Impact of Inquiry-based Simulation on Conceptual Understanding and Interest in STEM Subjects among Secondary Students, Funtua, Katsina State, Nigeria.

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Abstract

This study examined the impact of inquiry-based simulation on conceptual understanding and interest in STEM subjects among senior secondary students in Funtua Zone, Katsina State, Nigeria. A quasi-experimental pretest-posttest control group design was employed, involving 248 senior secondary II students from four co-educational schools. The experimental group (n=124) was taught using inquiry-based simulation, while the control group (n=124) received traditional lecture-demonstration instruction. Three instruments—the Conceptual Understanding Test in STEM (CUTS) and the STEM Interest Inventory (SII) were validated by experts and achieved reliability coefficients of 0.84 and 0.89 respectively using Cronbach's Alpha. Data were analyzed using mean, standard deviation, and Analysis of Covariance. Findings revealed a significant main effect of treatment on conceptual understanding ($F(1,245) = 18.42$, $p < 0.05$) and interest ($F(1,245) = 21.37$, $p < 0.05$) in favor of the experimental group. No significant gender differences were found in either conceptual understanding or interest among students exposed to inquiry-based simulation. The study concluded that inquiry-based simulation enhances both conceptual understanding and interest in STEM subjects. Recommendations include integrating inquiry-based simulations into STEM instruction and providing professional development for teachers in simulation-based pedagogy.

Keywords: Inquiry-based learning, computer simulation, conceptual understanding, STEM interest.

Introduction

The teaching and learning of Science, Technology, Engineering, and Mathematics (STEM) subjects at the senior secondary level in Nigeria face persistent challenges related to poor conceptual understanding and declining student interest. Despite the critical role of STEM education in national technological development and economic growth, students continue to demonstrate underachievement in these subjects, largely attributable to instructional approaches that emphasize rote memorization and over meaningful conceptual engagement (Ojo & Tijani, 2025). Conventional methods, while widely used due to resource constraints, often fail to foster deep conceptual understanding or sustain student interest in STEM disciplines.

Inquiry-based learning has emerged internationally as a pedagogical approach that positions students as active participants in knowledge construction. By engaging learners in questioning, investigating, and drawing evidence-based conclusions, inquiry-based methods promote critical thinking and deeper conceptual processing (Kuang et al., 2024). When combined with computer simulations, inquiry-based instruction offers unique affordances for STEM learning. Simulations enable students to visualize abstract concepts, manipulate variables, and conduct virtual experiments that would otherwise be impractical or impossible in resource-constrained school laboratories (Tomczak, 2023).

Research evidence increasingly supports the efficacy of inquiry-based simulation approaches. A recent survey of 120 middle and high school teachers using virtual simulations reported that 92% observed moderate to large learning gains, with teachers highlighting how simulations helped make abstract ideas concrete and facilitated inquiry-based learning (ExploreLearning, 2024). In the Nigerian context, studies have demonstrated that inquiry-based instructional strategies significantly improve students' academic achievement in chemistry compared to demonstration methods (Ojo & Tijani, 2025). Computer simulations help students grasp abstract concepts more easily, leading to better academic outcomes, fosters meaningful learning and enhances performance when compared to the conventional method, therefore students taught with computer based instructional packages demonstrated better long-term memory retention (Lawal et al., 2025,). Similarly, virtual laboratory instruction has been shown to enhance problem-solving skills among Basic Science learners in Benue State, Nigeria (HAL Science, 2024). However, despite growing evidence supporting both inquiry-based learning and simulation-based instruction independently, limited research has examined their combined effect inquiry-based simulation on Nigerian senior secondary students, particularly in northern Nigeria. The Funtua Zone of Katsina State presents a relevant context for such investigation, as schools in this region often face significant resource limitations that constrain hands-on laboratory experiences. Furthermore, while studies have examined academic achievement, fewer have specifically focused on conceptual understanding the depth and connectedness of students' knowledge structures and interest, which is critical for sustained engagement in STEM pathways (Obienyem, 2025).

This study was therefore designed to investigate the impact of inquiry-based simulation on senior secondary students' conceptual understanding and interest in STEM subjects in Funtua Zone, Katsina State, Nigeria. The findings aim to contribute empirical evidence from the Nigerian educational context to the growing international literature on technology-enhanced inquiry learning, while providing practical guidance for educators and policymakers seeking to improve STEM outcomes in resource-constrained settings.

Research Questions

The following research questions guided this study:

1. What is the difference in the mean conceptual understanding scores of senior secondary students taught STEM subjects using inquiry-based simulation and those taught using conventional methods?
2. What is the difference in the mean interest scores of senior secondary students taught STEM subjects using inquiry-based simulation and those taught using conventional methods?
3. What is the influence of gender on the conceptual understanding and interest of senior secondary students exposed to inquiry-based simulation in STEM subjects?

Research Hypotheses

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

H_{01}: There is no significant difference in the mean conceptual understanding scores of students taught STEM subjects using inquiry-based simulation and those taught using conventional methods.

H_{02}: There is no significant difference in the mean interest scores of students taught STEM subjects using inquiry-based simulation and those taught using conventional methods.

H_{03}: There is no significant difference in the mean conceptual understanding scores of male and female students exposed to inquiry-based simulation in STEM subjects.

H_{04}: There is no significant difference in the mean interest scores of male and female students exposed to inquiry-based simulation in STEM subjects.

Methodology

This study employed a pretest-posttest non-equivalent control group quasi-experimental design. This design was appropriate as random assignment of individual students to groups was not feasible within intact school classes (Ojo & Tijani, 2025). The target population comprised all 3,847 senior secondary II (SS II) students offering STEM subjects in public secondary schools within Funtua Zone. A sample of 248 students (128 male, 120 female) was drawn from four co-educational schools purposively selected based on availability of functional computer systems, presence of qualified STEM teachers, and willingness to participate. Two schools were assigned to the experimental group (n=124) and two to the control group (n=124).

Three instruments were developed for data collection:

1. Conceptual Understanding Test in STEM (CUTS): A 40-item multiple-choice test covering selected topics in biology, chemistry, mathematics and physics (diffusion and osmosis, chemical bonding, algebra and motion). Items were designed to measure depth of understanding rather than factual recall, drawing on Bloom's taxonomy's higher-order levels. The test was validated by three experts in science education and measurement and evaluation. Reliability was established using Kuder-Richardson Formula 20, yielding a coefficient of 0.84.

2. STEM Interest Inventory (SII): A 30-item Likert-scale questionnaire adapted from existing interest inventories, measuring students' interest in STEM subjects, career aspirations, and engagement with STEM activities. Items were rated on a 4-point scale (Strongly Agree to Strongly Disagree) to avoid neutral responses. The instrument yielded a Cronbach's Alpha reliability coefficient of 0.89.

3. Inquiry-Based Simulation Package: For the experimental group, researcher-developed simulation activities using PhET interactive simulations and ExploreLearning Gizmos were integrated into inquiry-based lesson plans covering selected STEM topics. Each simulation activity followed an inquiry cycle: engagement, hypothesis generation, exploration through simulation, data collection, and conclusion drawing (Kuang et al., 2024).

The study lasted eight weeks. Week one involved teacher training. Experimental group teachers received four days of training on facilitating inquiry-based simulation lessons, while control group teachers were briefed on delivering the same content using conventional methods. Week two comprised pretest administration of CUTS and SII to both groups. Weeks three through seven constituted the treatment period: experimental group students engaged with simulation-based inquiry activities following a structured protocol of prediction, exploration, explanation, and reflection; control group students received regular teacher-led instruction on identical content using conventional methods without simulations. Week eight involved posttest administration of CUTS and SII to both groups.

Several measures controlled for potential confounding variables: teacher variability was addressed by training all participating teachers and providing standardized lesson guides; initial group differences were statistically controlled using ANCOVA with pretest scores as covariates; testing effects were minimized by ensuring a six-week interval between pretest and posttest; and instrument decay was prevented by using the same instruments for both tests.

Results

Research Question 1: Difference in Conceptual Understanding Scores

Table 1: Mean Pretest and Posttest Conceptual Understanding Scores by Group

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Mean Gain
Experimental	124	28.42	6.18	67.34	8.92	38.92
Control	124	29.15	6.43	48.76	9.14	19.61

Table 1 shows that the experimental group had a mean gain of 38.92 in conceptual understanding scores compared to the control group's mean gain of 19.61. While both groups improved, the experimental group demonstrated substantially greater improvement from pretest to posttest.

Research Question 2: Difference in Interest Scores

Table 2: Mean Pretest and Posttest Interest Scores by Group

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Mean Gain
Experimental	124	62.37	8.24	81.56	7.68	19.19
Control	124	63.08	8.51	69.43	8.37	6.35

Table 2 indicates that the experimental group's mean interest score increased by 19.19 points, while the control group increased by only 6.35 points. The experimental group showed markedly higher posttest interest in STEM subjects.

Research Question 3: Gender Influence on Conceptual Understanding and Interest

Table 3: Mean Posttest Scores by Gender for Experimental Group

Gender	N	Conceptual Understanding Mean	Conceptual Understanding SD	Interest Mean	Interest SD
Male	66	67.82	8.71	81.94	7.52
Female	58	66.79	9.18	81.12	7.89

Table 3 shows minimal differences between male and female students in the experimental group on both conceptual understanding (male = 67.82, female = 66.79) and interest (male = 81.94, female = 81.12).

Hypothesis Testing

H_{01}: No significant difference in conceptual understanding by treatment

Table 4: ANCOVA Summary for Conceptual Understanding by Treatment

Source	Sum of Squares	df	Mean Square	F	p	Decision
Corrected Model	8456.34	2	4228.17	52.86	0.000	
Covariate (Pretest)	2847.62	1	2847.62	35.59	0.000	
Treatment	1473.28	1	1473.28	18.42	0.000	Significant
Error	19602.58	245	80.01			
Total	896521.00	248				

Table 4 reveals a significant main effect of treatment on conceptual understanding ($F(1,245) = 18.42$, $p = 0.000$). Since $p < 0.05$, H_{01} is rejected. Students taught using inquiry-based simulation demonstrated significantly higher conceptual understanding than those taught with traditional methods.

H_{02}: No significant difference in interest by treatment

Table 5: ANCOVA Summary for Interest by Treatment

Source	Sum of Squares	df	Mean Square	F	p	Decision
Corrected Model	6234.71	2	3117.36	48.93	0.000	
Covariate (Pretest)	2136.45	1	2136.45	33.54	0.000	
Treatment	1361.82	1	1361.82	21.37	0.000	Significant
Error	15612.47	245	63.72			
Total	**1589432.00**	**248**				

Table 5 shows a significant main effect of treatment on interest (F(1,245) = 21.37, p = 0.000). With p < 0.05, H_{02} is rejected. Students in the inquiry-based simulation group reported significantly higher interest in STEM subjects.

H_{03}: No significant gender difference in conceptual understanding within experimental group

Table 6: ANCOVA Summary for Conceptual Understanding by Gender

Source	Sum of Squares	df	Mean Square	F	p	Decision
Corrected Model	1842.36	2	921.18	11.64	0.000	
Covariate (Pretest)	1647.28	1	1647.28	20.82	0.000	
Gender	78.43	1	78.43	0.99	0.321	Not Significant
Error	9574.21	121	79.12			
Total	452873.00	124				

Table 6 indicates no significant gender difference in conceptual understanding among students exposed to inquiry-based simulation (F(1,121) = 0.99, p = 0.321). Since p > 0.05, H_{03} is not rejected. Male and female students benefited equally from the intervention.

H_{04}: No significant gender difference in interest within experimental group

Table 7: ANCOVA Summary for Interest by Gender

Source	Sum of Squares	df	Mean Square	F	p	Decision
Corrected Model	1523.47	2	761.74	12.83	0.000	
Covariate (Pretest)	1368.52	1	1368.52	23.05	0.000	
Gender	52.38	1	52.38	0.88	0.350	Not Significant
Error	7184.63	121	59.38			
Total	**826341.00**	**124**				

Table 7 reveals no significant gender difference in interest among students in the experimental group ($F(1,121) = 0.88$, $p = 0.350$). With $p > 0.05$, H_{04} is not rejected. Inquiry-based simulation was equally effective in fostering STEM interest for both male and female students.

Discussion of Findings

The findings of this study demonstrate that inquiry-based simulation significantly enhances senior secondary students' conceptual understanding in STEM subjects compared to traditional lecture-demonstration methods. Students exposed to inquiry-based simulation achieved substantially higher posttest scores and demonstrated greater gains from pretest to posttest. This finding aligns with international research documenting the effectiveness of simulation-based inquiry learning. Kuang et al. (2024) found that providing students with opportunities to engage in simulation-based inquiry facilitated knowledge acquisition in physics among secondary students. Similarly, Tomczak's (2023) action research with fifth-grade students revealed that combining inquiry-based activities with virtual simulations positively impacted students' conceptual understanding of scientific concepts.

The superiority of inquiry-based simulation can be attributed to several factors. First, simulations allow students to visualize abstract STEM concepts, making the invisible visible and the abstract concrete (ExploreLearning, 2024). When students can manipulate variables and immediately observe outcomes, they construct more robust mental models of scientific phenomena. Second, the inquiry-based structure predicting, exploring, explaining engages students in cognitive processes essential for deep understanding. As Obienyem (2025) reported, inquiry-based learning significantly improved students' science process skills including observing, hypothesizing, and analyzing data. These skills are fundamental to conceptual understanding. Third, simulations provide opportunities for repeated experimentation without the constraints of time, materials, or safety concerns that limit hands-on laboratories in Nigerian schools (HAL Science, 2024).

The significant improvement in STEM interest among students taught with inquiry-based simulation is equally noteworthy. The experimental group's mean interest gain of 19.19 points compared to 6.35 points in the control group indicates that this approach not only teaches content effectively but also transforms students' affective relationship with STEM subjects. This finding corroborates research from the University of Toronto's Discovery Program, which found that students were more excited and engaged when participating in inquiry-based STEM projects compared to regular classwork (Avikpe *et al*., 2025). Teachers in that study reported that immersive, inquiry-based experiences helped promote more effective long-term student learning mindsets.

The mechanism for increased interest likely involves the autonomy and agency that inquiry-based simulation affords. When students direct their own exploration, test their own hypotheses, and discover relationships independently, learning becomes personally meaningful (Ojo & Tijani, 2025). The interactive nature of simulations described by teachers as engaging students through manipulation, immediate feedback, and visual representations sustains attention and curiosity (Explore Learning, 2024). In contexts where STEM instruction often involves passive reception of information, the active, exploratory nature of inquiry-based simulation represents a significant departure that reawakens students' natural curiosity about how the world works.

The finding of no significant gender differences in either conceptual understanding or interest among students exposed to inquiry-based simulation is particularly important for STEM education in northern Nigeria, where gender disparities in educational participation remain concerning. This result indicates that well-designed inquiry-based simulation instruction benefits male and female students equally, supporting HAL Science's (2024) finding of no significant gender differences in problem-solving performance among students taught using virtual laboratories in Benue State. The gender-equitable outcomes suggest that inquiry-based simulation may help address the gender gap in STEM participation by providing learning experiences equally accessible and engaging to both boys and girls. This is consistent with the view that when instructional methods emphasize active engagement and conceptual understanding over competition or prior experience, gender differences in outcomes diminish.

The consistency of these findings with both international and Nigerian research strengthens their credibility. Gado Birnin Tudu *et al*. (2023), working in the Nigerian context, demonstrated that inquiry-based modular teaching approaches developed using systematic instructional design models were suitable and appropriate for secondary students' learning of scientific concepts . The current study extends this work by demonstrating not only cognitive gains but also affective outcomes increased interest which is critical for sustained engagement in STEM education and careers.

Conclusion

This study provides empirical evidence that inquiry-based simulation significantly enhances both conceptual understanding and interest in STEM subjects among senior secondary students in Funtua Zone, Katsina State, Nigeria. Students taught using inquiry-based simulation demonstrated substantially greater gains in conceptual understanding and reported significantly higher interest in STEM compared to peers taught with traditional lecture-demonstration methods. Importantly, the benefits of this approach accrued equally to male and female students, suggesting that inquiry-based simulation may contribute to addressing gender disparities in STEM education.

The findings support the theoretical premise that when students actively construct knowledge through inquiry and visualization, they develop deeper understanding and more positive attitudes toward STEM disciplines. In resource-constrained educational contexts where physical laboratories are inadequate or absent, simulation-based approaches offer viable alternatives that not only substitute for hands-on experiences but may, in some respects, surpass them by enabling visualization of abstract concepts and repeated experimentation without resource constraints.

The study contributes to the growing body of Nigerian research on technology-enhanced, student-centered STEM instruction and provides a foundation for evidence-based educational policy and practice in Katsina State and similar contexts across northern Nigeria.

Recommendations

Based on the findings and conclusions of this study, the following recommendations are made:

1. Ministry of Education, Katsina State should integrate inquiry-based simulation approaches into the senior secondary STEM curriculum and provide schools with access to validated simulation resources. Policy frameworks should recognize simulation-based instruction as a legitimate alternative to physical laboratory experiences in schools lacking adequate facilities.

2. School administrators in Funtua Zone and beyond should prioritize investment in computer infrastructure and simulation software licenses, recognizing these as essential tools for

effective STEM instruction. Schools should establish schedules that allow students adequate time for simulation-based inquiry activities.

3. STEM teachers should receive comprehensive professional development in facilitating inquiry-based simulation lessons. Training should address both technical skills in using simulation platforms and pedagogical skills in guiding student inquiry, questioning strategies, and facilitating conceptual discussions. Teacher preparation institutions should incorporate simulation-based pedagogy into their curricula.

4. Curriculum developers should design inquiry-based simulation activities aligned with the Nigerian senior secondary STEM curriculum, providing teachers with ready-to-use lesson plans, student activity sheets, and assessment guides that integrate simulations meaningfully into instruction.

5. Educational researchers should conduct longitudinal studies tracking students exposed to inquiry-based simulation through their tertiary education and career choices to determine long-term impacts on STEM participation. Further research should explore the effectiveness of this approach across different STEM subjects and in varied Nigerian contexts.

6. Examination bodies such as the West African Examinations Council and National Examinations Council should consider incorporating assessment items that reward conceptual understanding developed through inquiry-based approaches, sending positive signals to teachers and students about the value of these methods.

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