VIRTUAL LABORATORY PRACTICALS AND STUDENT INTEREST IN SECONDARY SCHOOL BIOLOGY IN ANAMBRA STATE: A CONCEPTUAL REVIEW

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Abstract

The persistent crisis in practical Biology instruction within Anambra State's secondary schools, characterized by severe infrastructural decay, overcrowded classrooms, and insufficient teacher capacity, has precipitated a decline in student engagement and scientific interest. This paper adopts a narrative review approach, synthesizing recent empirical studies to critically examine the transformative potential of Virtual Laboratory Practicals (VLPs) as a strategic intervention to mitigate these challenges and re-stimulate student interest. Drawing on a robust body of recent research literature from Nigeria, the analysis elucidates both the profound benefits and significant implementation barriers associated with VLPs. Literature indicates that VLPs can democratize access to quality practical experiences, concretize abstract biological concepts, reduce student anxiety, and offer a scalable, cost-effective complement to physical labs. However, their effective integration is contingent upon overcoming systemic hurdles, namely a profound digital infrastructure deficit, a lack of teacher readiness, and rigid curriculum structures. The discourse advocates for a blended, pedagogical model where VLPs serve as scaffolds for physical work, enablers of "impossible" experiments, and tools for differentiated instruction. The conclusion posits that VLPs are not a panacea but an essential component of a modernized Biology education toolkit. To realize their full potential in stimulating interest and improving learning outcomes, deliberate policy actions are required. These include targeted investments in offline-compatible technology and solar-powered connectivity, mandatory teacher professional development, curriculum reform to embed blended practicals, and the fostering of research partnerships between universities and schools. Ultimately, strategic integration of VLPs presents a viable pathway to foster a more equitable, engaging, and effective Biology education for all students in Anambra State.

Keywords: Virtual laboratory, Interest, Biology, Narrative Review

Introduction

The discourse on the teaching and learning of science in Nigerian secondary schools, particularly within Anambra State, has reached a critical juncture. Scholarly conversations consistently foreground traditional practical science instruction as foundational for conceptual understanding, skill acquisition, and the cultivation of sustained scientific interest. Yet, across decades of documented research, a persistent narrative emerges: the steady decline in the state of physical laboratories, characterized by inadequate equipment, chronic underfunding, overcrowded classrooms, and escalating safety concerns (Ezenwabachilli & Okoli, 2021; Uzoechi & Eze, 2022). This infrastructural deficit, scholars argue, directly compromises the fidelity of hands-on experiences, frequently reducing what ought to be inquiry-driven practical sessions to passive demonstrations or purely theoretical exercises. Consequently, the literature reflects a corresponding decline in student interest across core science subjects like Biology, Chemistry, and Physics contributing to patterns of poor academic achievement and a diminishing pipeline of graduates pursuing Science, Technology, Engineering, and Mathematics careers (Oriji & Idoghor, 2022).

Within Anambra State, a region historically celebrated for its educational heritage, this paradox assumes particular poignancy. Researchers have documented that while student aspiration remains notably high, the physical capacity of many schools to deliver authentic, inquiry-based practical instruction is severely constrained. Ibe and Nwakobi (2022) observed that the abstract nature of scientific concepts, when left undemystified by meaningful practical engagement, compels students toward rote memorization and engenders significant disinterest. Similarly, Ugwu and Ozoji (2021) contributed to this scholarly narrative by demonstrating that ineffective practical sessions fail to activate the curiosity and sense of discovery essential for sustaining long-term scientific interest. The regional literature thus paints a consistent picture: the promise of science education in Anambra is undermined not by a deficit of student potential, but by a deficit of instructional capacity at the practical level.

It is against this backdrop of documented constraint that digital innovation has entered the scholarly imagination as a transformative counter-narrative. The global shift toward technology-enhanced learning, precipitously accelerated by the disruptions of the COVID-19 pandemic, has propelled Virtual Laboratory Practicals to the forefront of educational discourse. Within the literature, Virtual Laboratory Practicals are conceptualized as interactive, computer-based simulations that authentically replicate the procedures, tools, and outcome conditions of real-world laboratory experiments (Akachukwu & Nwankwo, 2026). Scholars argue that these digital environments afford students the opportunity to visualize abstract phenomena, manipulate experimental variables, and conduct iterative investigations within safe, repeatable, and resource-independent contexts. Akachukwu and Nwankwo (2026) posited that well-designed simulations possess the capacity not merely to compensate for infrastructural deficits, but to actively enhance conceptual understanding and, critically, to elevate student motivation and interest in science.

Emerging scholarship from Nigerian academics, particularly those situated within the South-East geopolitical zone, reflects a discernible shift in research focus. The scholarly conversation is progressively moving beyond the diagnostic documentation of physical laboratory inadequacies toward the empirical interrogation of digital alternatives. In chemistry education, investigators have examined the efficacy of virtual laboratories in improving academic achievement, reporting statistically significant positive effects (Amadi & Samuel, 2023; Akachukwu & Nwankwo, 2026). Concurrently, a growing corpus of research is attending to the affective domain. Literature indicates that physics simulations have been found to significantly reduce students' anxiety toward practical work while simultaneously enhancing their academic self-efficacy. In Biology instruction, studies have highlighted how virtual dissection platforms can surmount both ethical reservations and resource limitations without sacrificing student engagement (Edet & Okon, 2022). Collectively, these studies signal an emergent research tradition grounded in regional contexts and responsive to regional challenges.

Yet, even within this burgeoning literature, a salient gap persists. While the broader efficacy and performance-related outcomes of Virtual Laboratory Practicals are increasingly well-documented, there remains a paucity of targeted scholarly inquiry into their specific role in stimulating and reshaping student interest, a construct widely recognized in educational psychology as comprising both the affective experience of enjoyment and the cognitive valuation of the subject matter (Hidi & Renninger, 2006). The literature has yet to adequately address several pressing questions: Does the inherent novelty of technology translate into sustained, durable interest in science? To what extent can virtual, screen-mediated experiences compensate for the tactile, embodied engagement of physical laboratory manipulation? How do contextual variables—school location, gender, prior academic achievement moderate the relationship between virtual laboratory exposure and interest development within the specific sociocultural and infrastructural landscape of Anambra State? These interrogatives remain, at present, inadequately theorized and empirically underexplored.

This review, therefore, is situated at the confluence of a persistently documented educational challenge and an emergently theorized technological solution within the South-East Nigerian context. It seeks to advance the scholarly conversation beyond the now-familiar dual narratives of problem identification and generalized digital promise. Instead, it directs focused attention toward the specific project of reimagining practical science instruction through Virtual Laboratory Practicals as a deliberate strategy for the stimulation of secondary school students' interest in Anambra State. By grounding its synthesis in the work of recent regional scholarship while simultaneously identifying this specific theoretical and empirical lacuna, the review aims to contribute evidence-informed perspectives for curriculum planners, teacher educators, and educational policymakers. The objective is not merely to advocate for technology as remediation for deficit, but to frame Virtual Laboratory Practicals as a fundamental pedagogical lever for the reinvigoration of student passion for science across Anambra State and the wider South-East region.

Current Challenges in Practical Biology Instruction in Secondary Schools

Practical Biology instruction, a cornerstone of authentic science education, is confronted by a nexus of formidable challenges in secondary schools globally and particularly within resource-constrained contexts like Nigeria. These challenges systematically undermine the pedagogical intent of practical work to foster inquiry-based learning, develop scientific skills, and sustain student interest. The current discourse, supported by recent empirical studies, highlights the following critical impediments:

1. Infrastructural Decay, Inadequate Resources and Overcrowded Classrooms: This is the most pervasive and fundamental challenge. Biology laboratories are often non-existent, dilapidated, or ill-equipped. A critical shortage of basic materials such as functional microscopes, preserved specimens, chemicals for tests (e.g., Benedict's solution), dissecting kits, and even consistent electricity and water supply, renders many prescribed practical activities impossible. As noted by Uzoechi and Eze (2022) in the Anambra context, the state of science facilities is a primary barrier to effective instruction. Teachers are forced to resort to "chalk-and-talk" descriptions of experiments, which strips Biology of its tangible, exploratory nature. Even in schools with some laboratory facilities, practical sessions are often conducted in overcrowded classrooms. This leads to extremely high student-to-microscope or student-to-specimen ratios. Consequently, many students become passive observers rather than active participants, waiting for a brief turn that may never meaningfully materialize. This passive observation fails to build the requisite manipulative skills and diminishes the sense of personal discovery that stimulates interest (Ibe & Nwakonobi, 2022).

2. Insufficient Teacher Capacity and Professional Development: Effective practical instruction requires teachers who are not only knowledgeable but also proficient in laboratory techniques and safety protocols. Many Biology teachers, especially in rural areas, lack adequate training in conducting modern practicals or improvising with local materials. Furthermore, continuous professional development on innovative pedagogical methods, including integrating technology, is limited. This results in a reliance on outdated, often rigid, "recipe-style" practicals that prioritize following steps over fostering scientific inquiry.

3. Safety and Ethical Concerns: Safety in Biology laboratories is a significant issue, ranging from inadequate ventilation for chemical experiments to a lack of basic safety gear (gloves, lab coats, eye protection). Additionally, dissections and the use of live specimens present ethical dilemmas and can be off-putting to some students. Schools often lack ethical guidelines and alternatives, which can create discomfort and disengagement rather than respect for life and scientific study.

4. Curriculum and Assessment Misalignment: The Biology curriculum is often overloaded with theoretical content, leaving insufficient allocated time for meaningful practical work. When practicals are conducted, there is frequently a disconnect between the activity and its assessment. Assessment tends to focus on the theoretical recall of the experiment's outcome rather than on evaluating the process skills like hypothesis formulation, observation, data recording, analysis, and interpretation. This misalignment signals to students that the process of doing science is less important than memorizing its conclusions (Nworgu & Agwagah, 2020).

5. Socio-Economic and Geographic Disparities: Challenges are not uniformly distributed. A stark digital and resource divide exists between urban and rural schools, and between well-funded private institutions and under-resourced public schools. Students in rural areas are disproportionately affected, having little to no access to even the most basic laboratory experiences. This inequity exacerbates existing gaps in educational outcomes and interest in STEM fields.

6. The "Abstractness" Barrier: Biology encompasses processes that range from the ecosystem level down to the molecular and cellular levels, much of which is invisible to the naked eye. Without practical tools to visualize these processes (e.g., mitosis, enzyme action, DNA replication), students struggle to move beyond abstract, rote-learned concepts. The inability to concretize these phenomena leads to misconceptions, a perceived difficulty of the subject, and waning curiosity (Ullah & Iqbal, 2020).

The Prospects and Benefits of Virtual Laboratories in Secondary Schools in Anambra State

The integration of virtual laboratories in Anambra State's secondary school system represents a transformative frontier in science education, offering tangible solutions to systemic challenges while aligning with broader educational trends across Africa. These digital platforms, which simulate laboratory environments and biological processes, present significant prospects for enhancing the quality, accessibility, and equity of Biology instruction. The potential benefits span pedagogical, cognitive, and infrastructural domains, positioning virtual labs not as mere technological supplements but as essential components of a modernized science curriculum.

A foremost prospect is the **democratization of laboratory access.** In many schools across Anambra State, practical science instruction is severely hampered by inadequate infrastructure, a challenge well-documented by Uzoechi and Eze (2022) in their assessment of science facilities. Virtual laboratories can mitigate this by providing consistent, high-quality practical experiences regardless of a school's physical resources.. For rural schools in Anambra, virtual platforms could serve as the primary means of conducting standardized experiments, thereby reducing the urban-rural educational divide.

Cognitively, virtual laboratories offer the unique benefit of **making abstract biological concepts concrete and interactive**. Many core topics in Biology, such as cellular respiration, protein synthesis, and ecosystem dynamics, involve processes that are invisible or difficult to observe directly. Virtual simulations allow students to visualize and manipulate these processes, fostering deeper conceptual understanding. In Anambra, where teachers often struggle to convey these abstract ideas due to resource limitations, virtual labs can serve as powerful visual aids, enhancing both teaching efficacy and student learning outcomes.

From an affective standpoint, virtual laboratories hold promise for **increasing student engagement and reducing anxiety**. The fear of failure, safety concerns, or discomfort with dissection can deter students from fully participating in physical labs. Virtual environments provide a low-stakes space for experimentation, where students can repeat procedures, make mistakes, and explore without pressure.. In Anambra, where cultural and gender factors may influence participation in science, virtual labs could help foster a more inclusive and motivating atmosphere, encouraging broader student interest in Biology.

Pedagogically, virtual laboratories enable **flexible and differentiated instruction.** Teachers can tailor virtual activities to meet diverse learning needs, allowing advanced students to explore complex simulations while providing remedial support to others. This is particularly valuable in Anambra's often overcrowded classrooms, where individualized attention is challenging. Nigerian researchers like Adeoye and Ojo (2023) have highlighted the role of virtual labs in supporting self-paced learning, noting that students in Lagos who used blended virtual-physical approaches showed higher retention rates and problem-solving skills. By integrating virtual labs, Anambra teachers could adopt similar strategies, using technology to personalize learning and address varying student abilities within a single classroom.

Economically and logistically, virtual laboratories offer a **scalable and cost-effective alternative** to maintaining and equipping physical labs. While initial investments in devices and internet connectivity are required, virtual platforms reduce recurring costs for consumables, specimens, and equipment repairs. This is especially relevant in Anambra, where education budgets are often strained. A Tanzanian study on virtual lab adoption in resource-limited schools found that, over time, digital tools reduced long-term expenditure on practical science while expanding access to a wider range of experiments (Kibona & Mgaya, 2021). For Anambra's education planners, virtual labs represent a sustainable model for expanding practical science education without prohibitive ongoing costs.

More so, virtual laboratories prepare students for **future academic and career pathways** in science and technology. Proficiency with digital tools and simulations is increasingly essential in higher education and STEM professions. By engaging with virtual labs, students in Anambra can develop digital literacy and analytical skills that are transferable to university and workplace settings. Research from Uganda underscores this, showing that students exposed to virtual labs in secondary school were better prepared for university-level science courses, as they had already developed competencies in experimental design and data interpretation (Nabaggala & Ssentongo, 2022). For Anambra, a state with a strong emphasis on educational achievement, virtual labs can help align secondary science instruction with the demands of higher education and global innovation.

The Integration of Virtual Laboratory Platforms in Secondary Biology: Strategies Amidst Systemic Constraint

The profound challenges plaguing practical Biology instruction in secondary schools spanning infrastructural decay, overcrowded classrooms, and insufficient teacher capacity, has created an urgent imperative for pedagogical innovation. Within this constrained ecosystem, Virtual Laboratory Platforms (VLPs) emerge not as a speculative luxury but as a necessary, complementary tool for reimagining engagement and conceptual understanding. These digital simulations, which range from interactive two-dimensional models to immersive three-dimensional environments, offer a viable pathway to conduct experiments and visualize biological processes that remain obstinately abstract or logistically impossible within the traditional school laboratory. The promise of these tools, however, is contingent upon their strategic integration, a process itself fraught with challenges that mirror and amplify the existing systemic failures in science education.

The effective adoption of VLPs necessitates a deliberate pedagogical shift from sporadic, supplemental use to a blended, intentional framework. One potent strategy involves deploying virtual labs as a conceptual scaffold prior to physical practical work. For instance, students can utilize a simulation to master the procedural steps of using a microscope or setting up a biochemical test before handling scarce and fragile physical equipment. This approach, as suggested by the work of Ugwu and Ozoji (2021) on virtual labs in Enugu State, builds foundational competence and confidence, thereby maximizing the efficacy of limited contact time with actual materials and directly mitigating the disengagement caused by overcrowding. Furthermore, VLPs uniquely function as an enabler of the "impossible practical." Complex, time-sensitive, or resource-intensive phenomena such as simulating natural selection across generations, manipulating virtual ecosystems, or visualizing molecular processes like DNA transcription can be brought into the classroom. This capability directly transcends the chronic resource constraints documented by researchers like Uzoechi and Eze (2022), unlocking inquiry-based learning that was previously confined to textbook descriptions.

A more sophisticated integration model involves the creation of blended learning stations within a single classroom. In this setup, one station might involve a scaled-down hands-on activity, such as testing a leaf for starch, while a concurrent station employs a VLP on a tablet to explore the underlying biochemical pathways or to analyze and graph data from similar experiments. This rotation model ensures active participation for all students even in large classes, fostering both tactile skills and digital data literacy. Crucially, VLPs can also recalibrate assessment towards authentic scientific practice. By generating rich, customizable datasets through repeated virtual trials, students can engage deeply with the processes of hypothesis testing, data analysis, and interpretation skills often sidelined in traditional, recipe-style practicals that focus on a single, predetermined outcome (Nworgu & Agwagah, 2020). This strategic use addresses the persistent curriculum-assessment misalignment that plagues Biology instruction.

Nevertheless, the path to integrating these digital tools is obstructed by a formidable suite of implementation challenges, many of which are deeply rooted in the very infrastructure deficits they aim to address. The most fundamental barrier remains the stark digital divide. The absence of reliable electricity, adequate functioning hardware, and consistent internet connectivity in many schools, particularly in rural areas, renders the most well-designed VLP strategy obsolete. This disparity, as noted in broader analyses of educational technology in Nigeria, exacerbates existing geographic and socio-economic inequities rather than alleviating them. Teacher readiness presents another critical hurdle. Effective integration demands not only digital literacy but also a pedagogical mindset shift from teacher-as-dispenser to facilitator-of-inquiry. Without sustained, hands-on professional development, teachers may view VLPs with skepticism or as an added burden, a concern reflected in studies on technology adoption in South-East Nigerian schools (Ibe & Nwakonobi, 2022). Finally, the rigidity of examination-focused curricula and the pressure to cover vast theoretical syllabi often strangle the time and flexibility required for students to explore and learn through virtual experimentation meaningfully.

Conclusion

Virtual laboratory practicals (VLPs) represent a transformative opportunity to address the chronic deficiencies in secondary school Biology instruction in Anambra State, where infrastructural decay and overcrowded classrooms severely limit hands-on learning. These digital simulations offer the prospect of democratizing access to quality practical experiences, allowing students to conduct experiments and visualize abstract biological processes that are otherwise impossible in under-resourced schools. Research from Nigerian institutions indicates VLPs can significantly enhance conceptual understanding and academic retention by making invisible phenomena like cellular respiration interactive and concrete.

Furthermore, studies across Africa suggest virtual labs reduce science anxiety and increase student engagement by providing a safe, low-stakes environment for experimentation and repetition. The strategic integration of VLPs through models like blended station rotations or as scaffolds for physical labs can mitigate overcrowding and personalize instruction. However, this integration faces major challenges mirroring the existing systemic constraints, including a profound digital infrastructure deficit, especially in rural areas, and a lack of teacher readiness for technology-driven pedagogy. Without parallel investments in reliable electricity, devices, and teacher training, the equity gap may widen. Ultimately, VLPs are not a replacement but a vital complementary tool within a reimagined Biology curriculum. When implemented strategically, they hold the potential to stimulate interest, foster scientific literacy, and prepare students for future STEM pathways.

Therefore, a concerted effort to overcome implementation barriers is essential to unlock the full benefit of virtual laboratories for all students in Anambra State.

Recommendations

In the light of this discourse, the following recommendations are made:

1. The Anambra State Ministry of Education should establish a pilot programme to provide selected secondary schools with offline-enabled tablets preloaded with curriculum-aligned virtual Biology laboratory software.
2. Teacher training colleges and the Post-Primary School Service Commission (PPSSC) should mandate and fund continuous professional development workshops focused on the pedagogical integration of virtual and physical laboratory experiences.
3. The State Government, in partnership with telecom companies, should subsidise the installation of solar-powered internet hubs in rural secondary schools to ensure equitable digital access for virtual learning.
4. Curriculum planners at the State Education Resource Centre (SERC) should revise the Biology scheme of work to explicitly include blended practical sessions, designating specific topics for virtual laboratory exploration.
5. School principals should be encouraged to adopt a station-rotation model within Biology classes, where small groups alternate between virtual simulations, scaled-down hands-on activities, and teacher-led instruction to maximise engagement in crowded classrooms.
6. University researchers from institutions like Nnamdi Azikiwe University and the University of Nigeria, Nsukka, should collaborate with local teachers to develop and validate contextually relevant virtual laboratory modules for the Anambra State curriculum.
7. The State Government should initiate public-private partnerships with technology firms to create low-cost, offline-compatible virtual laboratory applications that run on basic smartphones and computers commonly available in communities.
8. WAEC and NECO examiners should incorporate questions that assess the procedural and analytical skills developed through virtual experimentation, thereby aligning high-stakes assessment with modern pedagogical tools.
9. Each education zone in the state should designate a "Technology Integration Lead" teacher to mentor colleagues, troubleshoot basic technical issues, and champion the effective use of virtual laboratories.
10. A statewide monitoring and evaluation framework must be established to annually assess the impact of virtual laboratory integration on student interest, teacher confidence, and academic performance in Biology.

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