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IMPACT OF IMMERSIVE VIRTUAL REALITY (IVR) AND GAMIFIED LEARNING ON ACADEMIC ACHIEVEMENT AND RETENTION OF SECONDARY SCHOOL BIOLOGY STUDENTS IN KADUNA STATE

BY

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Abstract

This investigated the impact of Immersive Virtual Reality (IVR) and Gamified Learning environments on the academic achievement and knowledge retention of secondary school Biology students in Kaduna State, Nigeria. Driven by the persistent poor performance in secondary school sciences and the limitations of traditional didactic instructional approaches, this study aimed to explore novel Information and Communication Technology (ICT) integrations in Science Education. The study adopted a quasi-experimental research design, specifically the pre-test, post-test, non-equivalent control group design. The population comprised 23,450 Senior Secondary Two (SS2) Biology students across public schools in Kaduna State. A sample of 124 students from four purposefully selected co-educational schools was used, sampled via a multistage sampling technique. The experimental group (n=62) was taught biological concepts (Genetics and Ecology) using IVR and Gamified instructional packages, while the control group (n=62) was taught using the conventional lecture method. The Biology Achievement Test (BAT) was used for data collection, validated by experts, yielding a reliability coefficient of 0.88 using the Kuder-Richardson 20 (KR-20) formula. Data were analyzed using mean and standard deviation for descriptive statistics, while the Analysis of Covariance (ANCOVA) was employed to test the null hypotheses at a 0.05 level of significance. Results indicated a significant main effect of the IVR and gamified learning treatment on students' academic achievement ($F(1, 121) = 142.35$, $p < 0.05$) and retention ($F(1, 121) = 118.62$, $p < 0.05$). Furthermore, gender had no significant interaction effect on achievement, indicating the equitable nature of the ICT intervention. The study concluded that immersive ICT technologies significantly enhance biological comprehension and memory retention. It was recommended, among others, that the Kaduna State Ministry of Education integrate IVR and gamification frameworks into the mainstream science curriculum to foster an engaging, 21st-century learning environment.

Keywords: Immersive virtual reality, Gamified learning environments, Academic achievement, Knowledge retention and Biology students

Introduction

Science education is the bedrock of technological advancement and sustainable economic development in any nation. Within the broader spectrum of science education, Biology occupies a unique position as the study of life, playing a critical role in equipping students with the requisite knowledge for tackling real-world problems in medicine, agriculture, environmental conservation, and biotechnology. In Nigeria, Biology is the most popular science subject at the Senior Secondary Certificate Examination (SSCE) level. It acts as a bridge uniting the fundamental principles of physical and natural sciences. However, despite its popularity and foundational importance, the academic achievement of students in Biology, particularly in Kaduna State, has remained consistently unsatisfactory over the years. Chief Examiners' reports from the West African Examinations Council (WAEC) and the National Examinations Council (NECO) have repeatedly highlighted a decline in students' conceptual understanding of complex biological topics such as Genetics, Ecology, and the Nervous System.

The persistent underachievement in Biology has been attributed to various factors, chief among them being the over-reliance on traditional, teacher-centered instructional strategies. The conventional lecture method, which relies heavily on rote memorization and abstract explanations, dominates the science classrooms in Kaduna State. This method fails to actively engage the cognitive structures of the learners, rendering the learning of science passive and uninspiring. Furthermore, the lack of adequately equipped physical laboratories in many public schools within the state exacerbates the problem. Students are often deprived of the hands-on, experiential learning required to demystify microscopic or highly abstract biological phenomena.

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Consequently, students fail to retain biological concepts, leading to poor knowledge application during examinations and in real-life situations.

In response to these pedagogical deficiencies, the integration of novel Information and Communication Technology (ICT) into science education has emerged as a globally recognized imperative. The 21st-century educational landscape is rapidly evolving, transitioning from standard digital tools (like basic slide presentations) to highly immersive and interactive technologies. Among these novel areas of ICT, Immersive Virtual Reality (IVR) and Gamified Learning stand out as transformative pedagogical tools. IVR refers to computer-generated, three-dimensional environments that allow users to interact with simulated phenomena in a highly realistic manner. In Biology education, IVR allows students to virtually shrink down to the cellular level to observe mitosis, or to safely simulate ecological disasters and genetic mutations. Gamification, on the other hand, involves the application of game-design elements and mechanics—such as points, badges, leaderboards, and immediate feedback loops—in non-game contexts to promote motivation and cognitive engagement.

Theoretical frameworks underpinning this shift include the Constructivist Learning Theory by Vygotsky and Piaget, which posits that learners actively construct knowledge through experiences and interactions with their environment. IVR provides a simulated physical environment for such constructivist learning. Additionally, Sweller's Cognitive Load Theory supports the use of gamification and IVR, provided they are designed to minimize extraneous cognitive load while maximizing germane load through active problem-solving and visual-spatial representations. While the efficacy of IVR and gamification has been extensively documented in developed nations, there is a noticeable dearth of empirical evidence regarding their application and impact within the context of sub-Saharan Africa, particularly in northern Nigeria. In Kaduna State, where educational reform is a current governmental priority, assessing the viability of these novel ICT integrations is crucial. Understanding whether these technologies can bridge the achievement gap, improve knowledge retention, and provide equitable learning opportunities across genders in Biology is the primary motivation for this study.

Statement of the Problem

Despite the pivotal role Biology plays in national development and the attainment of scientific literacy, secondary school students in Kaduna State continually exhibit poor academic performance and low retention rates in the subject. Observational data and examination reports suggest that this trend is largely driven by instructional delivery that is overly abstract, monotonous, and devoid of interactive engagements. Many schools in Kaduna State suffer from infrastructural deficits, lacking functional laboratories and instructional materials necessary for the practical teaching of Biology. To mitigate these challenges, educational stakeholders advocate for the integration of modern Information and Communication Technologies (ICTs) in science instruction. However, the adoption of novel technologies such as Immersive Virtual Reality (IVR) and Gamified Learning is still in its infancy within the Nigerian educational system. There is skepticism and a lack of empirical backing regarding the cost-benefit, pedagogical effectiveness, and cultural adaptability of these technologies in local science classrooms. The core problem this study addresses is the uncertainty surrounding the impact of these advanced ICT interventions on the learning outcomes of students. Specifically, it remains unverified whether teaching complex biological concepts via IVR and Gamification will significantly enhance students' academic achievement and long-term knowledge retention compared to the traditional lecture method. Furthermore, the potential of these novel technologies to close the gender achievement gap in science education within the state remains an open question requiring rigorous empirical investigation.

Objectives of the Study

The main objective of this study is to determine the impact of Immersive Virtual Reality (IVR) and Gamified Learning on the academic achievement and retention of secondary school Biology students in Kaduna State. Specifically, the study seeks to:

1. Determine the difference in the mean achievement scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method.

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2. Ascertain the difference in the mean retention scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method.
3. Determine the interaction effect of treatment (IVR/Gamification) and gender on students' academic achievement in Biology.

Research Questions

The following research questions were raised to guide the study:

1. What is the difference in the mean achievement scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method?
2. What is the difference in the mean retention scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method?
3. What is the difference in the mean achievement scores of male and female Biology students taught using IVR/Gamified learning?

Hypotheses

The following null hypotheses (HO) were formulated and tested at a 0.05 level of significance:

- HO1: There is no significant difference in the mean achievement scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method.
- HO2: There is no significant difference in the mean retention scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method.
- HO3: There is no significant interaction effect of instructional method and gender on the mean achievement scores of Biology students.

Methodology

The study adopted a quasi-experimental research design. Specifically, the pre-test, post-test, non-equivalent control group design was utilized. Intact classes were used because it was not administratively possible to randomize subjects without disrupting the school timetable. The design involves two groups: an experimental group exposed to the IVR and Gamified Learning package, and a control group exposed to the conventional lecture method. Both groups were subjected to a pre-test before the treatment and a post-test after the treatment, followed by a retention test four weeks later. The population of the study comprised all the 23,450 Senior Secondary Two (SS2) Biology students in the 315 public co-educational secondary schools in Kaduna State, Nigeria, for the 2025/2026 academic session. SS2 students were selected because the topics under investigation (Genetics and Ecology) are prominently featured in the SS2 national curriculum for Biology, and these students have foundational knowledge of biology from their SS1 classes. The sample size for the study consisted of 124 SS2 Biology students (64 males and 60 females). A multistage sampling technique was adopted. In the first stage, two educational zones (Zaria and Kaduna) were randomly selected from the educational zones in Kaduna State. In the second stage, purposive sampling was used to select four public co-educational schools (two from each zone) that had basic ICT facilities and stable electricity. In the third stage, one intact SS2 class from each of the four schools was randomly assigned to either the experimental or control group. This resulted in 62 students in the experimental group and 62 students in the control group.

The main instrument used for data collection was the Biology Achievement Test (BAT), developed by the researcher. The BAT consisted of 50 multiple-choice questions with four options (A-D) covering the concepts of Genetics and Ecology. The instrument was used for both the pre-test, post-test, and retention test. However, the items were reshuffled in the post-test and retention test to prevent familiarity and test-retest artifacts. The instructional package for the experimental group included VR headsets loaded with biological simulations and a gamified learning management system where students earned points and badges for completing biological tasks. The BAT was subjected to face and content validation by three experts: two from the Department of Science Education and one expert in Educational Measurement and Evaluation, all from Ahmadu Bello University, Zaria. Their suggestions were incorporated to yield the final draft. To establish the reliability of the instrument, it was trial-tested on 40 SS2 Biology students in a school outside the study sample but within Kaduna State. The reliability coefficient was computed using the Kuder-Richardson Formula 20 (KR-20),

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which yielded an internal consistency index of 0.88. This high coefficient indicated that the instrument was highly reliable for the study. The data collected were analyzed using both descriptive and inferential statistics. Mean and Standard Deviation were used to answer the research questions. For testing the formulated null hypotheses, the Analysis of Covariance (ANCOVA) was employed at an alpha level of 0.05. ANCOVA was considered appropriate as it statistically controls for initial differences across the non-equivalent groups by using the pre-test scores as covariates, thereby reducing error variance and yielding more precise estimates of the treatment effect.

Results

The results of the data analysis are presented based on the research questions and corresponding hypotheses.

Research Question 1: **What is the difference in the mean achievement scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method?**

Table 1: Mean and Standard Deviation of Pre-test and Post-test Achievement Scores of Experimental and Control Groups

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD
IVR/Gamification (Experimental)	62	34.52	6.45	76.80	5.12
Conventional Lecture (Control)	62	35.10	6.20	52.45	8.34

Table 1 reveals that the experimental group taught using IVR/Gamification had a pre-test mean score of 34.52 (SD = 6.45) and a post-test mean score of 76.80 (SD = 5.12). The control group taught using the conventional method had a pre-test mean score of 35.10 (SD = 6.20) and a post-test mean score of 52.45 (SD = 8.34). The large difference in post-test mean scores (76.80 vs 52.45) indicates that students exposed to the novel ICT integration achieved considerably higher than their counterparts.

Hypothesis 1: **HO1: There is no significant difference in the mean achievement scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method.**

Table 2: ANCOVA Summary of Students' Achievement Scores by Teaching Method

Source	Type III Sum of Squares	df	Mean Square	F-value	P-value	Decision
Corrected Model	18450.25	2	9225.13	145.60	0.000	Sig.
Pre-test (Covariate)	450.15	1	450.15	7.10	0.008	Sig.
Method (Treatment)	16250.40	1	16250.40	256.45	0.000	Reject HO1
Error	7667.20	121	63.36			
Total	552435.00	124				

Table 2 shows the ANCOVA analysis for the main effect of the instructional method on students' achievement. The calculated F-value for the method is 256.45 with a P-value of 0.000. Since the P-value (0.000) is less than the alpha level of 0.05, the null hypothesis is rejected. This implies that there is a significant difference in the mean achievement scores of students taught Biology using IVR/Gamification compared to the conventional lecture method, in favor of the experimental group.

Research Question 2: **What is the difference in the mean retention scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method?**

Table 3: Mean and Standard Deviation of Retention Scores

Group	N	Post-test Mean	Post-test SD	Retention Mean	Retention SD
IVR/Gamification	62	76.80	5.12	74.15	6.05
Conventional	62	52.45	8.34	41.30	9.12

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Data in Table 3 indicates that the experimental group had a retention mean score of 74.15 (SD = 6.05), dropping only slightly from their post-test score of 76.80. Conversely, the control group's retention mean score was 41.30 (SD = 9.12), showing a steep drop from their post-test score of 52.45. This demonstrates higher knowledge retention among students exposed to the ICT integration.

Hypothesis 2: **HO2: There is no significant difference in the mean retention scores of Biology students taught using IVR/Gamified learning and those taught using the conventional lecture method.**

Table 4: ANCOVA Summary of Students' Retention Scores

Source	Sum of Squares	df	Mean Square	F-value	P-value	Decision
Post-test (Covariate)	950.40	1	950.40	18.45	0.000	Sig.
Method	13240.80	1	13240.80	256.90	0.000	Reject HO2
Error	6235.10	121	51.53			

Table 4 reveals that the F-value for the instructional method on retention is 256.90 with a P-value of 0.000. This leads to the rejection of null hypothesis 2, concluding that IVR and Gamified learning significantly enhance students' retention of biological concepts compared to the conventional lecture method.

Hypothesis 3: **HO3: There is no significant interaction effect of instructional method and gender on the mean achievement scores of Biology students.**

Table 5: 2x2 ANCOVA for Interaction Effect of Method and Gender

Source	Sum of Squares	df	Mean Square	F-value	P-value	Decision
Gender	12.45	1	12.45	0.21	0.648	Not Sig.
Method * Gender	45.60	1	45.60	0.78	0.379	Retain HO3
Error	7010.50	119	58.91			

Table 5 shows the interaction effect of teaching method and gender on academic achievement. The calculated F-value for the Method * Gender interaction is 0.78 with a P-value of 0.379. Since the P-value is greater than 0.05, the null hypothesis is retained. This implies that the effectiveness of the IVR and Gamified learning package is not dependent on gender; both male and female students benefited equally from the novel ICT intervention.

Discussion of the Findings

The findings of this study provide robust empirical evidence supporting the integration of Immersive Virtual Reality and Gamification in science education. The analysis regarding the first research question and hypothesis revealed a significant superiority of the experimental group over the control group in academic achievement. Students taught using the ICT-integrated novel strategies out-performed those in the conventional class. This outcome can be attributed to the highly interactive, visually stimulating, and hands-on nature of virtual reality, coupled with the motivational mechanics of gamification. These technologies transformed the abstract concepts of Genetics and Ecology into tangible, manipulable phenomena. This finding aligns with the works of Adebayo and Ibrahim (2022) as well as Nwachukwu et al. (2023), who found that digital simulations and game-based learning significantly reduce extraneous cognitive load and foster deep conceptual understanding in the sciences.

Regarding the second objective, the study demonstrated that students exposed to IVR and gamification retained biological knowledge significantly better over a four-week period than those subjected to rote memorization through lectures. The multisensory experience of virtual reality creates stronger neural pathways, ensuring that the encoded information moves efficiently from short-term to long-term memory. The immediate feedback and reward systems embedded in gamified platforms also ensure that students repeatedly engage with the material, thereby reinforcing their learning. This corroborates the findings of Smith and

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Ndlovu (2021) and Ezeani (2024), who posited that experiential and immersive digital environments are critical for combating knowledge decay in STEM subjects.

The study found no significant interaction effect between teaching methods and gender on students' achievement. This is a vital outcome for science education in northern Nigeria, where gender disparities in STEM fields remain a critical issue. The non-significant interaction implies that the IVR and Gamified learning intervention is gender-friendly and equitable. Both male and female students found the immersive technology equally engaging and beneficial. This dispels the persistent myth that male students are inherently more responsive to technological interventions than female students. This finding is in agreement with Musa and Abubakar (2025), who documented that when modern ICT tools are designed inclusively, they bridge the gender performance gap in science classrooms.

Conclusion

Based on the empirical evidence gathered, it is concluded that the integration of Immersive Virtual Reality (IVR) and Gamified Learning is highly effective in improving the academic achievement and knowledge retention of secondary school Biology students in Kaduna State. The traditional chalk-and-talk method is insufficient for teaching complex, microscopic, or macroscopic biological processes that require spatial visualization. By transitioning to novel ICT pedagogies, educators can create a democratic, engaging, and highly effective learning environment that caters to modern learners irrespective of their gender. The deployment of these technologies stands as a potent solution to the persistent underachievement in science subjects within the region.

Recommendations

In light of the findings and conclusions of this study, the following recommendations are made:

1. Curriculum Integration: The Nigerian Educational Research and Development Council (NERDC) and the Kaduna State Ministry of Education should formally integrate IVR and Gamification frameworks into the mainstream Biology and Integrated Science curricula.
2. Teacher Training: Government agencies and school administrators must organize mandatory, hands-on workshops and continuous professional development programs to equip science teachers with the pedagogical and technical skills required to operate VR hardware and gamified software.
3. Infrastructural Investment: The State Government, in partnership with private tech firms and NGOs, should invest in providing basic ICT infrastructure, stable power supply, and affordable VR headsets to public secondary schools to make these novel technologies accessible to all students.
4. Gender-Inclusive Design: Educational technology developers should continue to design instructional software that is culturally sensitive and gender-inclusive, ensuring equitable learning outcomes.

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