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Impact of Culturally-situated Digital Simulations on Academic Achievement in Circular Geometry and Uniform Motion among Secondary School Students in Minna Niger State

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

This study investigated the impact of culturally situated digital simulations on students' academic achievement in circle geometry and uniform circular motion among secondary school students in Minna, Niger State, Nigeria. A quasi-experimental pretest–posttest control group design was adopted. The sample comprised 114 Senior Secondary School II students selected through a multistage sampling technique. The experimental group was exposed to culturally-situated digital simulations incorporating familiar cultural contexts, while the control group was taught using Lecture methods. Data were collected using the Circle Geometry Achievement Test (CGAT) and Uniform Circular Motion Achievement Test (UCMAT), with reliability indices of 0.81 and 0.79 respectively. Data were analyzed using mean, standard deviation, and

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ANCOVA at a 0.05 level of significance. Findings revealed that students exposed to culturally-situated digital simulations achieved significantly higher mean scores in circle geometry (23.30) compared to those taught using Lecture methods (10.85) and the difference was significant with F (1, 113) = 42.786, P= (0.000) < 0.05. Equally, the findings showed that there was significant difference in the mean academic achievement of students taught uniform circler motion with culturally-situated digital simulations and those taught using Lecture methods with F (1, 113) = 51.783, P= (0.000) < 0.05. The results underscore the effectiveness of integrating culturally responsive pedagogy with digital simulations in enhancing academic achievement. The study recommends the adoption of culturally relevant digital instructional tools in mathematics and physics classrooms to improve learning outcomes.

Keywords: Culturally-situated digital simulations; academic achievement; circular geometry; uniform motion.

1. Introduction

Mathematics and physics education are central to scientific and technological advancement, yet students in Nigerian secondary schools continue to demonstrate persistent difficulties in mastering abstract concepts such as circle geometry and uniform circular motion. These topics require high levels of spatial reasoning, conceptual visualization, and the ability to relate symbolic representations to real-world phenomena. However, Lecture methods in many Nigerian classrooms are predominantly teacher-centered, emphasizing rote learning and procedural knowledge, which often limits deep conceptual understanding.

The relationship between circular geometry and uniform circular motion represents a fundamental interdisciplinary connection in science and mathematics education, as both domains depend on shared concepts such as radius, angular displacement, and rotational relationships. However, in Nigeria, students' understanding of these concepts remains inadequate, largely due to persistent reliance on Lecture methods that present abstract ideas without meaningful contextualization, resulting in poor performance in mathematics and related science subjects (Adamu, 2022; Mosia, & Egara, 2025). Specifically, studies on circle geometry in Nigerian secondary schools have reported that students exhibit low achievement and weak conceptual understanding, necessitating the adoption of more innovative instructional strategies. Within the evolving digital landscape, the convergence of culturally responsive pedagogy and digital technologies offers a promising pathway for linking circular geometry concepts with their applications in uniform circular motion. By situating learning within culturally familiar and technologically enriched environments, students are more likely to develop deeper conceptual understanding and transferable knowledge across mathematics and physics domains. Therefore, examining the relationship between circular geometry and uniform circular motion within a culturally responsive digital framework is critical for improving students' learning outcomes in Nigerian secondary schools.

Recent advancements in educational technology have introduced digital simulations as powerful tools for enhancing conceptual learning. Digital simulations allow learners to visualize abstract mathematical and physical processes dynamically, thereby fostering active engagement and deeper understanding. Empirical evidence shows that simulation-based instruction significantly improves students' academic achievement and attitudes toward learning when compared to traditional teaching approaches (Aduloju et al., 2025; Shultz et al., 2024). Similarly, digital storytelling and multimedia-based approaches have been found to improve achievement and retention in circle geometry by creating interactive and cognitively engaging learning environments. Despite these advances, the effectiveness of digital tools depends largely on how well they are aligned with learners' sociocultural contexts. This has led to increased interest in culturally responsive pedagogy (CRP), which emphasizes the integration of students' cultural backgrounds, experiences, and real-life contexts into instructional design. CRP enhances students' engagement and achievement by making learning more meaningful and relevant. In mathematics education, culturally situated instruction has been shown to improve learners' conceptual understanding and foster positive attitudes toward the subject by connecting mathematical ideas to everyday experiences and local contexts.

Emerging studies have begun to explore the integration of culturally responsive pedagogy with digital technologies such as augmented reality (AR), virtual reality (VR), and simulations. These approaches create immersive and contextually relevant learning experiences that bridge the gap between abstract concepts and real-life applications. For example, culturally responsive digital environments enable students to interact with mathematical ideas through familiar cultural scenarios, thereby enhancing comprehension and retention (Bertrand *et al.,* 2024).

In Nigeria, there is growing recognition of the importance of culturally responsive teaching in mathematics, particularly in geometry instruction, where culturally relevant examples can significantly improve understanding and engagement (Falebita *et al.,* 2024). However, the integration of culturally situated digital simulations into the teaching of complex topics such as circle geometry and uniform circular motion remains underexplored. Given the abstract nature of these topics and the persistent challenges students face, there is a need to investigate innovative instructional approaches that combine technological affordances with cultural relevance to improve learning outcomes.

2. Statement of the Problem

Despite continuous curriculum reforms and pedagogical innovations, students' achievement in mathematics and physics in Nigerian secondary schools remains unsatisfactory, particularly in abstract topics such as circle geometry and uniform circular motion. These concepts are often perceived as difficult due to their reliance on visualization, spatial reasoning, and the integration of mathematical and physical principles. Traditional instructional approaches, which dominate classroom practice, often fail to provide students with meaningful learning experiences that connect abstract concepts to real-life contexts. As a result, students tend to memorize formulas without understanding underlying principles, leading to poor academic performance and low retention levels. While digital simulations have been introduced as a means of enhancing conceptual understanding, many of these tools are designed without consideration for the cultural backgrounds and lived experiences of learners, thereby limiting their effectiveness.

Research indicates that culturally responsive pedagogy can significantly enhance student engagement and achievement by contextualizing learning within students' cultural frameworks (Lestari *et al.,* 2025; Rigney *et al.,* 2020). Similarly, digital-based instructional strategies such as simulations and storytelling have been shown to improve learning outcomes in mathematics. However, there is a paucity of empirical studies that integrate both approaches - culturally situated pedagogy and digital simulations - particularly within the Nigerian educational context.

Furthermore, existing studies on digital simulations in Nigeria have largely focused on general mathematics or science achievement without addressing specific challenging topics such as circle geometry and uniform circular motion, nor have they examined the role of cultural contextualization in enhancing the effectiveness of these technologies. This creates a critical gap in the literature. Therefore, this study seeks to investigate the impact of culturally situated digital simulations on students' achievement in circle geometry and uniform circular motion in Nigerian secondary schools. The study aims to determine whether integrating cultural relevance into digital simulations can significantly improve students' understanding and academic performance compared to Lecture methods.

3. Research Objectives

The main aims of the study is to examine the impact of culturally situated digital simulations on academic achievement in circular geometry and uniform circular motion in Minna Niger State, Nigeria. The specific objectives were set to:

1. Examine the impact of culturally situated digital simulations on academic achievement in circular geometry among secondary school students in Minna Niger State, Nigeria.
2. Examine the impact of culturally situated digital simulations on academic achievement in uniform circular motion among secondary school students in Minna Niger State, Nigeria.

4. Research Questions

Based on the stated research objectives, the following research question were raised to guide the study:

1. What is the difference in the mean academic achievement scores of students taught circular geometry using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria?
2. What is the difference in the mean academic achievement scores of students taught uniform circular motion using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria?

5. Research Hypotheses

The following hypotheses were stated to be tested at 0.05 significance level:

1. There is no significant difference in the mean academic achievement scores of students taught circular geometry using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria.
2. There is no significant difference in the mean academic achievement scores of students taught uniform circular motion using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria.

6. Methodology

The study employed quasi-experimental pretest–posttest control group design. This design is appropriate because it allows for the comparison of learning outcomes between students exposed to culturally-situated digital simulations (experimental group) and those taught using Lecture teaching methods (control group), while controlling for initial differences through pretesting. This approach has been widely used in similar educational studies to measure instructional effectiveness. The population consisted of three one hundred and forty five (3245) Senior Secondary School II (SS II) students offering mathematics and physics in public secondary schools in Minna Metropolis, Niger State, Nigeria. SS II students are selected because circle geometry and uniform circular motion are key components of their curriculum. A multistage sampling technique was used to select the sample that participated in the study. Initially, two schools were selected using purposive sampling (based on availability of ICT facilities). Second stage involve the selection of one intact classes using simple random sampling from selected schools. In the third stage, balloting method was used to assign one school as experimental group and the other as control groups. The total sample selected was one hundred and fourteen (114) students offering mathematics and physics consisting of seventy one (71) male and (43) females. Circle Geometry Achievement Test (CGAT), Uniform Circular Motion Achievement Test (UCMAT) and Instructional Package (Culturally Situated Digital Simulations) were used to collect data. The instruments were validated by panel of experts from science education, test and measurement and educational technology from Federal University of Technology, Minna. The reliability of CGAT and UCMAT were established using test-retest reliability method and the indices were calculated using PPMC and the indices were found to be 0.81 and 0.79. The experimental group was taught using culturally situated digital simulations, which integrate local contexts (market wheel motion, bicycle dynamics, traditional circular artifacts) into simulation-based learning. While the control group was receive instruction using Lecture methods. The treatment lasted for 6 weeks, covering both circle geometry and uniform circular motion topics. Pretest was administered to determine baseline knowledge before treatment and posttest to measure achievement after treatment. Data collected were analyzed using descriptive statistics of mean, standard deviation while the hypotheses were tested using inferential statistics of ANCOVA (to control for pretest differences) and z-test at 0.05 level of significance.

7. Results

7.1 Pre-test Result for Academic Achievement Circular Geometry and Uniform Circular Motion

Mean, SD, and z-test were used to analyzed pre-test data of academic achievement scores for experimental and control group prior to the treatment to determine the homogeneity or otherwise of the students in experimental and control groups regarding their academic achievement before treatment. The results are presented in Table 1.

Table 1. Z-test results of Pre-test mean academic achievement scores in circular geometry and uniform circular motion of the experimental and control groups prior to treatment

S/N	Group	N	Mean	S.D	Z	Df	p-value	Decision
Pre_CGAT	Experimental	47	25.29	9.94	2.614	112	.010	Sig.
	Control	67	20.97	10.54				
Pre_UCMAT	Experimental	47	26.29	10.94	4.305	112	0.00	Sig
	Control	67	19.10	6.87				

Table 1 shows the Z-test Results of Pre-Test Mean academic achievement scores in circular geometry and uniform circular motion of the Experimental and Control Groups Prior to Treatment. The result indicated that there was significant difference in both the academic achievement scores in circular geometry and uniform circular motion of experimental group and control group with z (df=112) = 2.614, P (0.010) < 0.05 and z (df=112) = 4.305, P (0.000) < 0.05 respectively. This indicates that the experimental and control groups were not homogenous and not comparable for the experiment since there was different pre-requisite academic achievement scores in circular geometry and uniform circular motion before treatment. Therefore, ANCOVA was used to analyze the data.

Research Question One: What is the difference in the mean academic achievement scores of students taught circular geometry using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria?

To answer this research question, Mean and Standard Deviation were used. The result is presented in Table 2.

Table 2. Mean and SD of academic achievement in circular geometry scores of the experimental and control groups after treatment

			Pretest		Posttest			
S/N	**Group**	**N**	**Mean**	**SD**	**Mean**	**SD**	**MG**	**MGD**
1	Experimental	47	25.29	9.94	48.59	16.35	23.30	12.45
2	Control	67	20.97	10.54	31.82	10.91	10.85	

Table 2 presents the mean, standard deviation and mean gain of academic achievement in circular geometry scores of the experimental and control groups after treatment. The result shows that experimental group that were taught with culturally situated digital simulations had pre-test means of 25.29 and post-test mean of 48.59 with standard deviation of 9.94 and 16.35 respectively, a mean of (23.30) was gained. The result also revealed that control group that were taught with lecture method had pre-test means of 20.97 and post-test mean of 31.82 with standard deviation of 10.54 and 10.91 respectively, a mean of (10.85) was gained. A mean gain difference of 12.45 was obtained and thus, students taught with culturally situated digital simulations had higher mean gain of 23.30 than those taught with lecture method with mean gain of 10.85 respectively. This indicates that culturally situated digital simulations enhanced students' academic achievement in circular geometry than lecture method.

> **H_{01}:** there is no significant difference in the mean academic achievement scores of students taught circular geometry using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria.

To test this research hypothesis, ANCOVA used. The result is presented in Table 3.

Table 3. ANCOVA results of academic achievement in circular geometry scores of the experimental and control groups after treatment

Source	**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Corrected Model	7868.551[a]	2	3934.276	21.768	.000
Intercept	33996.160	1	33996.160	188.100	.000
PRE_CGAT	95.616	1	95.616	.529	.469
GROUP	7732.948	1	7732.948	42.786	.000
Error	20061.554	111	180.735		
Total	198992.000	114			
Corrected Total	27930.105	113			

[a] R Squared = .282 (Adjusted R Squared = .269)
[b] Computed using alpha = .05

Results in Table 3 shows ANCOVA Results of Academic Achievement in circular geometry Scores of the Experimental and Control Groups after Treatment. The result indicates that F (1, 113) = 42.786, P= (0.000) < 0.05, indicating a significant difference between the mean academic achievement in circular geometry of students taught using culturally situated digital simulations and those taught with lecture method. Therefore, the hypothesis was rejected and concluded that there was significant difference in the academic achievement in

circular geometry of the students taught using culturally situated digital simulations and those taught with lecture method. The significant difference was in favour of the culturally situated digital simulations group (experimental group).

Research Question Two: What is the difference in the mean academic achievement scores of students taught uniform circular motion using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria?

To answer this research question, Mean and Standard Deviation were used. The result is presented in Table 4.

Table 4. Mean and SD of academic achievement in uniform circular motion scores of the experimental and control groups after treatment

			Pretest		Posttest			
S/N	**Group**	**N**	**Mean**	**SD**	**Mean**	**SD**	**MG**	**MGD**
1	Experimental	47	26.29	10.94	67.57	13.49	41.28	19.06
2	Control	67	19.10	6.87	41.32	20.04	22.22	

Table 4 presents the mean, standard deviation and mean gain of academic achievement in uniform circular motion scores of the experimental and control groups after treatment. The result shows that experimental group that were taught with culturally situated digital simulations had pre-test means of 26.29 and post-test mean of 67.57 with standard deviation of 10.94 and 13.49 respectively, a mean of (41.28) was gained. The result also revealed that control group that were taught with lecture method had pre-test means of 19.10 and post-test mean of 41.32 with standard deviation of 6.87 and 20.04 respectively, a mean of (22.22) was gained. A mean gain difference of 19.06 was obtained and thus, students taught with culturally situated digital simulations had higher mean gain of 41.28 than those taught with lecture method with mean gain of 22.22 respectively. This indicates that culturally situated digital simulations enhanced students' academic achievement in uniform circular motion than lecture method.

> **H_{01}:** there is no significant difference in the mean academic achievement scores of students taught uniform circular motion using culturally situated digital simulations and those taught using Lecture method in Minna Niger State, Nigeria.

To test this research hypothesis, ANCOVA used. The result is presented in Table 5.

Table 5. ANCOVA results of academic achievement in uniform circular motion scores of the experimental and control groups after treatment

Source	**Type III Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Corrected Model	19028.382[a]	2	9514.191	30.253	.000
Intercept	42978.128	1	42978.128	136.661	.000
PRE_UCMAT	.182	1	.182	.001	.981
GROUP	16285.034	1	16285.034	51.783	.000
Error	34908.083	111	314.487		
Total	363963.000	114			
Corrected Total	53936.465	113			

a. R Squared = .353 (Adjusted R Squared = .341)
b. Computed using alpha = .05

Results in Table 5 shows ANCOVA Results of Academic Achievement in uniform circular motion Scores of the Experimental and Control Groups after Treatment. The result indicates that F (1, 113) = 51.783, P= (0.000) < 0.05, indicating a significant difference between the mean academic achievement in uniform circular motion of students taught using culturally situated digital simulations and those taught with lecture method. Therefore, the hypothesis was rejected and concluded that there was significant difference in the academic achievement in uniform circular motion of the students taught using culturally situated digital simulations and those taught with lecture method. The significant difference was in favour of the culturally situated digital simulations group (experimental group).

8. Major Findings

1. There was a significant difference in academic achievement in circle geometry between students taught using culturally situated digital simulations and those taught using Lecture methods, in favor of the experimental group.
2. There was a significant difference in academic achievement in uniform circular motion, with the experimental group outperforming the control group.
3. Pre-test results indicated initial differences between groups; however, ANCOVA analysis confirmed that post-treatment differences were attributable to the intervention.

9. Discussion

The findings of this study demonstrate that culturally situated digital simulations significantly enhance students' academic achievement in both circle geometry and uniform circular motion. The superior performance of the experimental group supports the growing body of evidence that digital simulations improve academic achievement by enabling dynamic visualization of abstract concepts. This findings corroborate with Aduloju *et al.* (2025) and Thomas et al. (2024) findings, who found that culturally situated digital simulations significantly enhance students' conceptual understanding which in turn foster academic achievement. The reason for the similar findings is that integration of cultural contexts into simulations appears to further strengthen learning outcomes by making instruction more meaningful and relatable. This aligns with the principles of culturally responsive pedagogy, which emphasize connecting learning to students' lived experiences (Luecke, 2025). By embedding familiar examples such as bicycle motion and local artifacts, the simulations likely reduced cognitive abstraction and increased engagement.

The findings are also consistent with studies highlighting the effectiveness of immersive and technology-enhanced learning environments, including augmented Reality and Virtual Reality, in improving mathematics achievement (Bertrand et al., 2024; Makransky & Petersen, 2021). Similarly, the observed improvement in circle geometry aligns with research showing that interactive and multimedia-based approaches enhance retention and understanding. Furthermore, the significant gains recorded in uniform circular motion suggest that simulations are particularly effective in teaching physics concepts that involve motion and dynamic processes. This supports prior research emphasizing the role of simulation tools in bridging the gap between theory and real-world application (Radianti *et al.,* 2020; Aga, 2025; Jojo, 2024).

10. Conclusion

The study concludes that culturally situated digital simulations are highly effective in improving students' academic achievement in circle geometry and uniform circular motion. The integration of cultural relevance into digital learning environments enhances students' engagement, conceptual understanding, and retention of abstract concepts. Compared to Lecture method methods, this approach provides a more interactive, meaningful, and student-centered learning experience. The results highlight the importance of aligning instructional technologies with learners' sociocultural contexts to maximize their educational impact. Thus, culturally situated digital simulations represent a valuable pedagogical innovation for improving mathematics and physics education in Nigerian secondary schools.

11. Recommendations

1. Educational stakeholders should incorporate culturally situated digital simulations into the mathematics and physics curriculum to enhance students' understanding of abstract concepts.
2. Teachers should be trained on the development and effective use of culturally responsive digital instructional tools.
3. Instructional designers should develop simulation tools that reflect local cultural contexts and real-life experiences of learners.
4. Government and school authorities should invest in ICT facilities to support the implementation of digital simulation-based learning.
5. Future studies should explore the long-term effects of culturally situated digital simulations and extend investigations to other difficult topics in mathematics and science.

6. Educational policymakers should promote the adoption of culturally responsive pedagogy as a standard practice in teaching.

12. Limitations

Despite the rigor applied in conducting the study, the following limitations were encountered:

1. Pre-existing differences among the groups may have influenced the outcomes due to in ability to use randomization in assigning participant to groups, thereby limiting the internal validity of the findings.
2. The duration of the intervention was relatively short, which may not have been sufficient to fully capture the long-term effects of the instructional strategy on students' achievement.

Consent

As per international standards or university standards written informed consent was obtained from all participants.

Ethical Approval

As per international standards or university standards written Permission was also sought from school authorities for this study.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests Disclaimer

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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