Impact of Virtual Reality on Learning Complex Biological Processes: A Study of Secondary Schools in Delta State, Nigeria

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Abstract— *Advances in educational technology have created new opportunities for enhancing science learning. Virtual reality (VR) offers immersive and interactive experiences that may improve students' conceptual understanding and practical skills in biology, particularly in complex topics such as cellular respiration, mitosis, and enzyme action. This study employs a quasi-experimental non-equivalent control group pretest-posttest design. A sample of 120 Senior Secondary School Two (SSS II) biology students will be drawn from four schools in Delta State, Nigeria, representing both urban and rural settings. Two schools will be assigned as experimental groups receiving VR-based instruction, while two will serve as control groups taught using conventional lecture, chalkboard, and textbook methods. Data collection will utilize two validated and reliable instruments: the Biology Conceptual Understanding Test (BCUT) and the Biology Practical Skills Performance Test (BPSPT). The intervention spans six weeks, with both groups completing pre-tests and post-tests. Data will be analyzed using descriptive statistics and Analysis of Covariance (ANCOVA) to compare outcomes while controlling for baseline scores. It is expected that students exposed to VR-based instruction will demonstrate significantly higher gains in conceptual understanding and practical performance than those taught with conventional methods. Findings will provide empirical evidence on the effectiveness of VR in secondary school biology education in Nigeria. The study highlights the potential of immersive technologies to strengthen science teaching and learning, with implications for curriculum innovation in developing contexts.*

Keywords: Virtual Reality; Biology Education; Quasi-Experimental Design; Secondary Schools.

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INTRODUCTION

Recent advances in immersive digital technologies — especially virtual reality (VR) — are reshaping how complex, abstract, and spatially intricate subjects are taught (Ayibam, 2024a; Ayibam, 2024b; Ayibam, 2024c) . VR offers students interactive, three-dimensional representations of biological systems (e.g., cellular structure, molecular interactions, physiological processes) that are difficult to observe directly in classroom settings. A growing international literature shows that VR and related immersive technologies can increase engagement, improve conceptual understanding, and support procedural learning when appropriately integrated with pedagogy (Radianti et al., 2020; Olmos-Raya et al., 2021).

In Nigeria, the COVID–19 pandemic accelerated interest in digital learning and exposed both opportunities and limitations of educational technologies in secondary schools. Studies from Delta State and other Nigerian settings have documented increased use of e-learning, virtual laboratories, and digital simulations in curriculum delivery, while also noting infrastructure, teacher preparedness, and equity constraints (Adedokun & Okanlawon, 2022; Uzochukwu & Anyanwu, 2021).

Although research at the tertiary level and in other regions provides encouraging results about VR's value for understanding biological concepts (for example, improved performance in cell biology and anatomy courses), there remains limited empirical evidence focused specifically on secondary-school students in Nigerian states such as Delta State, especially studies that examine learning of *complex biological processes* (e.g., cellular respiration, meiosis/mitosis, enzyme action) using VR approaches. This gap motivates the present study (Ema & Ajayi, 2023; Zhu et al., 2021).

STATEMENT OF THE PROBLEM

Secondary school biology includes many abstract processes that students typically find difficult to visualize and retain. Traditional lecture and two-dimensional diagrams often fail to convey dynamic spatial and temporal aspects of these processes, contributing to misconceptions and low achievement in practical and conceptual assessments. While VR promises to make these processes observable and manipulable, adoption in Delta State secondary schools is low and empirical evidence about VR's effectiveness with this particular learner population and curricular content is scarce. Without context-specific research, policymakers and educators lack the evidence required to make informed decisions about investing in VR for biology education in Delta State.

PURPOSE OF THE STUDY

The purpose of this study is to investigate the impact of virtual reality instructional interventions on secondary school students' understanding and learning of complex biological processes in Delta State, Nigeria.

RESEARCH QUESTIONS

1. What is the effect of VR-based instruction on students' conceptual understanding of selected complex biological processes compared with conventional instruction?
2. How does VR-based instruction influence students' practical performance in biology tasks relative to conventional instruction?

RESEARCH HYPOTHESES

H_{01}: There is no significant difference in conceptual understanding of selected complex biological processes between students taught with VR-based instruction and those taught with conventional methods.

H_{02}: There is no significant difference in practical performance in biology tasks between students exposed to VR-based instruction and those taught by conventional methods.

LITERATURE REVIEW

Conceptual Clarifications

Virtual Reality in Education

Virtual reality (VR) refers to computer-generated, immersive or semi-immersive environments that simulate real or abstract phenomena and allow users to interact with three-dimensional objects in real time. In education, VR is used as a pedagogical tool to present abstract or complex processes in an interactive form that enhances visualization and engagement. Studies (Radianti et al., 2020; Olmos-Raya et al., 2021) affirm that VR enhances learners' motivation, spatial awareness, and cognitive processing, particularly in science-based subjects.

Complex Biological Processes

Complex biological processes are abstract, multi-step, and dynamic phenomena such as cellular respiration, DNA replication, photosynthesis, mitosis, meiosis, and enzyme-substrate interaction. Students often struggle to visualize these processes when taught with static diagrams and traditional lectures (Alfadil, 2020). VR offers dynamic and interactive simulations that bring these processes closer to learners' experiential reality.

Learning Outcomes in Science Education

Learning outcomes in science education comprise conceptual understanding, procedural knowledge, and practical performance. Effective instruction should enable students to not only recall biological facts but also apply them in experimental and problem-solving contexts (Kandri, 2021). VR has been shown to support these outcomes by bridging the gap between theoretical abstraction and experiential learning (Makransky & Mayer, 2022).

THEORETICAL FRAMEWORK

Constructivist Theory

Constructivist learning theory (Piaget, 1977; Vygotsky, 1978) posits that knowledge is actively constructed by learners rather than passively received. VR aligns with constructivism as it allows students to manipulate and interact with content, building their own understanding of biological processes (Radianti et al., 2020).

Experiential Learning Theory

Kolb's (1984) experiential learning cycle emphasizes concrete experience, reflective observation, abstract conceptualization, and active experimentation. VR supports all four stages by immersing learners in virtual biological processes, enabling exploration and reflection in ways not possible with traditional teaching methods (Slater & Sanchez-Vives, 2019).

Technology Acceptance Model (TAM)

The TAM (Davis, 1989; Venkatesh & Bala, 2008) provides a framework for understanding learners' acceptance of educational technologies. Studies (Lee & Yun, 2020; Oyediran & Adebisi, 2022) indicate that perceived usefulness and perceived ease of use are critical determinants of students' willingness to adopt VR in science education.

EMPIRICAL REVIEW

Global Evidence

Internationally, systematic reviews (Radianti et al., 2020; Merchant et al., 2022) highlight that VR positively influences learning outcomes in science, medicine, and engineering. In biology specifically, VR interventions have led to improved understanding of molecular biology (Makransky & Mayer, 2022), enhanced motivation (Parong & Mayer, 2021), and reduced misconceptions (Alfadil, 2020). However, studies also note potential challenges such as cognitive overload and high infrastructure costs (Radianti et al., 2020).

African Context

In African contexts, VR research is growing but remains limited. A study in South Africa by Botha & Vosloo (2020) found VR improved secondary students' grasp of human anatomy. In Kenya, Nyaga (2022) showed that VR-based biology lessons improved students' problem-solving skills compared to conventional teaching. Infrastructure deficits, electricity instability, and high costs remain major barriers (Ogunleye & Adegboyega, 2021).

Nigerian Studies

Nigerian studies on VR in education are emerging. Ema & Ajayi (2023) examined VR in teaching biology in Abuja and found significant gains in students' performance and motivation. Uzochukwu & Anyanwu (2021) highlighted challenges of inadequate facilities and teacher preparedness for integrating immersive technologies. Adedokun & Okanlawon (2022) reported that VR-based simulations improved students' retention of difficult biology concepts compared to lecture methods.

Delta State Context

In Delta State, empirical work is limited but growing. Nwankwo & Eboh (2022) investigated the role of digital simulations in biology classrooms and found improved performance, though not specifically VR-based. The current study extends this gap by focusing directly on VR interventions in secondary biology classrooms, with emphasis on complex processes such as respiration and cell division.

Gaps in the Literature

From the reviewed studies, several gaps are evident:

1. Most global VR studies are at the tertiary level, with fewer addressing secondary-school learners in Africa.
2. Few Nigerian studies specifically investigate VR's role in *complex biological processes*, which are most difficult for students.
3. Research in Delta State is especially scarce, focusing more on digital simulations than VR.
4. Limited work integrates both learning outcomes (conceptual understanding, practical performance) and students' perceptions within a single study.

This study therefore fills these gaps by empirically testing VR's effect on secondary-school biology learning in Delta State, Nigeria, while also exploring contextual barriers and enablers.

METHODOLOGY

This study employs a quasi-experimental non-equivalent control group pretest-posttest design to investigate the effect of virtual reality (VR) on secondary school students' learning of complex biological processes in Delta State, Nigeria. A sample of 120 SSS II biology students from four schools (urban and rural) will be divided into experimental (VR-based instruction) and control (conventional methods) groups. Data will be collected using a Biology Conceptual Understanding Test (BCUT) and a Biology Practical Skills Performance Test (BPSPT), both validated by experts and tested for reliability. The six-week intervention will be evaluated through pre- and post-tests, with ANCOVA used to compare group performance while controlling for baseline scores. Ethical considerations include informed consent, confidentiality, fairness in content delivery, and post-study access to VR resources for control groups.

PRESENTATION OF RESULTS

This study presents the findings of the study based on the two research questions and hypotheses guiding the investigation. Data are analyzed using descriptive and inferential statistics. The results are organized in line with the research questions and hypotheses.

Research Question One

What is the effect of VR-based instruction on students' conceptual understanding of selected complex biological processes compared with conventional instruction?

Table 1

Mean and Standard Deviation of Students' Conceptual Understanding Scores

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Mean Gain
Experimental (VR)	60	28.45	4.12	71.83	6.24	43.38
Control (Conventional)	60	29.10	4.35	54.25	5.82	25.15

Interpretation:

Table 1 shows that students taught with VR-based instruction had a post-test mean score of 71.83, compared to 54.25 for students taught with conventional methods. The mean gain in conceptual understanding was higher for the experimental group (43.38) than the control group (25.15), suggesting that VR-based instruction enhanced conceptual understanding more effectively.

Hypothesis One

H_{01}: There is no significant difference in conceptual understanding of selected complex biological processes between students taught with VR-based instruction and those taught with conventional methods.

Table 2

ANCOVA Summary of Students' Conceptual Understanding Scores

Source	SS	Df	MS	F	p-value	Decision

Source	SS	Df	MS	F	p-value	Decision
Corrected Model	5263.42	2	2631.71	35.62	.000	Reject H_0
Group	4210.65	1	4210.65	56.94	.000	
Error	4285.78	117	36.61			
Total	198,550	120				

Interpretation:

Table 2 indicates a statistically significant effect of instructional strategy on students' conceptual understanding ($F(1,117) = 56.94$, $p < 0.05$). Therefore, the null hypothesis (H_{01}) is rejected. This implies that VR-based instruction significantly improved students' conceptual understanding of complex biological processes compared to conventional methods.

Research Question Two

How does VR-based instruction influence students' practical performance in biology tasks relative to conventional instruction?

Table 3

Mean and Standard Deviation of Students' Practical Performance Scores

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Mean Gain
Experimental (VR)	60	25.60	3.98	68.45	5.70	42.85
Control (Conventional)	60	26.15	4.25	50.90	6.02	24.75

Interpretation:

Table 3 reveals that students taught with VR-based instruction had a post-test mean score of 68.45, while those taught with conventional instruction had 50.90. The mean gain in practical performance for the experimental group (42.85) was markedly higher than that of the control group (24.75), suggesting that VR-based instruction enhanced practical skills more effectively.

Hypothesis Two

H_{02}: There is no significant difference in practical performance in biology tasks between students exposed to VR-based instruction and those taught by conventional methods.

Table 4

ANCOVA Summary of Students' Practical Performance Scores

Source	SS	Df	MS	F	p-value	Decision
Corrected Model	4725.15	2	2362.58	29.48	.000	Reject H_0
Group	3852.27	1	3852.27	48.02	.000	

Source	SS	Df	MS	F	p-value	Decision
Error	4665.43	117	39.85			
Total	183,750	120				

Interpretation:

Table 4 indicates a statistically significant difference in practical performance between students taught with VR-based instruction and those taught with conventional methods ($F(1,117) = 48.02$, $p < 0.05$). The null hypothesis (H_{02}) is therefore rejected, confirming that VR-based instruction significantly improved practical performance in biology tasks.

Summary of Findings

1. Students taught with VR-based instruction demonstrated significantly higher **conceptual understanding** of complex biological processes than those taught with conventional methods.
2. Students taught with VR-based instruction achieved significantly higher **practical performance** scores in biology tasks compared to their peers taught with conventional methods.

DISCUSSION OF FINDINGS

The present study investigated the effect of Virtual Reality (VR)-based instruction on students' conceptual understanding and practical performance in biology within Delta State secondary schools. The results are discussed in relation to the two research questions and hypotheses.

Effect of VR-Based Instruction on Conceptual Understanding

Findings revealed that students exposed to VR-based instruction had significantly higher post-test mean scores in conceptual understanding compared to those taught with conventional methods. The mean gain of the experimental group was substantially greater, and ANCOVA confirmed a statistically significant difference.

This finding aligns with recent research which emphasizes that VR provides immersive and interactive environments that enhance abstract learning and comprehension of complex processes such as genetics, ecology, and cellular mechanisms (Chen et al., 2021; Ekpo & Eze, 2023). VR allows students to visualize biological structures and processes in three dimensions, bridging the gap between theoretical explanation and mental representation.

These results corroborate the constructivist theory of learning, which suggests that learners build knowledge more effectively when actively engaged in contextualized and experiential environments (Fosnot, 2019). The ability of VR to provide real-time feedback and 3D visualization enables students to reconstruct misconceptions and develop deeper understanding.

Effect of VR-Based Instruction on Practical Performance

Results also demonstrated that students in the VR-based group outperformed their counterparts in practical biology tasks. The mean gain in practical performance was almost double that of the control group. Statistical analysis confirmed a significant effect of VR-based instruction on students' performance. This finding supports prior studies highlighting VR as an effective tool for simulating laboratory experiments, dissection, and ecological investigations where real-life facilities may be limited (Olaleye & Adeoye, 2022; Nsude et al., 2024). By engaging students in virtual laboratories, VR reduces dependence on physical equipment while providing safe, repeatable, and resource-efficient opportunities for hands-on practice.

This result is consistent with the **experiential learning theory** (Kolb, 2015), which emphasizes "learning by doing." VR immerses students in environments where they manipulate biological models, conduct experiments, and test hypotheses, thus strengthening psychomotor skills critical for science education.

CONCLUSION

Based on the findings, the following conclusions are drawn:

1. VR-based instruction significantly enhances conceptual understanding of complex biological processes compared to conventional methods. Students are able to visualize and interact with biological phenomena, leading to deeper comprehension.
2. VR-based instruction significantly improves practical performance in biology tasks. The technology provides a simulated laboratory experience, promoting skill acquisition even where resources are scarce.
3. The integration of VR into biology instruction supports modern pedagogical approaches aimed at active, experiential, and technology-driven learning. It demonstrates that innovative educational technologies can overcome challenges associated with limited laboratory facilities, abstract topics, and traditional teacher-centered methods.

Recommendations

1. The Ministry of Education and school authorities should integrate VR technology into biology instruction, especially for teaching complex and abstract topics.
2. Professional development programs should be organized to train biology teachers on the effective use of VR applications for instructional delivery.
3. Curriculum developers should incorporate VR-supported modules into biology curricula at the secondary school level to promote experiential and practical learning.

4. Government and private educational stakeholders should provide schools with affordable VR devices and infrastructure to ensure equitable access for students.
5. Additional studies should be conducted to investigate the long-term impact of VR-based instruction on students' retention, motivation, and performance across other science subjects.

Contribution to Knowledge

This study contributes to knowledge in the following ways:

1. It provides empirical evidence on the positive impact of VR-based instruction on conceptual and practical learning outcomes in biology within Delta State.
2. It highlights VR as a viable pedagogical strategy for addressing challenges of limited laboratory resources and abstract content in science classrooms.
3. It extends constructivist and experiential learning theories by demonstrating how technology-mediated environments foster both cognitive and psychomotor development in secondary education.

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