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Effect of 3D Animated Science Narratives on Biology Concept Retention among Secondary Students in Zing, Taraba State, Nigeria.

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ABSTRACT

This study examined the effect of immersive, three-dimensional (3D) animated science narratives on the retention of complex biology concepts among Senior Secondary Two (SS 2) students in Zing Education Zone, Taraba State, Nigeria. A quasi-experimental pre-test/post-test control group design was adopted. A sample of 120 SS 2 biology students from four public secondary schools was selected through multi-stage purposive and random sampling and assigned to experimental ($n = 60$) and control ($n = 60$) groups. The experimental group received instruction through 3D animated science narratives while the control group received conventional chalk-and-talk instruction. Two instruments were used: the Biology Retention Achievement Test (BRAT; KR-20 = 0.81) and the Students' Motivation towards Biology Instruction Questionnaire (SMBIQ; $\alpha = 0.78$). Three hypotheses were tested at the 0.05 level using Analysis of Covariance (ANCOVA) and independent samples t-tests. Results showed that the experimental group achieved significantly higher retention scores than the control group, $F(1, 117) = 47.31$, $p < .001$, partial $\eta^2 = .288$. Gender was not a significant moderator of this advantage, $t(58) = 1.61$, $p = .113$. The experimental group also reported significantly higher motivation than the control group, $t(118) = 10.36$, $p < .001$. The study concluded that Immersive 3D animated science narrative instruction was significantly more effective than conventional chalk-and-talk instruction in promoting biology concept retention among SS 2 students in Zing Education Zone, Taraba State. This advantage held across gender and was accompanied by a substantial increase in student motivation towards biology learning. The study recommends integrating 3D animated science narratives into biology instruction, supported by investment in ICT infrastructure and teacher training.

Keywords: Immersive 3D Animation, Biology Retention, Science Narratives, Secondary Education, Student Motivation

INTRODUCTION

Science education continues to grapple with helping learners build accurate, lasting mental models of phenomena that are abstract, microscopic, or too slow or fast to observe directly. This challenge is acute in biology, where core topics such as cell division, circulation, and genetic inheritance require learners to mentally represent dynamic processes at scales invisible to the naked eye (Nwosu & Eze, 2021; Ogundele & Adeyemi, 2022). Conventional instruction, which relies on static diagrams and verbal exposition, often leaves students with fragile and incomplete conceptual structures in these domains.

Biology plays a pivotal role as a foundational science subject essential for advancements in medical, agricultural, and environmental sectors. However, many secondary school students continuously struggle to grasp complex, abstract, and microscopic biological processes such as cellular respiration, genetics, and cell division. Traditional educational practices heavily rely on the conventional chalk-and-talk methodology, which favors rote memorization over conceptual understanding.

Immersive three-dimensional (3D) animation presents a powerful pedagogical alternative by transforming abstract ideas into concrete visual narratives. Grounded in Mayer's (2021) multimedia learning framework,

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presenting information through dual verbal and visual channels helps reduce extraneous cognitive load and accelerates the storage of information into long-term memory structures.

The Immersive three-dimensional (3D) computer-generated animation, embedded within structured narrative frameworks, offers a theoretically grounded alternative. Unlike static diagrams or conventional video, 3D animated narratives externalize dynamic spatial processes, distribute cognitive load across visual and auditory channels, and recruit motivational engagement that deepens encoding and retrieval (Mayer, 2020; Skulmowski & Xu, 2022). Nigeria's National Digital Economy Policy and ongoing NERDC curriculum reforms have created room for multimedia integration in classrooms (Federal Ministry of Education [FME], 2022), and rising smartphone access is gradually narrowing the digital divide in some areas (Aliyu & Bello, 2023). Even so, evidence on 3D animated science instruction in North-Eastern Nigeria, particularly Taraba State, remains thin; most available studies come from South-Western Nigeria or international settings whose infrastructural realities differ markedly from those of rural Taraba schools.

The conceptual architecture of this study integrates Paivio's (2020) Dual-Coding Theory alongside modern Cognitive Load frameworks. According to these frameworks, the human cognitive architecture processes visual graphics and text narratives along independent pathways. When complex biological mechanisms are contextualized inside an animated story arc, the visual representation enhances spatial mapping while the narrative voice provides immediate thematic reinforcement.

Recent localized studies, including Osuafor and Okeke (2023), suggest that integrating interactive digital media across West African science classrooms triggers higher short-term retention rates. However, concrete experimental literature mapping the explicit deployment of immersive 3D narrative animation within rural and semi-urban classrooms—such as those across Zing Education Zone in Taraba State—has historically remained limited. This inquiry directly addresses this critical empirical void.

Zing Education Zone, in Zing Local Government Area of Taraba State, serves a largely rural and semi-urban population. Biology is compulsory for science students at the senior secondary level and is a gateway subject for tertiary study in medicine, agriculture, and life sciences. School inspection reports and supervisory accounts point to persistently weak performance in biology topics demanding dynamic spatial reasoning, such as cell division and genetics. This study was therefore designed to generate locally relevant evidence on whether 3D animated science narratives improve biology concept retention among SS 2 students in this zone.

Statement of the Problem

Nigerian public secondary schools consistently face challenges regarding student performance and retention in science subjects. Annual institutional summaries, such as the West African Examinations Council (WAEC, 2024) chief examiners' reports, outline persistent weaknesses in students' ability to recall and correctly answer questions on core biological concepts. This ongoing deficiency is deeply tied to passive instructional environments where standard classrooms lack engaging digital tools, and teachers lack specialized media resources to stimulate structural visualization.

Despite strong policy advocacy for technology-enhanced instruction in Nigeria, empirical evidence on the effectiveness of 3D animated science narratives for biology retention among secondary students in North-Eastern Nigeria is scarce. Studies from South-Western Nigeria and abroad report substantial gains from 3D animated instruction (Ogundele & Adeyemi, 2022; Ibrahim et al., 2023; Hou et al., 2023), but whether these findings generalize to Zing Education Zone's infrastructural and pedagogical context is unknown. It is also unclear whether any retention advantage differs by gender, or whether it is accompanied by changes in student motivation.

Purpose of the Study

The primary purpose of this study was to investigate the effect of immersive, three-dimensional (3D) animated science narratives on the retention of complex biology concepts and learning motivation among Senior Secondary Two (SS 2) students in Zing Education Zone, Taraba State, Nigeria.

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Specific Objectives

i. To determine the difference in biology concept retention scores between students taught using immersive 3D animated science narratives and those taught using the conventional chalk-and-talk instruction.

ii. To assess whether gender moderates the effect of immersive 3D animated science narrative instruction on students' retention of biology concepts.

iii. To evaluate the difference in motivation levels between students exposed to immersive 3D animated science narratives and those exposed to conventional instruction.

Research Questions and Hypotheses

To guide the study the following research questions and accompanied hypotheses at 0.05 level of significance as follows:

Research Question 1 (RQ1): Is there a significant difference in retention scores between students taught with 3D animations and those taught with conventional methods?

H01: There is no significant difference in biology retention scores between students taught using immersive 3D animated science narratives and those taught using conventional instructional methods.

RQ2: Does gender moderate the retention scores of students taught with 3D animations?

H02: Gender does not significantly moderate the biology concept retention scores of students in the experimental group.

RQ3: Is there a significant difference in motivation levels between the two groups?

H03: There is no significant difference in motivation levels between students taught using immersive 3D animated science narratives and those taught using conventional methods.

Significance of the Study

This study offers direct practical value to secondary students by rendering complex subject matter clear, accessible, and easily recallable. For biology educators, it establishes empirical justification for moving toward modern digital strategies within contemporary science classrooms. Finally, curriculum planners and West African policy stakeholders receive verifiable data supporting the critical expansion of ICT infrastructure and digital tool integration across regional institutions.

METHODOLOGY

Research Design

This inquiry utilized a quasi-experimental, non-equivalent pre-test/post-test control group research design, appropriate because intact SS 2 classes could not be randomly reassigned without disrupting school timetables. Pre-test scores served as covariates to control for baseline differences between groups (Creswell & Creswell, 2023).

Study Area and Population

The target population encompassed all Senior Secondary Two (SS 2) biology students across public schools situated within Zing Education Zone, Taraba State. The study was conducted in Zing Education Zone, Taraba State, an agrarian, largely underserved area with respect to educational technology during the 2025/2026 academic session.

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Sample and Sampling Technique

Multi-stage purposive and random sampling protocols were applied to select four representative public secondary institutions, yielding a total sample size of 120 students. This cohort was structured evenly into an Experimental group (n = 60) and a Control group (n = 60). Schools were purposively selected based on availability of a functional projector or computer and administrative willingness to participate. One intact biology class was then randomly selected from each school by balloting. Two schools were randomly assigned to the experimental condition and two to the control condition, yielding 60 students per group (51 male, 69 female overall). Table 1 presents the distribution of respondents by group and gender.

Table 1. Distribution of Respondents by Group and Gender

Group	Male	Female	Total
Experimental	26	34	60
Control	25	35	60
Total	**51**	**69**	**120**

Instrumentation

The experimental cohort received classroom biology instructions mediated by immersive 3D animated science narratives. Conversely, the control group was instructed utilizing standard conventional chalk-and-talk pedagogies. Quantitative data collection relied on two validated tools: the Biology Retention Achievement Test (BRAT), which secured an internal consistency coefficient of 0.81 via Kuder-Richardson Formula 20 (KR-20), and the Students' Motivation towards Biology Instruction Questionnaire (SMBIQ), achieving a Cronbach's alpha reliability index of 0.78 recommended by Pallant (2020); and was considered good, reliable and suitable for the study.

Procedure

Data collection proceeded in three phases. In Phase 1, the BRAT was administered as a pre-test to all 120 students. In Phase 2 (three weeks), the experimental group received instruction via 3D animated modules (sourced from the Visible Biology 3D library and supplemented with open-source Blender modules), projected in class with structured teacher facilitation: a five-minute activation activity, 20-minute animation viewing, 10-minute paired discussion, and 10-minute reflective exercise per lesson. The control group received conventional chalk-and-talk instruction on the same topics from their regular teacher. Both groups received twelve 45-minute periods. In Phase 3, two weeks after instruction ended, the delayed BRAT post-test and the SMBIQ were administered to all students.

Method of Data Analysis

Research questions were answered using means and standard deviations. Hypothesis 1 was tested using ANCOVA with pre-test scores as covariate; Hypotheses 2 and 3 were tested using independent samples t-tests. The Null hypotheses were checked at the 0.05 alpha threshold via ANCOVA for retention scores and independent samples t-tests for structural comparison. All tests were conducted at the 0.05 significance level using SPSS Version 27.

RESULTS

Research Question 1. Table 2 shows that the groups were comparable at baseline (Experimental: M = 38.42, SD = 6.17; Control: M = 37.95, SD = 6.43; difference = 0.47). Post-instruction, the experimental group's mean rose to 71.83 (SD = 8.34), a gain of 33.41 marks, compared with the control group's rise to 54.27 (SD = 9.12), a gain of 16.32 marks a post-test difference of 17.56 marks favouring the experimental group.

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Table 2. Pre-test and Post-test Mean Retention Scores

Group	N	Pre-test M (SD)	Post-test M (SD)	Mean Gain
Experimental	60	38.42 (6.17)	71.83 (8.34)	33.41
Control	60	37.95 (6.43)	54.27 (9.12)	16.32

Hypothesis 1. ANCOVA results (Table 3) showed a statistically significant effect of instructional method on post-test retention after controlling for pre-test scores, $F(1, 117) = 47.31$, $p < .001$, partial $\eta^2 = .288$ a large effect, accounting for roughly 29% of variance in retention scores. H01 was rejected.

Table 3. ANCOVA Summary for Instructional Method on BRAT Post-test

Source	Df	F	P	Partial η^2
Pre-test (covariate)	1	85.47	< .001	.422
Instructional Method	1	47.31	< .001	.288
Error	117	—	—	—

Research Question 2. Within the experimental group, male students (M = 73.61, SD = 7.92) scored marginally higher than female students (M = 70.17, SD = 8.51), a difference of 3.44 marks; both subgroups scored well above the control group mean of 54.27.

Hypothesis 2. An independent samples t-test found no statistically significant gender difference, $t(58) = 1.61$, $p = .113$. H02 was not rejected.

Research Question 3. The experimental group's mean SMBIQ score (M = 63.47, SD = 7.81; 79.3% of maximum) considerably exceeded the control group's (M = 48.12, SD = 9.34; 60.2% of maximum), a gap of 15.35 points.

Hypothesis 3. An independent samples t-test confirmed this difference was statistically significant, $t(118) = 10.36$, $p < .001$. H03 was rejected.

Major Results/Interpretation*:* Hypothesis 1 (H01) asserted that no significant divergence in retention benchmarks existed between instructional methods. Inferential calculation using ANCOVA rejected this position, revealing that the experimental group achieved significantly superior long-term retention benchmarks compared to the control group, $F(1, 117) = 47.31$, $p < .001$, partial $\eta^2 = .288$.

Hypothesis 2 (H02) expected gender to function as a differentiator for academic retention within the treated cluster. Data analysis using an independent samples t-test failed to reject the null hypothesis, demonstrating that gender did not operate as a statistically meaningful moderator of the treatment advantage, $t(58) = 1.61$, $p = .113$.

Hypothesis 3 (H03) assumed no significant variance in self-reported motivational profiles between groups. An independent samples t-test successfully rejected this assumption, displaying a strong statistical advantage in active learning motivation for students within the immersive 3D experimental setting, $t(118) = 10.36$, $p < .001$.

Key Findings*:* (i) Students taught using 3D animated science narratives achieved significantly higher retention than those taught conventionally, with a large effect size; (ii) Gender did not significantly moderate this retention advantage; and (iii) The experimental group reported significantly higher motivation towards biology learning than the control group.

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DISCUSSION OF FINDINGS

The main finding indicates that immersive 3D animated narratives markedly increase biology concept retention over conventional procedures. Visual animation successfully lowers cognitive barriers by allowing students to observe complex biological interactions dynamically. This prevents the immediate decay of information commonly linked with abstract memorization (Sweller, 2020).

Crucially, the data confirms that this visual learning advantage functions independent of student gender. This finding counter historical studies that suggested technological approaches introduce systemic gender performance biases (Bamidele et al., 2021). Furthermore, the substantial rise in motivation metrics underscores the dual advantage of narrative media, which stimulates emotional interest alongside structural comprehension.

The large retention advantage for the 3D animated group aligns with the theoretical predictions of Cognitive Load Theory (Sweller et al., 2019) and the Cognitive Theory of Multimedia Learning (Mayer, 2020), and corroborates earlier findings. The effect size obtained here (partial $\eta^2 = .288$) is comparable to the large effect reported by Ogundele and Adeyemi (2022) in a study where learners taught the circulatory system via 3D animated narratives scored significantly higher on a delayed retention test than peers taught conventionally, and sits within the range synthesized by Hou et al. (2023) in their meta-analysis of animation-enhanced science instruction. The advantage likely reflects multiple mechanisms: 3D visualization externalized dynamic spatial processes that would otherwise demand heavy mental simulation, reducing intrinsic cognitive load (Ayres & Paas, 2021); narrative structure provided a coherent causal framework that scaffolded schema construction, consistent with Vygotsky's (1978) social constructivist account; and structured teacher facilitation kept engagement active rather than passive (Abubakar & Suleiman, 2024).

Jack and fellow researchers proved that digital tools like virtual labs, computer animations, and simulations greatly improve secondary school students' memory retention and academic achievement in chemistry (Jack, 2023a&b; Jack & Danladi, 2020; Jack & Muhammad, 2025a&b; Jack & Sheriff, 2020; Jack & Shidawa, 2025a&b). Jack and Shidawa, 2025b) found that virtual lab experiments help students remember chemistry facts much longer in Taraba State; Jack and Danladi (2020) showed that animated lessons make complex topics like chemical bonding easier to understand and recall; Jack and Sheriff (2020) reported higher test scores and better long-term memory when computers are used to teach chemistry; and Jack (2023) demonstrated that pairing computer simulations with team problem-solving helps students master difficult chemistry concepts. The research conducted by Jack and Muhammad (2025a&b) evaluates the effectiveness of a Digital Learning Environment (DLE)—which leverages visual, multi-media, and interactive elements such as animations. The primary findings across both studies focus on student achievement and metacognitive skills within science narratives (specifically secondary school chemistry. The integration of digital learning materials provides a strong framework for breaking down highly abstract chemistry concepts.

The non-significant gender difference is consistent with Aliyu and Bello (2023) and Ogundele and Adeyemi (2022), who similarly found no significant gender moderation of retention gains once access barriers and teacher facilitation were held constant. The marginally higher male mean may reflect residual spatial-processing advantages reported in some studies, but the absence of statistical significance suggests that well-facilitated 3D animated instruction is broadly equitable across gender in this context a positive signal for biology education in a zone where gender gaps in science achievement are a recognized concern.

The substantially higher motivation reported by the experimental group is consistent with self-determination theory (Ryan & Deci, 2020) and with prior findings linking 3D animated instruction to greater intrinsic motivation (Green & Jenkins, 2023; Sun et al., 2022; Nwosu & Eze, 2021). Some of this gain may reflect a novelty effect from introducing digital instruction in a zone where such resources are rare (Scheiter, 2021); however, the narrative framing of the animations embedding biological processes in relatable storylines plausibly activated the deeper emotional engagement that narrative-based science communication research associates with improved learning motivation (Dahlstrom, 2021; Negrete, 2022).

Implications to Science Education and Communication

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The results imply that science instruction can no longer rely purely on abstract verbal explanations. To remain impactful, educational institutions must actively transition toward visual instructional media. Practically, this transition requires secondary classrooms to be equipped with foundational technological tools, such as steady power sources or localized solar panels and digital projection systems, alongside updated training models for pre-service science educators.

Pedagogically, the results suggest that biology teachers particularly those handling high-interactivity topics such as cell division, circulation, and genetics can achieve meaningfully better learning outcomes by supplementing or replacing chalk-and-talk delivery with well-facilitated 3D animated narratives, provided the animation is paired with structured pre- and post-viewing activities rather than passive viewing alone.

For curriculum and policy, the results offer Taraba State's education authorities and the NERDC locally grounded evidence to justify investment in digital instructional resources for underserved zones, rather than relying solely on findings from better-resourced South-Western Nigerian or international settings. Because the retention advantage held regardless of gender, the findings also suggest that scaling 3D animated instruction is unlikely to widen existing gender gaps in science achievement, and may help narrow them by making abstract content more visually accessible to students who report higher anxiety toward abstract science tasks.

Theoretically, the study reinforces the applicability of Cognitive Load Theory and the Cognitive Theory of Multimedia Learning to under-researched rural Nigerian classrooms, while extending the evidence base for narrative-structured (rather than purely expository) animated instruction. The motivational findings further suggest that 3D animated science narratives may serve a dual role improving immediate retention while also cultivating the sustained engagement that underlies long-term STEM participation, an outcome of strategic importance for regions seeking to build local scientific and technical capacity.

CONCLUSION

Immersive 3D animated science narrative instruction was significantly more effective than conventional chalk-and-talk instruction in promoting biology concept retention among SS 2 students in Zing Education Zone, Taraba State. This advantage held across gender and was accompanied by a substantial increase in student motivation towards biology learning. The findings extend theoretical predictions from Cognitive Load Theory, the Cognitive Theory of Multimedia Learning, and Social Constructivism, and replicate prior empirical patterns from South-Western Nigeria and international contexts within a North-Eastern Nigerian setting that has received limited prior research attention. These benefits at scale, however, depends on addressing persistent infrastructural constraints, including limited ICT equipment, unreliable electricity, and the need for sustained teacher professional development.

In conclusion, instructional delivery supported by immersive 3D animated science narratives is exceptionally effective at enhancing biology concept retention and raising classroom motivation among Senior Secondary Two students. This educational benefit remains robust across both male and female groups, making it a reliable alternative to traditional chalk-and-talk instruction.

RECOMMENDATIONS

Based on the conclusion, the following recommendations are made:

1. School administrators should organize regular capacity-building workshops to train secondary school biology teachers in using interactive digital media. Biology teachers should also integrate 3D animated science narratives into instruction for high-interactivity topics such as cell division, circulation, and genetics.

2. Government bodies and community partners should prioritize funding for small-scale solar power solutions to reliably support digital tools in rural schools. The Taraba State Secondary Education Board and the Universal Basic Education Commission should also prioritize functional ICT infrastructure

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projectors, computers, and reliable electricity in public secondary schools as a precondition for scaling digital instruction.

3. The Taraba State Ministry of Education should systematically integrate curated 3D instructional media resources into public secondary science curricula. The Ministry of Education and the National Teachers' Institute should design structured professional development programmes to build teachers' technical and pedagogical capacity for facilitating 3D animated science instruction.

4. The NERDC, with universities and technology developers, should invest in locally produced, curriculum-aligned 3D biology animations, including narration in local languages to reduce second-language processing demands.

5. Pre-service biology teacher education programmes should incorporate instruction in the design principles of multimedia learning to prepare future teachers for technology-enhanced instruction.

Limitations & Future Research

This study faced geographical constraints, as the sample was restricted to 120 secondary subjects inside a single education zone in Taraba State. Additionally, inconsistent regional power grids created technical hurdles that required careful charging management for electronic projection equipment. Lastly, the evaluation protocol was bounded to medium-term retention metrics over a few weeks, leaving long-term impacts over multiple academic cycles unexamined.

Future studies should expand this experimental model across diverse geopolitical zones in Nigeria to confirm the generalizability of these findings. Researchers should also measure long-term concept retention across full multi-year academic profiles and evaluate the cost-effectiveness of deploying localized mobile app alternatives.

Contribution to Knowledge

This research adds empirical data to West African educational literature by showing that 3D science narratives can improve retention in resource-constrained schools. It also highlights how immersive storytelling can bridge gender-based achievement gaps in secondary school STEM fields.

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