Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - *E*- ISSN: 3156-5492 | *P*- ISSN: 3156-5514

Effect of Virtual Laboratory-Supplemented Instruction on Academic Achievement and Attitudes Toward Cell Division among Secondary School Students

[1]Kehinde Olumuyiwa ADESINA
khennygbade@gmail.com | +2347030670641
https://orcid.org/0009-0000-6956-6182

[2]Oluwatosin Boluwatife ADESINA
bolutifetosin@gmail.com | +2348169884140
https://orcid.org/0009-0006-8019-7422

[3]Temitope Dorcas BELLO
temitopeomowunmi631@gmail.com | +2348105389752
https://orcid.org/0009-0003-1797-9243

[1]Lagos State Teaching Service Commission
[2]Lagos State University

DOI : https://doi.org/10.5281/zenodo.22904735

Abstract

This study investigated the effect of Virtual Laboratory-supplemented instruction on secondary school students' achievement and attitudes toward Cell Division in Biology. A quasi-experimental, pre-test post-test non-equivalent control-group design was adopted. The sample comprised 194 students from two intact classes in a public secondary school, with 95 assigned to the Virtual Laboratory-supplemented group and 99 to the Lecture-only group. The intervention supplemented teacher-led instruction with three virtual laboratory sessions covering general cell structure, mitosis, and meiosis. Achievement data were analysed using analysis of covariance (ANCOVA), with pre-test achievement as the covariate, alongside an HC3 heteroskedasticity-robust sensitivity analysis. Attitude change was examined using Welch's independent-samples t-test and the Mann–Whitney U test. The Virtual Laboratory-supplemented group had a higher adjusted post-test achievement mean (62.74) than the Lecture-only group (40.92), representing an adjusted mean difference of 21.82 percentage points. The instructional-group effect was statistically significant, $F(1, 191) = 124.213$, $p < .001$, *partial* $\eta^2 = .394$. *The HC3 analysis confirmed the robustness of this effect,* $t = 10.843$, $p < .001$, *95% CI [17.874, 25.761]. Attitude change was also significantly greater in the Virtual Laboratory-supplemented group, Welch's* $t(102.467) = 13.420$, $p < .001$, $r = .68$; *the Mann–Whitney U test yielded a consistent result,* $U = 1{,}225.50$, $z = -9.468$, $p < .001$. *The findings suggest that structured virtual laboratory activities can enhance Biology achievement and attitudes toward Cell Division within the study context.*

Keywords: Virtual Laboratory; Biology Education; Academic Achievement; Attitudes; Cell Division

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

1.0 Introduction

Cell Division is a foundational topic in secondary school Biology because it underpins understanding of growth, development, tissue repair, reproduction, inheritance, and continuity of life. However, learning the topic requires students to understand microscopic processes involving chromosome duplication, chromosome movement, spindle formation, and cytokinesis that cannot be directly observed through ordinary classroom observation. Consequently, teachers often rely on diagrams, static illustrations, explanations, and models. Beyond learning biological terminology, students must develop coherent mental representations of structures, relationships, and changes across successive stages of the cell cycle. Such learning can be challenging because students' prior conceptions may persist when instruction provides insufficient opportunities to examine and reconstruct them (Aleknavičiūtė et al., 2023). Conceptual Change Theory similarly proposes that meaningful scientific learning involves reorganising existing conceptions when learners encounter evidence that enables them to evaluate and reconstruct previous explanations (Posner et al., 1982; Treagust & Duit, 2008).

Conventional teacher-led instruction remains essential in Biology because explanation, questioning, scaffolding, and discussion support students' interpretation of scientific concepts. However, it may provide limited opportunities to manipulate and repeatedly examine dynamic representations of processes that cannot be directly observed. This limitation has contributed to interest in virtual laboratories, which enable learners to explore scientific phenomena through interactive simulations, manipulate representations, repeat activities, observe changes, and receive feedback. Reviews have reported cognitive, practical, and affective benefits of virtual laboratories in Biology education, while emphasising that their effectiveness depends substantially on teachers' instructional design and pedagogical integration (Byukusenge et al., 2022; Wörner et al., 2022).

Evidence from Nigeria also indicates potential achievement benefits. Aondofa and Ene (2024) reported higher Biology achievement among senior secondary students taught using a virtual laboratory application in Makurdi, Benue State. Ubom et al. (2025) similarly found significantly higher achievement among secondary school Biology students exposed to virtual laboratory instruction in Kwali Area Council, Abuja, while Lasisi et al. (2025) reported a significant achievement advantage for a Human-Centred Design-based virtual laboratory among senior secondary students in Ogun State. Goji (2026) also reported positive associations between virtual laboratory utilisation and academic performance among senior secondary Biology students in Adamawa State. International evidence is broadly consistent: Santos and Prudente (2022) found a medium overall effect of virtual laboratories on science achievement, and Byukusenge et al. (2022) identified benefits across cognitive, practical, and affective domains in Biology education.

Despite this evidence, important gaps remain. First, existing studies have frequently examined virtual laboratory instruction as a broad instructional approach rather than its use as a supplement to conventional teacher-led instruction. This distinction is important because virtual laboratories need not replace teacher explanation, questioning, and scaffolding; rather, they can provide additional opportunities to explore phenomena that are difficult to observe directly. Evidence synthesising real and virtual laboratory experiences suggests that the two approaches are complementary and that effectiveness depends on how teachers integrate virtual experiences into the wider learning process (Wörner et al., 2022).

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

Second, much of the evidence concerns science or Biology generally and not specific conceptually demanding topics. Cell Division is particularly relevant because understanding mitosis and meiosis requires students to coordinate structures, sequences, spatial relationships, and changes that static diagrams may not adequately represent. Research on visual literacy in molecular and cellular Biology indicates that students may know biological terminology while experiencing difficulty interpreting the visual representations used to communicate biological processes (Newman et al., 2023; Uminski et al., 2025). Scaffolding students' interpretation of scientific representations is therefore important in Biology learning (Arneson & Offerdahl, 2018; Offerdahl et al., 2017). Virtual environments may provide additional opportunities to engage with dynamic representations, but their value depends on how these representations are embedded within instruction.

Third, although cognitive outcomes of virtual laboratory use have received considerable attention, affective outcomes are less consistently established. Reviews have identified positive attitudes and other affective benefits (Byukusenge et al., 2022; Lailiyah et al., 2024), but these outcomes should not be assumed to occur automatically. Zhang et al. (2021), for example, found stronger evidence for conceptual learning than motivational outcomes in virtual physiology laboratories. In Nigeria, Kareem (2022) examined students' attitudes toward virtual laboratories in Biology in Lagos State, providing evidence of learners' perceptions of the technology. However, general perceptions of virtual laboratories do not necessarily indicate whether a specific virtual laboratory-supported learning experience changes students' attitudes toward the Biology topic being taught.

These gaps indicate a need for research examining virtual laboratories as a supplement to conventional teacher-led instruction, particularly for conceptually demanding Biology topics and across both cognitive and affective outcomes. The present study therefore investigated the effect of Virtual Laboratory-supplemented instruction on secondary school students' achievement and attitudes toward Cell Division in Biology. The intervention supplemented conventional classroom teaching with three virtual laboratory sessions addressing general cell structure, mitosis, and meiosis. By examining both achievement and topic-specific attitudes, the study provides evidence on whether structured engagement with dynamic representations alongside conventional instruction is associated with improved learning outcomes.

The study was guided by two research questions and two null hypothesis tested at 0.05 level of significance

Research Questions

1. Does Virtual Laboratory-supplemented instruction result in differences in students' academic achievement in Cell Division compared with Lecture-only instruction, after controlling for pre-test achievement?
2. Does Virtual Laboratory-supplemented instruction result in differences in students' attitudes toward Cell Division compared with Lecture-only instruction?

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

Research Hypotheses

H₀1: There is no significant difference in the academic achievement of students taught Cell Division using Virtual Laboratory-supplemented instruction and those taught using Lecture-only instruction, after controlling for pre-test achievement.

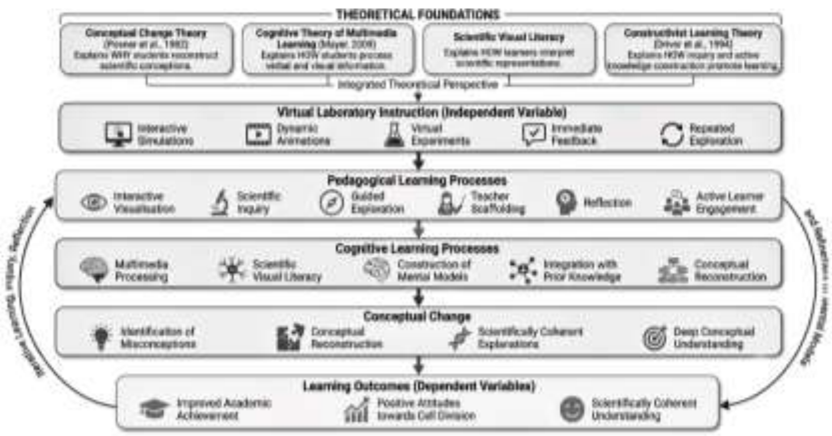
H₀2: There is no significant difference in the attitudes toward Cell Division of students taught using Virtual Laboratory-supplemented instruction and those taught using Lecture-only instruction.

2.0 Literature Review

2.1 Integrated Theoretical Framework

Figure 1.

Integrated Conceptual Framework of the Study.



Conceptual Change Theory is the main orientation, because it treats learning as a kind of process where current conceptions might be pushed , rearranged, or swapped out for explanations that are more scientifically coherent (Posner et al., 1982; Treagust & Duit, 2008). This is especially important for Biology, since students can show stubborn conceptions about chromosome behaviour, DNA replication, mitosis, and meiosis that do not always move easily with typical lessons (Aleknavičiūtė et al., 2023). In this view, good teaching should let learners examine phenomena, face contradictions in what they already believe, and then rebuild their understanding in a more accurate direction.

Conceptual Theory of Multimedia Learning CTML supports this by explaining what is going on in learners minds when information is presented in more than one mode. Mayer (2009) argues that meaningful multimedia learning depends on selecting and organising relevant verbal and visual pieces, then weaving them together with prior knowledge. This matters a lot for Cell Division because many key events are micro-scale, fast, and generally not visible to the naked eye. Virtual laboratory settings can offer visual and interactive representations, so students can look at changes in cellular structures and processes , while also connecting those observations to explanatory input.

Scientific Visual Literacy sits as an extra layer, because it is about how learners interpret and reason with the visual representations scientists use to communicate knowledge. In Biology, a lot of

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

processes that students cannot directly watch are instead shown via diagrams, models, animations, and other visual forms (Arneson & Offerdahl, 2018; Offerdahl et al., 2017). So students need more than just seeing visuals; they need to be able to decode the depicted structures, connections, orders, and meanings. Studies on molecular and cellular representations suggest that students may seem comfortable with biological terms, but still keep mistaken conceptions, especially once they have to interpret the scientific representations themselves (Newman et al., 2023; Uminski et al., 2025). In that sense, Scientific Visual Literacy links multimedia processing with the growth of more scientifically coherent conceptual models.

Constructivist Learning Theory is the base for the pedagogical and social learning. From a constructivist point of view, learners actively construct understanding by relating new experiences to their existing ideas, while classroom interaction, questioning, talk, and teacher scaffolding also help students refine what they think about science (Driver et al., 1994). Therefore, inside a virtual laboratory setting, students can engage with representations of biological processes, interpret what they observe, try out their emerging explanations, and then get support that guides them toward accepted scientific concepts.

Overall, these four perspectives work as complementary rather than competing framework. The integrated framework places the virtual laboratory not as a magically effective tool on its own, but as an instructional environment that has its real value depending on the kinds of learning opportunities that are actually created through its use.

2.2 Conceptual and Empirical Review

Learning Cell Division: Conceptual and Representational Difficulties

Cell Division is fundamental to Biology because understanding mitosis and meiosis supports learning about growth, reproduction, inheritance, and continuity of life. However, these processes occur largely at the microscopic level and require students to coordinate chromosomes, DNA replication, spindle formation, and sequential cellular changes. Consequently, learning involves more than memorising stage names; students must construct coherent mental representations of dynamic structures and relationships.

Conceptual Change Theory provides a useful perspective on this challenge. Posner et al. (1982) proposed that meaningful learning involves confronting existing conceptions with new explanatory frameworks, while Treagust and Duit (2008) highlighted the complexity of reorganising students' existing scientific conceptions. Evidence that prior conceptions can persist despite instruction further demonstrates the difficulty of conceptual change (Aleknavičiūtė et al., 2023). The challenge is also representational because students must interpret diagrams, animations, and models of processes they cannot directly observe. Visual literacy and appropriate scaffolding are therefore important in Biology learning (Arneson & Offerdahl, 2018; Offerdahl et al., 2017), while recent research has identified difficulties in interpreting molecular and chromosomal representations (Newman et al., 2023; Uminski et al., 2025).

These challenges provide a rationale for instructional resources that can complement conventional teaching with dynamic and interactive representations. In the present study, the virtual laboratory was therefore positioned as a supplement to teacher-led instruction rather than a replacement for it.

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

Virtual Laboratories in Biology Education

Virtual laboratories provide simulated environments in which learners can interact with representations of scientific phenomena, manipulate variables, repeat procedures, and observe processes that may be difficult to investigate directly or practically. However, virtual laboratories are not a uniform instructional intervention; they differ in interactivity, fidelity, learner control, feedback, and pedagogical integration. Their effectiveness therefore depends not simply on technology use but on how activities are designed and incorporated into instruction.

Byukusenge et al. (2022) reported cognitive, practical, and affective benefits of virtual laboratories in Biology while emphasising implementation factors. Similarly, Wörner et al. (2022) argued that virtual and real laboratory experiences can serve complementary rather than competing purposes. This supports a supplementary model in which virtual activities extend opportunities for exploration while teachers retain responsibility for explanation, questioning, scaffolding, and interpretation. Evidence from a Human-Centred Design-based virtual laboratory also suggests that instructional responsiveness and design can influence learning outcomes (Lasisi et al., 2025).

Virtual Laboratories and Academic Achievement

Achievement is the most extensively investigated outcome of virtual laboratory use, with evidence generally favouring virtual laboratory-supported learning, although effects vary across contexts and designs. A meta-analysis by Santos and Prudente (2022) reported a medium overall effect on science achievement, while Byukusenge et al. (2022) identified positive cognitive outcomes in Biology. Wörner et al. (2022), however, emphasised that the affordances of virtual and physical laboratory experiences differ, reinforcing the importance of instructional context rather than assuming a universal technology effect.

Recent Nigerian studies provide further contextual evidence. Aondofa and Ene (2024), Ubom et al. (2025), Lasisi et al. (2025), and Goji (2026) each reported positive achievement outcomes associated with virtual laboratory use among secondary school Biology students in Benue, Abuja, Ogun, and Adamawa States, respectively. Although the convergence of these findings supports the potential of virtual laboratories in Nigerian Biology education, differences in samples, settings, designs, and instructional approaches limit direct comparison and do not establish a universal effect.

Importantly, evidence of general Biology achievement gains does not establish whether virtual laboratories provide particular value for topics involving dynamic microscopic processes. Cell Division is therefore a relevant context for examining whether interactive representations add value when incorporated into conventional teacher-led instruction.

Virtual Laboratories and Students' Attitudes

Achievement gains do not necessarily imply corresponding changes in students' attitudes. Affective responses may depend on students' perceptions of the learning environment, task design, perceived difficulty, participation, and engagement with content. Byukusenge et al. (2022) identified affective benefits associated with virtual laboratories, while Lailiyah et al. (2024) reported positive affective outcomes in a systematic review. However, evidence for affective effects is less consistent than evidence for cognitive outcomes. Zhang et al. (2021), for example,

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

found stronger evidence for learning outcomes than motivational outcomes in virtual physiology laboratories, suggesting that positive attitudes cannot be assumed to result automatically from technology use.

Within Nigeria, Kareem (2022) examined students' attitudes toward virtual laboratories in Biology in Lagos State. Such evidence is useful for understanding learners' perceptions of virtual laboratory technology, but perceptions of the technology do not necessarily demonstrate changes in attitudes toward a specific Biology topic following participation in a virtual laboratory-supported learning experience. Examining topic-specific attitude change can therefore provide a more precise assessment of the affective contribution of the intervention.

2.3 Synthesis and Research Gap

The literature establishes three related points. First, Cell Division presents substantial conceptual and representational challenges because students must interpret microscopic structures and dynamic sequences (Aleknavičiūtė et al., 2023; Newman et al., 2023; Uminski et al., 2025). Second, virtual laboratories can support Biology and science learning, particularly achievement, but their effectiveness depends on instructional design and integration (Byukusenge et al., 2022; Santos & Prudente, 2022; Wörner et al., 2022). Third, affective outcomes are promising but less consistent and may depend more strongly on implementation conditions (Lailiyah et al., 2024; Zhang et al., 2021).

Nigerian evidence further supports the relevance of virtual laboratories for Biology achievement (Aondofa & Ene, 2024; Ubom et al., 2025; Lasisi et al., 2025; Goji, 2026), but existing studies differ in context and instructional design. Less is established about the added value of integrating virtual laboratory activities into conventional teacher-led instruction for a specific conceptually demanding topic, particularly when both achievement and topic-specific attitudes are examined. Similarly, attitude research has more often focused on perceptions of virtual laboratory technology than on changes in attitudes toward the Biology content being learned.

The present study addresses these gaps by comparing students receiving conventional Biology instruction with those receiving the same instruction supplemented by structured virtual laboratory activities focused on Cell Division. It therefore examines the supplementary contribution of virtual laboratory experiences to both cognitive and affective outcomes rather than treating virtual laboratory use as a standalone instructional replacement. This focus provides evidence relevant to the practical integration of virtual laboratories into ordinary secondary Biology teaching.

3.0 Methodology

3.1 Research Design and Participants

The study used a quasi-experimental pre-test–post-test design with two groups: an experimental group (virtual lab supplement) and a lecture-only control group. Since participants came from existing classes, we couldn't randomly assign individuals, hence the quasi-experimental approach. Both groups covered the same Cell Division content, but the experimental group got additional virtual lab sessions. Pretest scores helped establish baseline equivalence and served as a statistical control in the achievement analysis.

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

The sample included 194 secondary-school Biology students: 95 in the virtual lab group and 99 in the control group. Both were taught the same core material and assessed with the same measures, allowing us to isolate whether adding virtual activities made a difference.

3.2 Intervention and Research Instruments

The virtual component comprised three supplemental sessions (about 50 minutes total), covering: (1) general cell structure, (2) mitosis, and (3) meiosis. These weren't replacements for teacher-led instruction, they supplemented it. Sessions were woven into the regular timetable (partly during the usual break period) to minimise disruption.

The study used two tools. First, a researcher-developed Cell Biology Performance Test (CBPT), administered as both pretest and post-test to capture learning gains. Second, a 10-item Student Attitude scale focused specifically on students' attitude toward Cell Division classes (drawn from a broader questionnaire). Higher scores reflected more favourable attitudes.

3.3 Instrument Validity and Reliability

Both instruments were reviewed for content alignment and suitability. For the 10-item attitude scale, internal consistency was checked using Cronbach's alpha via SPSS. Importantly, that alpha applies only to these 10 specific items, not to the wider questionnaire or its other subscales.

3.4 Procedure for Data Collection

Before instruction began, both groups completed the CBPT and attitude measure as pretests. Both groups received the conventional teachers-led cell biology instruction using the same lesson plan. The experimental group then received additional three virtual lab sessions. After the intervention, the same achievement test and attitude scale were administered as post-tests. All responses were coded using 5-likert scale where Strongly agree (SA) is scored 5 points, Agree (A) was scored 4 points, Undecided (U) was scored 3 points, Disagree (D) was scored 2 points, and Strongly disagree (SD) was scored 2 point for analysis. This scoring was reversed for negatively structured questions.

3.5 Data Analysis and ethics

For achievement, the study used an ANCOVA with post-test scores as the dependent variable, instructional condition as the independent variable, and pretest achievement as the covariate while also checking the homogeneity-of-regression-slopes assumption. The study set α at .05, reported partial η^2 for effect size, and because group variances were unequal, an HC3 heteroskedasticity-robust sensitivity was checked as well.

For attitudes, change scores were calculated (post minus pre). Given non-normality and unequal variances, comparison of groups was done using Welch's t-test, with a Mann–Whitney U test as a non-parametric robustness check, reporting mean differences, 95% CIs, and r for effect size.

All procedures followed standard ethical protocols: responses were confidential, data were anonymised with coded identifiers, and we scheduled everything to keep regular school activities running smoothly.

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

4. Results

4.1 Descriptive Statistics

Table 1

Observed/Descriptive Achievement data

	groups	N	Pre-test *M*	Pre-test *SD*	Post-test *M*	Post-test *SD*	Change *M*	Change *SD*
Achievement								
	Virtual Lab-supplemented	95	24.29	12.14	62.75	15.85	38.46	3.71
	Lecture-only	99	27.95	12.68	40.91	10.65	12.96	-2.03
	Total	194	26.16	12.52	51.60	17.31	25.44	4.79
Attitude								
	Virtual Lab-supplemented	95	2.329	1.06	4.06	0.41	1.732	1.21
	Lecture-only	99	2.339	1.03	2.36	1.05	0.025	0.26
	Total	194					0.86	1.22

The analysis comprised 194 students, including 95 in the Virtual Laboratory-supplemented group and 99 in the Lecture-only group. All participants had complete pre- and post-intervention data. Descriptive statistics for achievement and attitude outcomes are presented in Tables 1.

4.2 Academic Achievement

Research Question 1 examined whether Virtual Laboratory-supplemented instruction was associated with differences in students' achievement in Cell Division. An ANCOVA was conducted with post-test achievement percentage score as the dependent variable, instructional method as the fixed factor, and pre-test achievement as the covariate.

Table 2: *Analysis of Covariance of Post-test Achievement |Scores by Treatment group*

Source	**df**	**F**	***p***	**Partial η²**
Pre-test achievement	1,191	.005	< .946	.001
Treatment group	1,191	124.213	< .001	.394
Error	191			
Total	194			

Note. The dependent variable was post-test achievement scores, with pre-test achievement score entered as covariate. Treatment group comprised the virtual laboratory-supplemented group (n = 95) and lecture-only group (n = 99)

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

As shown in Table 2, pre-test achievement was not a significant predictor of post-test achievement, $F(1, 191) = .005$, $p = < .946$, partial $\eta^2 = .001$. In contrast, treatment group had a statistically significant effect on post-test achievement, $F(1, 191) = 124.213$, $p < .001$, partial $\eta^2 = .394$. Thus, after controlling for pre-test achievement, students who received the Virtual Laboratory-supplemented instruction performed significantly better on the post-test than those who received lecture-only instruction. The partial η^2 of .394 indicates a large treatment effect.

Table 3

Effect	**Robust estimate**	***t***	***p***	**95% CI**
Pre-test achievement	-0.072	-0.072	.943	[-0.159, 0.148]
Treatment group	*21.82*	10.843	< .001	[17.874, 25.761]

HC3-Roburst Analysis of Covariate for the effect of Treatment on Post-test Achievement Scores

Note. HC3 = heteroskedasticity-consistent standard errors. The treatment effect is expressed as virtual Laboratory-supplemented instruction relative to Lecture-only instruction.

The HC3-robust analysis was conducted to assess whether the ANCOVA findings remained reliable under heteroscedasticity-robust standard errors. As shown in Table 3, the pre-test achievement effect was not statistically significant, $t = -0.072$, $p = .943$, 95% CI [−0.159, 0.148]. In contrast, the treatment-group effect remained statistically significant, $t = -10.843$, $p < .001$, 95% CI [−25.761, −17.874]. The robust analysis therefore supports the conclusion from the conventional ANCOVA that treatment group was significantly associated with post-test achievement, indicating that the primary finding was not dependent on the assumption of homoscedasticity.

4.3 Attitudes Toward Cell Division

Research Question 2 examined whether Virtual Laboratory-supplemented instruction was associated with differences in students' attitudes toward Cell Division.

Table 4:

Test of significance of Attitude Change by Treatment Group

Source	***n***	**Mean change**	**SD**	**Test statistic**	***df***	***p***	***Mean diff***	***95% CI***
Virtual Laboratory-supplemented	95	1.732	1.212	–	–	–	–	–
Lecture-only	99	0.025	0.263	–	–	–	–	–
Between-group comparison				13.420		< .001	1.706	[1.454, 1.959]

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

Table 4 shows that attitude increased substantially among students who received the Virtual Laboratory-supplemented instruction (M = 1.732, SD = 1.212), whereas virtually no change was observed among students in the lecture-only group (M = 0.025, SD = 0.263). The difference in mean attitude change between the groups was statistically significant, Welch's t(102.467) = 13.420, p < .001, with a mean difference of 1.706 points (95% CI [1.454, 1.959]). This indicates that the Virtual Laboratory intervention produced a significantly greater improvement in students' attitudes than lecture-only instruction.

Table 5

The non-Robustness check for Attitude change Using the Mann-Whitney U Test parametric robustness check produced the same substantive conclusion. The Mann–Whitney U test showed a statistically significant difference in attitude change between the treatment groups, U = 1,225.500, z = −9.468, p < .001, with a large effect size (r = .68). Thus, the significant improvement in attitude associated with the Virtual Laboratory-supplemented instruction was robust to the use of a distribution-free test.

Effect	*U*	*z*	*p*	Effect size (r)
Treatment group	1,225.500	-9.468	< .001	.68

5. Discussion

5.1 Principal Findings and Comparison with Previous Research

on both achievement and attitudes toward Cell Division. This aligns with recent Nigerian evidence (Aondofa & Ene, 2024; Ubom et al., 2025; Lasisi et al., 2025; Goji, 2026), reinforcing the contextual promise of these tools. However, given the differences in samples, topics, and designs, we view these as converging lines of evidence rather than proof of a uniform effect.

The achievement effect here exceeded the medium overall effect reported by Santos and Prudente (2022). This is not interpreted as evidence that virtual labs universally produce larger effects; rather, the topic itself Cell Division may explain it. Since the study supplemented rather than replaced teacher-led instruction, students gained additional chances to visualise dynamic, microscopic processes that static diagrams struggle to convey. This is compatible with Conceptual Change Theory (Posner et al., 1982; Treagust & Duit, 2008) and Multimedia Learning Theory (Mayer, 2009), both of which emphasise restructuring conceptions through integrating visual and verbal information. It also resonates with evidence on visual literacy challenges (Newman et al., 2023; Uminski et al., 2025). Thus, the value likely lies in the representational and interactive affordances, not the technology per se, echoing Wörner et al. (2022) on complementary roles and Lasisi et al. (2025) on learner-centred design.

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

Evidence from the positive attitudinal change is consistent with Byukusenge et al. (2022) and Lailiyah et al. (2024). Crucially, the study measured attitudes toward cell division, not just toward the virtual tool. This is a distinction from work of Kareem (2022), which focused on perceptions of usability. Zhang et al. (2021), however, caution that affective gains depend heavily on how virtual labs are integrated, therefore, the study's structured supplementary approach likely played a role in this observed change in attitude.

The dual cognitive-affective improvement are promising. However, the study didn't directly measure conceptual change, engagement, or cognitive load, so the study can't claim those as mediators. The study's contribution shift away from just another study confirming that virtual lab works to provide evidence that a supplementary model, added to regular teaching, can meaningfully boost outcomes for a demanding topic. This supports integration, not replacement.

5.2 Limitations and Interpretation

The study has several limitations. First, using intact classes rather than random assignment means we can't entirely rule out unmeasured pre-existing differences, so causal claims need caution. Second, the findings come from one school and one Biology topic; so, broader generalisation requires replication across contexts. Third, our instruments were researcher-developed, validated but not definitive and the attitude results apply specifically to the 10-item scale. Fourth, attitude change scores showed notable non-normality and unequal variances, though the Welch's t-test and Mann-Whitney U analysis converged robustly. Finally, the study did not track engagement, motivation, or cognitive processing directly, leaving the precise mechanisms behind these differences open for future investigation.

5.3 Conclusion

Two key findings stand out. First, on achievement, the virtual lab group substantially outperformed the control group with an adjusted mean difference of 21.82 percentage points, with a significant effect, $F(1, 191) = 124.213$, $p < .001$, partial \eta^2 = .394. Second, for attitudes, the virtual lab group showed a significantly greater positive shift toward Cell Division (Welch's $t(102.467) = 13.420$, $p < .001$; Mann–Whitney $U = 1,225.50$, $z = -9.468$, $p < .001$, $r = .68$), with both parametric and non-parametric tests converging.

The study's main contribution is not just another confirmation that virtual labs work, rather, it provide Nigerian evidence that adding virtual experiences as a supplement to teacher-led instruction can meaningfully enhance both achievement and topic-specific attitudes for a conceptually demanding topic like Cell Division. This positions the virtual lab as a pedagogical complement not a replacement for teachers or conventional labs while also it also extends previous local work by examining cognitive and affective outcomes together.

Theoretically, these improvements fit the idea that interactive visuals help learners engage with dynamic microscopic processes that static diagrams struggle to convey. However, the study did not directly measure conceptual change, engagement, or cognitive load, so these explanations remain plausible rather than empirically confirmed.

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - E- ISSN: 3156-5492 | P- ISSN: 3156-5514

The study was a single-school study with intact, non-randomised groups. While it statistically controlled for pretest differences, we can't rule out all pre-existing disparities. So, we interpret these as strong associations within this specific context, not universal causal proof. Overall, well-integrated virtual labs show genuine promise as supplementary tools for tackling difficult Biology concepts, provided they're deliberately connected to teacher explanation and curriculum goals.

5.4 Recommendations for Future Research

1. Future studies should replicate this work across more topics, schools, and populations, using stronger randomisation or quasi-experimental designs to strengthen causal claims.
2. Researchers should also investigate how virtual labs work, measuring engagement, cognitive load, motivation, and conceptual understanding and track whether gains persist over time.
3. Comparative work examining physical labs, blended models, and different levels of teacher scaffolding would help clarify the optimal conditions and learner profiles for virtual lab effectiveness.

References

Aondofa, A. B., & Ene, E. J. (2024). Effect of virtual laboratory application in senior secondary school students' achievement in Biology in Makurdi LGA, Benue State. *International Journal of Academic Multidisciplinary Research, 8*(1), 105–114.

Aleknavičiūtė, V., Lehtinen, E., & Södervik, I. (2023). Thirty years of conceptual change research in biology: A review and meta-analysis of intervention studies. *Educational Research Review, 41*, Article 100556. https://doi.org/10.1016/j.edurev.2023.100556

Arneson, J. B., & Offerdahl, E. G. (2018). Visual literacy in Bloom: Using Bloom's taxonomy to support visual learning skills. *CBE—Life Sciences Education, 17*(1), Article ar7. https://doi.org/10.1187/cbe.17-08-0178

Byukusenge, C., Nsanganwimana, F., & Tarmo, A. P. (2022). Effectiveness of virtual laboratories in teaching and learning biology: A review of literature. *International Journal of Learning, Teaching and Educational Research, 21*(6), 1–17. https://doi.org/10.26803/ijlter.21.6.1

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5–12. https://doi.org/10.3102/0013189X023007005

Goji, M. (2026). Assessment of the availability and utilization of virtual laboratory on academic performance of senior secondary school Biology students in Adamawa State, Nigeria. *International Journal of Education and Evaluation, 12*(2), 273–281. https://doi.org/10.56201/ijee.v12.no.2.2026.pg273.281

Kareem, A. A. (2022). Students' attitudes toward virtual laboratory in teaching biology in Lagos State. *Journal of Curriculum and Instruction, 14*(1), 39–47.

Lailiyah, N. W., Widarti, H. R., Munzil, & Surif, J. (2024). Research trends of virtual laboratory in science learning to improve affective domain: A systematic literature review. *Jurnal Pendidikan Sains Indonesia, 12*(4), 915–934. https://doi.org/10.24815/jpsi.v12i4.40091

Lasisi, O. O., Omoniyi, T., Olurinola, O. D., Hassan, O., & Aremu, J. O. (2025). Effect of Human-Centred Design (HCD)-based virtual laboratory on senior secondary school students' academic achievement in Biology. *Journal of Education in Black Sea Region, 10*(2), 73–83. https://doi.org/10.31578/jebs.v10i2.338

Mayer, R. E. (2009). Multimedia learning (2nd ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511811678

Newman, D. L., Spector, H., Neuenschwander, A., Miller, A. J., Trumpore, L., & Wright, L. K. (2023). Visual literacy of molecular biology revealed through a card-sorting task. *Journal of Microbiology & Biology Education, 24*(1), Article e00198-22. https://doi.org/10.1128/jmbe.00198-22

Offerdahl, E. G., Arneson, J. B., & Byrne, N. (2017). Lighten the load: Scaffolding visual literacy in biochemistry and molecular biology. *CBE—Life Sciences Education, 16*(1), Article es1. https://doi.org/10.1187/cbe.16-06-0193

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227. https://doi.org/10.1002/sce.3730660207

Santos, M. L., & Prudente, M. (2022). Effectiveness of virtual laboratories in science education: A meta-analysis. *International Journal of Information and Education Technology, 12(*2), 150–156. https://doi.org/10.18178/ijiet.2022.12.2.1598

Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*(2), 297–328. https://doi.org/10.1007/s11422-008-9090-4

Ubom, A. E. B., Apochi, M. A., & Akanmu, F. O. (2025). Effect of virtual laboratory instruction on secondary school Biology students' achievement in Kwali Area Council, Abuja, Nigeria. *American Journal of Language, Literacy and Learning in STEM Education, 3*(4), 61–70.

Uminski, C., Newman, D. L., & Wright, L. K. (2025). Probing visual literacy skills reveals unexpected student conceptions of chromosomes. *CBE—Life Sciences Education, 24*(1), Article ar17. https://doi.org/10.1187/cbe.24-07-0176

Wörner, S., Kuhn, J., & Scheiter, K. (2022). The best of two worlds: A systematic review on combining real and virtual experiments in science education. *Review of Educational Research, 92*(6), 911–952. https://doi.org/10.3102/00346543221079417

Wright, L. K., Cortez, P., Franzen, M. A., & Newman, D. L. (2022). Teaching meiosis with the DNA triangle framework: A classroom activity that changes how students think about chromosomes. *Biochemistry and Molecular Biology Education, 50*(1), 44–54. https://doi.org/10.1002/bmb.21583

Vol. 2, No. 1, 2026 - Kwararafa University Journal of Multidisciplinary Research and Innovation
Pub. Link: https://aa.unij.co.uk/index.php/kujmri/issue/view/6 - *E* - ISSN: 3156-5492 | *P* - ISSN: 3156-5514

Zhang, X., Al-Mekhled, D., & Choate, J. (2021). Are virtual physiology laboratories effective for student learning? A systematic review. *Advances in Physiology Education, 45*(3), 467–480. https://doi.org/10.1152/advan.00016.2021