 with a gain in interest scores of 0.52. There was no difference in the mean interest scores of the male and female students. Table 2 also reveals that the male students taught algebra using LM has pre-interest mean interest score of 2.62 and post-test mean interest score of 2.89 with a gain in mean interest scores of 0.27 while the female students had pre-interest mean interest score of 2.61 and post-test mean interest score of 2.87 with a gain in mean scores of 0.26. The difference in gained mean interest scores of the male and female students is 0.01 with male students having higher interest scores than their female counterparts.

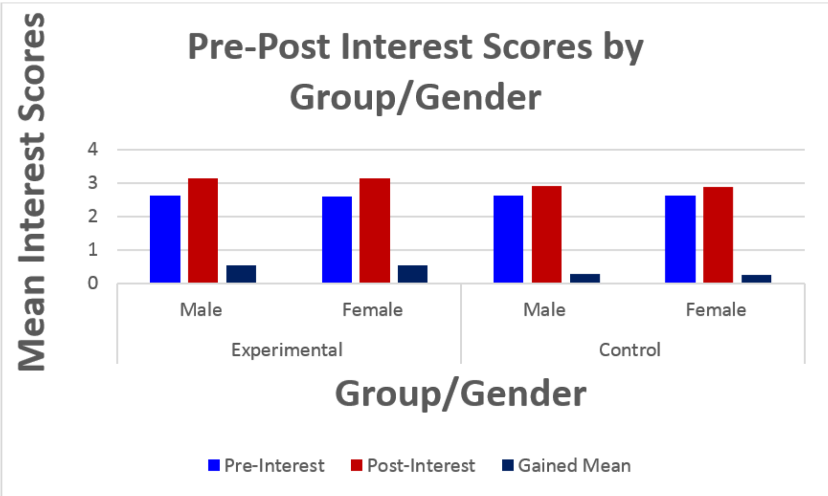

Figure 4. *The effect of simulation-based instruction on students' interest in algebra based on gender.*

Hypothesis One: There was no significant difference between the mean achievement scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).

Table 5. *ANCOVA Test of Significance of Difference between the mean achievement scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).*

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Decision
Corrected Model	6221.635[a]	4	1555.409	30.132	.000	.376	
Intercept	43221.306	1	43221.306	837.300	.000	.807	
Pre_Test	494.537	1	494.537	9.580	.002	.046	
Group	5690.547	1	5690.547	110.239	.000	.355	Sig.
Gender	143.921	1	143.921	2.788	.097	.014	Not Sig.

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Decision
Group * Gender	.256	1	.256	.005	.944	.000	Not sig.
Error	10323.974	200	51.620				
Total	932775.000	205					
Corrected Total	16545.610	204					

Table 5 indicates that there was a statistically significant main effect of instructional method on students' achievement in Algebra, F (1, 200) = 110.239, p <.001, partial η^2 =.355. The Table shows an effect size of (0.355), indicating a large effect since it exceeds the (0.14) which defined significant large effect size [6]. This suggests that 35.5% of the variance in students' achievement scores can be attributed to the instructional method used. Consequently, the null hypothesis was rejected, indicating a significant difference between the pre-test and post-test mean achievement scores of students taught Algebra using the Simulation Model of Instruction (SMI) and those taught using the Lecture Method (LM), in favour of the SMI.

Hypothesis Two: There was no significant difference between the mean achievement scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).

Data relating to hypothesis 2 is also contained in Table 5.

Table 5 also indicates that there was no statistically significant main effect of gender on students' achievement in Algebra, F (1, 200) = 2.788, p =.097, partial η^2 =.014. This suggests that only 1.4% of the variance in achievement scores can be attributed to gender, representing a small effect size. Consequently, the null hypothesis was not rejected, indicating that there was no significant difference in the pre-test and post-test mean achievement scores of male and female students taught Algebra using the Simulation Model of Instruction (SMI) and the Lecture Method (LM).

Hypothesis Three: There was no significant difference between the mean interest rating scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).

Table 6. *ANCOVA Test of Significance of the mean interest rating scores of students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Decision
Corrected Model	3.001[a]	4	.750	12.233	.000	.197	
Intercept	12.112	1	12.112	197.473	.000	.497	
Pre_Interest	.053	1	.053	.863	.354	.004	
Group	2.923	1	2.923	47.655	.000	.192	Sig.
Gender	.007	1	.007	.107	.744	.001	Not Sig.
Group * Gender	.000	1	.000	.003	.955	.000	Not Sig.
Error	12.267	200	.061				
Total	1890.087	205					
Corrected Total	15.268	204					

Table 6 shows a statistically significant main effect of instructional method on students' interest in Algebra, F (1, 200) = 47.655, p <.001, partial η^2 =.192. This means that 19.2% of the variance in students' interest scores can be attributed to the instructional method used a large effect size. As a result, the null hypothesis was rejected, indicating a significant difference between the pre-interest and post-interest mean scores of students taught Algebra using the Simulation Model of Instruction (SMI) and those taught using the Lecture Method (LM), with the SMI group showing greater improvement in interest.

Hypothesis Four: There was no significant difference between the mean interest rating scores of male and female students taught Algebra using Simulation Model of Instruction (SMI) and those taught using Lecture Method (LM).

Data relating to hypothesis 5 is also contained in Table 6.

Table 6 also indicates that there was no statistically significant main effect of gender on students' interest in Algebra, F (1, 200) = 0.107, p =.744, partial η^2 =.001. This means that only 0.1% of the variance in interest scores could be attributed to gender, representing a negligible effect size. Consequently, the null hypothesis was not rejected, implying that there was no significant difference in the pre-interest and post-interest mean scores of male and female students taught Algebra using the Simulation Model of Instruction (SMI) and the Lecture Method (LM).

Hypothesis Five: There was no interaction effect of teaching methods (SMI & LM) and gender on students' achievement in Algebra.

Data relating to hypothesis 3 is contained in Table 5.

Table 5 further shows that there is no interaction effect of teaching methods and gender on students' achievement in Algebra F (1, 200) = 0.005, P =0.944 > 0.05. Therefore, the null hypothesis was not rejected meaning that there was no significant interaction effect of teaching strategies and gender on students' achievement in Algebra.

Hypothesis Six: There was no interaction effect between teaching methods (SMI & LM) and gender on students' interest rating scores in Algebra.

Data relating to hypothesis 6 is contained in Table 6.

Table 6 further reveals that there was no statistically significant interaction effect between teaching methods and gender on students' interest in Algebra, F (1, 200) = 0.003, p =.955, partial η^2 =.000. This indicates that less than 0.1% of the variance in interest scores was due to the interaction between instructional method and gender, representing a negligible effect size. As such, the null hypothesis was not rejected, suggesting that there was no significant interaction effect of teaching strategies and gender on students' interest in Algebra.

5. Discussion

The findings of this study revealed that Simulation-Based Instruction (SBI) significantly enhanced both achievement and interest in algebra among senior secondary school students in Nigeria. Students exposed to simulation-based learning outperformed their counterparts who were taught using the conventional lecture method, as evidenced by their notably higher post-test scores in algebraic problem-solving and conceptual understanding. This supports the view that interactive and student-centered learning environments promote greater cognitive engagement and improve the retention of mathematical concepts. The visual, hands-on nature of the simulations likely helped to demystify the abstract nature of algebra, making it more concrete and accessible to learners. These results align with constructivist learning theories [15] and Cognitive Load Theory [13], which advocate for active learning and instructional designs that optimize mental processing.

Beyond academic performance, simulation-based instruction also significantly increased students' interest in algebra. Students in the experimental group showed heightened enthusiasm, curiosity, and motivation during lessons, suggesting that the interactive features of simulations—such as real-time feedback, dynamic visualization, and learner autonomy—made learning more enjoyable and meaningful. These elements not only reduced learners' anxiety but also promoted sustained interest and deeper emotional investment in learning. This is consistent with findings from [5], who reported that simulation environments stimulate students' intrinsic motivation and positive attitudes toward mathematics.

Interestingly, the study found no statistically significant gender differences in achievement or interest among students exposed to Simulation-Based Instruction. Although female students slightly outperformed their male peers, the differences were not statistically significant, indicating that SBI is gender-inclusive and effective across demographic lines. This outcome may be attributed to the multi-sensory and interactive nature of simulation tools, which appeal to a variety of learning styles and provide equal opportunities for exploration and feedback. The collaborative features embedded in simulation activities also likely contributed to this equity, creating supportive learning environments where all students, regardless of gender, could thrive. This aligns with the findings of [11], who noted that simulation-based learning reduces gender-based performance gaps by offering flexible and engaging instruction that meets the needs of diverse learners.

Additionally, the study observed no significant interaction effect between instructional method and gender on students' achievement and interest. This further confirms the universal effectiveness of Simulation-Based Instruction and reinforces its potential as an inclusive pedagogical tool in mathematics education. The fact that both male and female students benefited equally suggests that gender stereotypes related to mathematical ability may be mitigated when instruction is engaging, relevant, and accessible through simulation models.

However, the study is not without limitations. One notable limitation is its geographic scope, as it focused exclusively on schools within Ebonyi state. This restricts the generalizability of the findings to other regions of Nigeria or differing educational contexts. Furthermore, the short duration of the intervention (four weeks) may not have been sufficient to fully capture the long-term effects of simulation-based instruction on students' learning trajectories or retention over time. Future research should consider longitudinal studies with larger and more diverse samples to validate and extend the present findings. Moreover, examining other variables such as socio-economic background, prior knowledge, and digital literacy could provide a more comprehensive understanding of how simulation-based instruction impacts different student populations.

In summary, the study confirms that Simulation-Based Instruction is an effective and inclusive strategy for improving students' achievement and interest in algebra. Its adoption can serve as a transformative approach to revitalizing mathematics education in Nigeria and beyond.

6. Conclusion

This study revealed that simulation-based instruction significantly improves senior secondary students' achievement and interest in algebra in Nigerian Secondary schools. By engaging students through interactive and dynamic learning experiences, the simulation model overcomes the limitations of traditional lecture methods, enhancing conceptual understanding and motivation. Importantly, the approach benefits both male and female students equally, highlighting its potential as an inclusive instructional strategy to reduce gender disparities in mathematics education.

Given algebra's vital role in academic and career success, integrating simulation-based teaching methods offers a practical way to boost mathematics learning outcomes in Nigerian secondary schools. Stakeholders such as educators and policymakers should consider adopting these innovative strategies to foster improved student performance and positive attitudes toward mathematics. However, because the study was limited to a specific geographic area and a short intervention period, the findings may not be fully generalizable. Therefore, broader trials across multiple regions, grade levels, and mathematics topics are recommended to validate and expand upon these results.

7. Recommendations

Based on the findings of the study, the following recommendations were made:

1) Mathematics teachers should integrate simulation-based instructional models *such as GeoGebra* into their teaching practice, especially when delivering algebra concepts, to enhance student achievement and interest.
2) Curriculum developers and education policymakers should incorporate simulation resources and activities within the official secondary school mathematics curriculum to promote interactive and practical learning experiences.
3) Schools should invest in adequate technological infrastructure and resources, such as computers and simulation software, to support the effective delivery of simulation-based lessons.
4) Further research should be conducted to evaluate the long-term effects of simulation-based instruction on students' learning across different mathematics topics and educational contexts, including its impact on diverse learner groups.

Abbreviations

ANCOVA	Analysis of Covariance
FME	Federal Ministry of Education
GeoGebra	Geometry and Algebra Software
AIS	Algebraic Interest Scale
AAT	Algebraic Achievement Test
SBI	Simulation-Based Instruction
SMI	Simulation Model of Instruction
SS2	Senior Secondary Two
STEM	Science, Technology, Engineering, and Mathematics
WAEC	West African Examinations Council

Author Contributions

Emmanuel Nwigboji: Conceptualization, Formal Analysis, Investigation, Methodology, Software, Supervision, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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