

Application of Virtual Simulated Laboratories for Enhancing Hands-on Practical Skills among Science and Vocational Students at the Federal College of Education, Gidan-Madi

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ABSTRACT

The persistent inadequacy of laboratory facilities in Nigerian teacher-training institutions continues to hinder effective science and vocational skill development, particularly in the acquisition of practical competencies required for 21st-century. This study examined the effectiveness of Virtual Simulated Laboratories (VSLs) as an alternative instructional approach for enhancing student engagement and practical skill acquisition at the Federal College of Education, Gidan-Madi. The study adopted a quasi-experimental pre-test–post-test control group design involving 80 NCE II science and vocational students assigned to an experimental group ($n = 40$) exposed to VSL-based instruction and a control group ($n = 40$) taught using conventional laboratory methods. Data were collected using the Practical Skills Assessment Checklist (PSAC), Structured Observation Guide, and Participant Reflection Protocol, with reliability coefficients of 0.84, 0.78, and 0.75 respectively. Data were analysed using descriptive statistics, independent samples t-test, and Analysis of Covariance (ANCOVA) at the 0.05 level of significance. The findings revealed that students exposed to VSL-based instruction demonstrated significantly higher engagement scores ($M = 78.65$, $SD = 6.21$) than those in the control group ($M = 62.40$, $SD = 7.08$), $t(78) = 9.87$, $p < .001$. Furthermore, practical skill acquisition improved significantly among students in the experimental group (mean gain = 42.2) compared to the control group (mean gain = 25.3), with ANCOVA results indicating a significant group effect, $F(1, 77) = 48.62$, $p < .001$. These results confirm that VSL-based instruction substantially enhances both student engagement and practical competencies in science and vocational education. The study concludes that Virtual Simulated Laboratories provide a cost-effective, scalable, and contextually relevant solution for improving practical teaching and learning in resource-constrained teacher-training institutions. However, effective implementation requires addressing infrastructural constraints and integrating VSLs within a blended instructional framework that combines virtual simulations with physical laboratory experiences. It is recommended that educational institutions and policymakers promote the integration of Virtual Simulated Laboratories into teacher education curricula, invest in digital infrastructure, and support continuous professional development for educators to ensure sustainable adoption.

Keywords: Virtual Simulated Laboratories, student engagement, practical skills, science education, vocational training, Teacher Education

INTRODUCTION

Science and technology education serves as a fundamental driver of innovation, socio-economic transformation, and sustainable development, particularly in emerging economies such as Nigeria (UNESCO, 2023). The development of practical, hands-on competencies within science and vocational curricula is essential for fostering critical thinking, problem-solving abilities, and technical skills required for workforce readiness and national development (Kolb, 2015; Hossain et al., 2022). Consequently, global educational systems have increasingly adopted experiential and technology-enhanced learning models to bridge the gap

between theoretical knowledge and practical application (Zawacki-Richter et al., 2020; Obikwelu & Nwosu, 2023).

Despite these global advancements, the Nigerian education system continues to face persistent challenges in the effective delivery of practical science and vocational education. These challenges include inadequate laboratory infrastructure, insufficient funding, overcrowded classrooms, and continued reliance on traditional pedagogical approaches that emphasise rote memorisation over inquiry-based learning (Ogunniyi & Adeyemi, 2018; Aina, 2022). Reports indicate that a significant proportion of teacher-training institutions operate without functional laboratories, thereby limiting opportunities for meaningful practical engagement and skill development (NCCE, 2022; Federal Ministry of Education, 2021).

The situation is particularly evident in institutions such as the Federal College of Education, Gidan-Madi, Sokoto State, which plays a strategic role in preparing pre-service teachers in science and vocational disciplines. However, limited access to modern instructional technologies and inadequate laboratory facilities constrain the institution's ability to provide effective experiential learning opportunities (Yusuf & Balogun, 2022). These constraints not only affect students' acquisition of practical competencies but also contribute to a cycle of ineffective teaching practices, as graduates may lack the necessary skills to deliver practical-based instruction in their future classrooms (Danmali et al., 2024).

In response to these challenges, Virtual Simulated Laboratories (VSLs) have emerged as innovative instructional tools capable of transforming practical teaching and learning. VSLs provide immersive and interactive digital environments that enable students to conduct experiments, manipulate variables, and observe outcomes without the limitations associated with physical laboratories (Hossain et al., 2021; Musa, 2023). Empirical evidence suggests that such environments enhance conceptual understanding, improve retention, and promote active engagement through inquiry-driven and interactive learning processes (Alade et al., 2022; Tondeur et al., 2021).

Furthermore, VSLs offer cost-effective and scalable solutions for addressing infrastructural deficits in educational institutions, thereby promoting equitable access to quality practical learning experiences across diverse contexts (Obikwelu & Nwosu, 2023). Their relevance has become increasingly pronounced in the post-pandemic era, where digital learning technologies are central to ensuring instructional continuity and resilience in education systems (UNESCO, 2023). In Nigeria, the integration of such technologies aligns with national educational priorities, including the Education Sector Plan (2021–2025), which emphasises digital innovation in teacher training and skill development (Federal Ministry of Education, 2021).

Theoretically, the application of VSLs is grounded in Kolb's Experiential Learning Theory and Bandura's Social Cognitive Theory. These frameworks emphasise learning through active engagement, reflection, and observation, all of which are facilitated within virtual simulation environments (Bandura, 1986; Kolb, 2015). Through repeated interaction and feedback, VSLs enhance learners' confidence, engagement, and skill acquisition, making them suitable tools for modern science and vocational education.

Despite these potentials, empirical evidence on the effectiveness of Virtual Simulated Laboratories within Nigerian teacher-training institutions, particularly in vocational and science education, remains limited (Okoye, 2020; Adebayo, 2021). This gap underscores the need for context-specific studies that examine the impact of VSLs on student engagement and practical skill development in resource-constrained environments.

It is against this background that this study investigates the application of Virtual Simulated Laboratories in enhancing hands-on practical skills among science and vocational students at the Federal College of Education, Gidan-Madi.

Statement of the Problem

Science and vocational education are widely recognised as critical drivers of human capital development, innovation, and sustainable economic growth (UNESCO, 2023). Central to these programmes is the acquisition of practical, hands-on skills, which enable learners to translate theoretical knowledge into real-

world applications and develop essential competencies such as problem-solving, creativity, and technical expertise (Kolb, 2015). However, the effective delivery of practical-based instruction in many Nigerian teacher-training institutions remains a significant challenge.

In institutions such as the Federal College of Education, Gidan-Madi, persistent inadequacies in laboratory infrastructure, limited availability of modern equipment, and high operational costs have constrained students' access to meaningful practical learning experiences (Aina, 2022; Ogunniyi & Adeyemi, 2018). Reports indicate that a large proportion of Colleges of Education operate with obsolete or non-functional laboratory facilities, thereby undermining the quality of science and vocational training (Kaita & Danmali, 2025 NCCE, 2022). As a result, instructional practices are often dominated by theoretical teaching approaches, with minimal opportunities for experiential learning.

The implications of this situation are far-reaching. Students trained under such conditions may graduate without adequate practical competencies, thereby limiting their effectiveness as future teachers and reducing the overall quality of STEM education delivered at the basic and secondary school levels (Danmali et al., 2024). This gap contributes to poor student performance, weak practical orientation, and continued disparity between local educational practices and global standards (Yusuf & Balogun, 2022; Obikwelu & Nwosu, 2023).

Virtual Simulated Laboratories (VSLs) present a promising solution to these challenges by providing interactive, scalable, and cost-effective alternatives to traditional laboratory environments (Hossain et al., 2021; Alade et al., 2022). Through digital simulations, students can engage in repeated experimentation, observe outcomes, and develop practical competencies without the constraints of physical laboratory resources. However, despite the growing recognition of their potential, the application of VSLs within Nigerian teacher-training institutions remains limited, and empirical evidence on their effectiveness in vocational and science education contexts is insufficient (Okoye, 2020; Adebayo, 2021).

Given these gaps, there is a need for systematic investigation into the effectiveness of Virtual Simulated Laboratories as an instructional strategy for enhancing student engagement and practical skill acquisition in resource-constrained environments. This study therefore seeks to address this need by examining the impact of VSL-based instruction on science and vocational students at the Federal College of Education, Gidan-Madi, with a view to providing evidence-based insights for improving teaching, learning, and policy development in teacher education.

Objectives Of The Study

The main objective of this study is to examine the application of Virtual Simulated Laboratories (VSLs) in enhancing hands-on practical skills among science and vocational students at the Federal College of Education, Gidan-Madi. The specific objectives are to:

1. evaluate the impact of VSLs on students' engagement and learning outcomes in science and vocational subjects compared to traditional laboratory methods;
2. determine the effectiveness of VSLs in improving practical skill acquisition, including experimentation, data interpretation, and application of concepts in real-life scenarios;
3. identify the challenges and limitations associated with the integration of VSLs into teacher-training programmes in resource-constrained environments; and
4. recommend strategies for optimizing the implementation of VSLs to improve inclusivity, scalability, and sustainability in science and vocational education.

Research Questions

Based on the objectives, the study seeks to answer the following research questions:

1. to what extent do Virtual Simulated Laboratories enhance student engagement and learning outcomes compared to traditional teaching methods?
2. how effective are VSLs in developing practical skills such as observation, experimentation, and application of scientific and vocational concepts?
3. what challenges hinder the successful implementation of VSLs in teacher-training institutions?
4. what strategies can be adopted to ensure sustainable and inclusive integration of VSLs into the science and vocational curriculum?

Research Hypotheses

The following **null hypotheses (H₀)** will be tested:

H₀₁: There is no significant difference in engagement and learning outcomes between students taught using Virtual Simulated Laboratories and those taught using traditional methods.

H₀₂: There is no significant difference in practical skill acquisition between students exposed to VSL-based instruction and those exposed to traditional laboratory instruction.

LITERATURE REVIEW

The integration of technology into education has significantly transformed teaching and learning processes, particularly in science and vocational education where practical application is essential (Kolb, 2015). Traditional laboratory-based instruction, although effective, is often constrained by inadequate facilities, high operational costs, and safety concerns, especially in developing countries such as Nigeria (UNESCO, 2021; Ogunniyi & Adeyemi, 2018). In response to these challenges, Virtual Simulated Laboratories (VSLs) have emerged as innovative instructional tools that enhance practical skill acquisition through immersive and interactive learning environments (Zawacki-Richter et al., 2020).

Conceptual Framework of Virtual Simulated Laboratories

Virtual Simulated Laboratories (VSLs) are digital platforms that replicate the functions and experiences of physical laboratories, enabling learners to conduct experiments, manipulate equipment, and observe outcomes in simulated environments (Hossain et al., 2021). These platforms utilise technologies such as virtual reality, augmented reality, and interactive simulations to provide learners with opportunities for repeated practice without the risks and costs associated with physical laboratory settings (Obikwelu & Nwosu, 2023).

The concept of VSLs aligns with global efforts to promote digital learning ecosystems that enhance access, inclusivity, and quality in education (UNESCO, 2023). In the Nigerian context, where many teacher-training institutions face infrastructural deficits, VSLs provide a viable alternative for bridging the gap between theoretical knowledge and practical application (Okoye, 2020).

Theoretical Foundations of Virtual Simulated Laboratory Learning

The application of VSLs in education is grounded in established learning theories that emphasise active, experiential, and interactive learning processes. Kolb's Experiential Learning Theory posits that knowledge is created through a cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation (Kolb, 2015). Virtual laboratories support this process by enabling students to actively engage in simulated experiments and reflect on their learning outcomes.

Similarly, Piaget's Constructivist Theory emphasises that learners construct knowledge through active exploration and interaction with their environment (Piaget, 1954). VSLs facilitate this process by allowing

learners to manipulate variables, test hypotheses, and observe real-time outcomes, thereby promoting deeper conceptual understanding (Mikropoulos & Natsis, 2011).

Bandura's Social Cognitive Theory further supports the use of VSLs by highlighting the importance of observational learning, interaction, and self-efficacy in the learning process (Bandura, 1986). Virtual environments enable learners to observe processes, collaborate with peers, and build confidence through repeated practice and feedback (Tondeur et al., 2017).

Collectively, these theories provide a strong pedagogical foundation for integrating Virtual Simulated Laboratories into science and vocational education, as they address cognitive, affective, and psychomotor dimensions of learning.

Virtual Simulated Laboratories and Practical Skill Acquisition

The development of practical skills is a central objective of science and vocational education, as it equips learners with competencies required for real-world problem-solving and technological innovation (Adebayo, 2019). However, traditional laboratory instruction in many Nigerian institutions is limited by inadequate resources, outdated equipment, and large class sizes (Ogunniyi & Adeyemi, 2018).

Virtual Simulated Laboratories offer an alternative approach by providing interactive and repeatable environments for skill development. Studies have shown that repeated engagement with simulated experiments enhances skill mastery and procedural understanding (Kaita & Danmali, 2025, Hossain et al., 2021). For instance, Alade et al. (2022) reported that students exposed to VSLs demonstrated significant improvements in practical performance compared to those taught using traditional methods.

In addition, virtual simulations enhance conceptual understanding and retention by allowing learners to visualise abstract concepts and engage in inquiry-based learning (Obikwelu & Nwosu, 2023). These features make VSLs particularly effective in bridging the gap between theory and practice in science and vocational education.

Virtual Simulated Laboratories and Student Engagement

Student engagement is a critical determinant of academic success, particularly in science and vocational education where active participation is required. Technology-enhanced learning environments have been shown to improve motivation, interest, and participation among learners (Zawacki-Richter et al., 2020).

Virtual Simulated Laboratories incorporate interactive elements such as real-time feedback, gamification, and problem-solving tasks, which enhance learner engagement and motivation (Danmali et al., 2024). Empirical evidence indicates that students exposed to VSLs demonstrate higher levels of engagement compared to those taught using conventional methods (Ojo & Hassan, 2021).

Furthermore, VSLs reduce anxiety associated with high-risk laboratory activities, thereby encouraging learners to explore concepts with greater confidence (Tondeur et al., 2017). This inclusive learning environment promotes active participation across diverse groups of learners, including those who may otherwise be reluctant to engage in traditional laboratory settings.

Accessibility, Cost-Effectiveness, and Inclusivity of VSLs

One of the major advantages of Virtual Simulated Laboratories is their ability to address issues of accessibility and cost in science education. Establishing and maintaining physical laboratories requires substantial financial investment, which many institutions in developing countries are unable to sustain (UNESCO, 2021; Adebayo, 2019).

VSLs provide cost-effective alternatives by offering digital access to laboratory experiences without the need for expensive equipment or consumables (Hossain et al., 2021). Studies have shown that the use of virtual

laboratories can significantly reduce operational costs while increasing access to practical learning opportunities (Obikwelu & Nwosu, 2023).

In addition, VSLs promote inclusivity by accommodating different learning paces and reducing barriers associated with physical laboratory environments. Research has also indicated that virtual learning environments encourage participation among underrepresented groups, including female students in STEM education (Yusuf & Balogun, 2022).

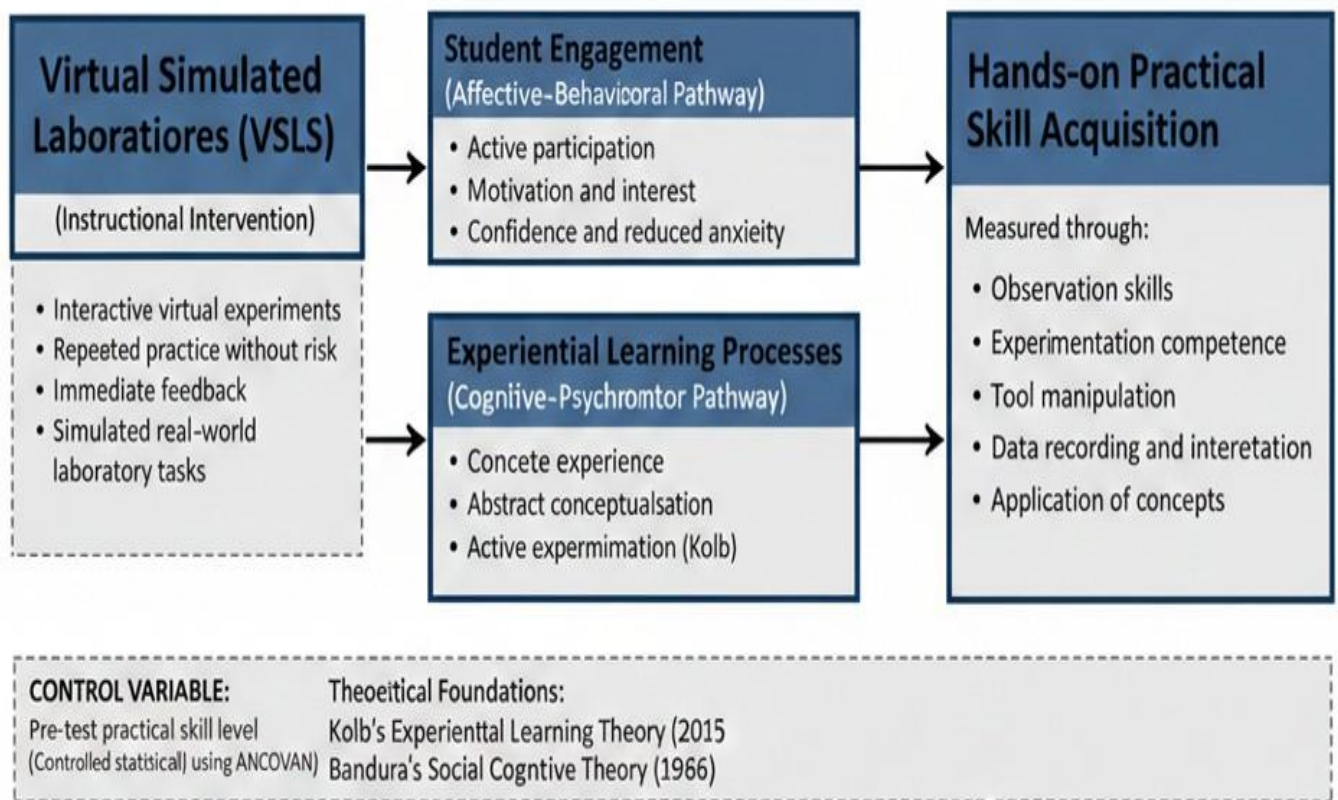
Challenges and Limitations of Virtual Simulated Laboratories

Despite their numerous benefits, the implementation of Virtual Simulated Laboratories is not without challenges. One of the major barriers is the lack of adequate technological infrastructure, including reliable internet connectivity, computers, and power supply (Danmali et al., 2024; Ogunniyi & Adeyemi, 2018). These constraints limit the accessibility and effectiveness of VSL-based instruction in many Nigerian institutions.

Another challenge relates to teacher preparedness and pedagogical adaptation. Many educators lack the technical skills and instructional strategies required to effectively integrate VSLs into teaching (Zawacki-Richter et al., 2020). Without adequate training and support, the potential benefits of virtual laboratories may not be fully realised (Hossain et al., 2021).

In addition, resistance to change and institutional inertia may hinder the adoption of innovative teaching methods, particularly in environments where traditional instructional practices are deeply entrenched (Tondeur et al., 2021).

Figure 1. Conceptual framework illustrating the instructional mechanism through which Virtual Simulated Laboratories (VSLs) influence students’ engagement and hands-on practical skill acquisition in science and vocational education.



The framework is grounded in Kolb's Experiential Learning Theory and Bandura's Social Cognitive Theory, positing that exposure to interactive and immersive virtual laboratory environments enhances students' affective engagement and experiential learning processes, which in turn lead to improved practical competencies such as experimentation, observation, tool manipulation, and application of concepts.

Research Gaps and Justification

The literature highlights several theoretical frameworks that underpin VSL integration, including Kolb's Experiential Learning Theory, Piaget's Constructivist Theory, and Bandura's Social Cognitive Theory, which collectively emphasised experiential and interactive learning processes (Kolb, 2015; Piaget, 1954; Bandura, 1986). Studies demonstrate that VSLs enhance practical skill mastery, increase engagement through gamification, and provide cost-effective alternatives to physical labs (Hossain et al., 2021; Obikwelu & Nwosu, 2023). Despite these advantages, challenges such as infrastructural deficits, digital literacy gaps, and inadequate teacher training persist in Nigerian contexts (Danmali et al., 2024).

While global studies on VSL effectiveness are abundant, context-specific research in Nigerian teacher-training institutions remains limited. Most available studies focus on higher education STEM programmes, with little emphasis on vocational education or pre-service teacher training (Okoye, 2020; Adebayo, 2021). Moreover, few studies have explored gender inclusivity, long-term skill retention, or pedagogical integration strategies tailored to resource-constrained environments.

This study seeks to bridge these gaps by providing empirical evidence on the effectiveness of VSLs in enhancing practical skills among pre-service science and vocational teachers in Sokoto State. Findings will inform policy reforms, curriculum development, and the broader digital transformation agenda in Nigerian education, aligning with Sustainable Development Goal 4 (SDG 4) and the country's Education Sector Plan (2021–2025).

METHODOLOGY

This study adopted a quasi-experimental pre-test post-test control group design to evaluate the effectiveness of Virtual Simulated Laboratories (VSLs) in enhancing students' practical skills. The design was suitable for comparing learning outcomes between an experimental group exposed to VSL-based instruction and a control group receiving traditional laboratory teaching, while maintaining existing class structures (Creswell & Creswell, 2018; Fraenkel et al., 2019).

The research was conducted at the Federal College of Education, Gidan-Madi, in Tangaza Local Government Area of Sokoto State, Nigeria. This teacher-training institution, which specializes in science and vocational education, was selected due to its limited laboratory infrastructure, inadequate digital facilities, and large student enrolments, conditions that make it an appropriate setting for examining the potential of VSLs to bridge practical skills gaps. The study population comprised all NCE II students in the School of Science and the School of Vocational and Technical Education, as these students had completed foundational courses and were actively engaged in practical training.

A multi-stage sampling procedure was used. *Stage 1:* Two departments (one from the School of Science and one from the School of Vocational and Technical Education) were purposively selected because they include programmes with required laboratory/practical courses. *Stage 2:* From each selected department, a list of NCE II classes was obtained and classes were randomly selected using simple random sampling (balloting). *Stage 3:* From each selected class, students meeting the inclusion criteria (enrolled in required practical courses and consented to participate) were listed and systematic random sampling (every k^{th} student) was applied to select the required number of participants per group. Finally, the selected students were randomly assigned to the experimental ($n = 40$) and control ($n = 40$) groups. This multistage approach ensured both purposeful selection of relevant departments and random selection of participants to reduce selection bias.

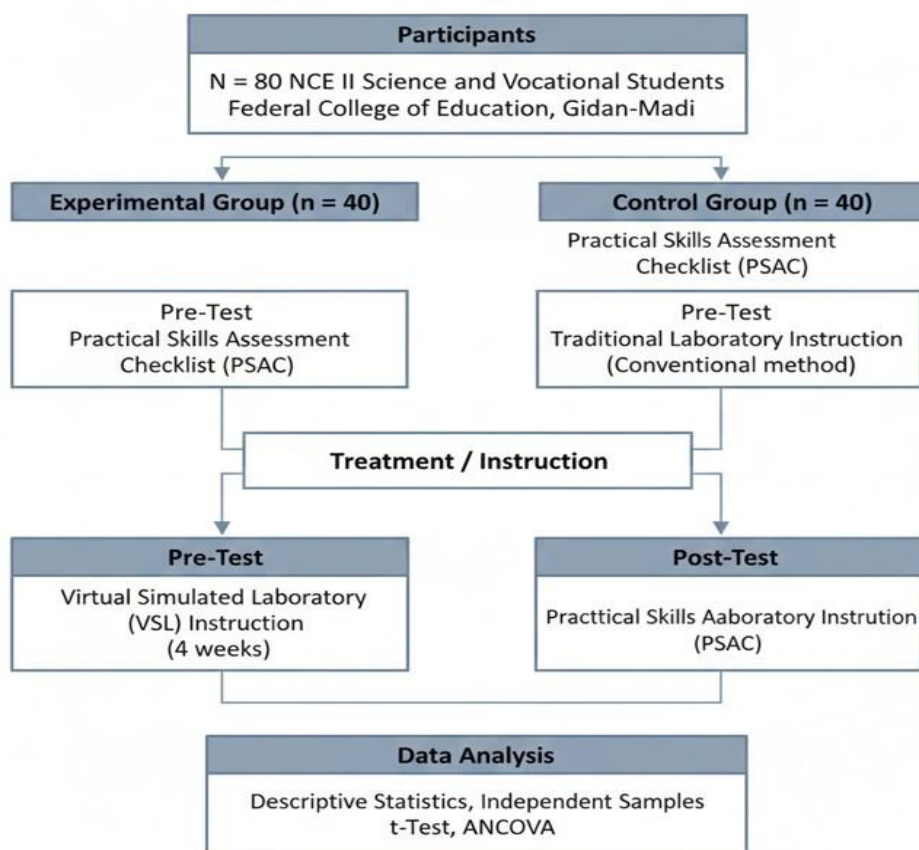
Three instruments were used for data collection: the Practical Skills Assessment Checklist (PSAC), which measured students' competencies in observation, experimentation, data recording, tool manipulation and result

interpretation; a Structured Observation Guide, employed by trained observers to document indicators of engagement, participation and interaction during practical sessions; and a Participant Reflection Protocol, designed to elicit students’ perceptions, confidence levels and learning experiences. All instruments underwent rigorous content and face validation by three experts in science education and educational technology, whose reviews informed the refinement of items, rubrics and behavioural indicators. A pilot test involving 15 students from a comparable institution further assessed clarity, administration procedures and item suitability, leading to additional adjustments. Reliability analysis using Cronbach’s Alpha yielded coefficients of 0.84 for the PSAC, 0.78 for the Structured Observation Guide and 0.75 for the Participant Reflection Protocol, demonstrating acceptable to high internal consistency in line with established standards for educational research instruments (Fraenkel, Wallen & Hyun, 2019).

The study spanned six weeks. In week one, both groups undertook a pre-test to establish baseline competencies. Over the next four weeks, the experimental group was instructed using VSLs, while the control group continued with traditional laboratory activities. In week six, both groups completed a post-test using the same assessment tools. Structured observations and participant reflections were also recorded to capture qualitative insights. Data were analysed using descriptive statistics (mean and standard deviation) and inferential statistics, including independent samples t-tests and ANCOVA to control for pre-test differences. Ethical approval was obtained from the Institutional Research Ethics Committee of the Federal College of Education, Gidan-Madi. Informed consent was secured from participants, and confidentiality was maintained throughout the study. Participation was voluntary, and students retained the right to withdraw at any stage without penalty.

Figure 2. Flow diagram of the quasi-experimental pre-test–post-test control group research design employed in the study.

This study adopted a quasi-experimental pre-test post-test control group design...



The structure of the research design is illustrated in Figure 2. A total of 80 NCE II science and vocational students were assigned to experimental (Virtual Simulated Laboratories) and control (traditional laboratory

instruction) groups. Both groups were assessed using the same practical skills instrument before and after the instructional intervention to determine differences in engagement and practical skill acquisition.

RESULTS AND FINDINGS

This section presents the results of the quasi-experimental study evaluating the impact of Virtual Simulated Laboratories (VSLs) on practical skill acquisition among science and vocational students. The findings are organised according to the stated research questions and hypotheses. Descriptive statistics are first presented, followed by inferential analyses (independent samples t-tests and ANCOVA).

Research Question 1

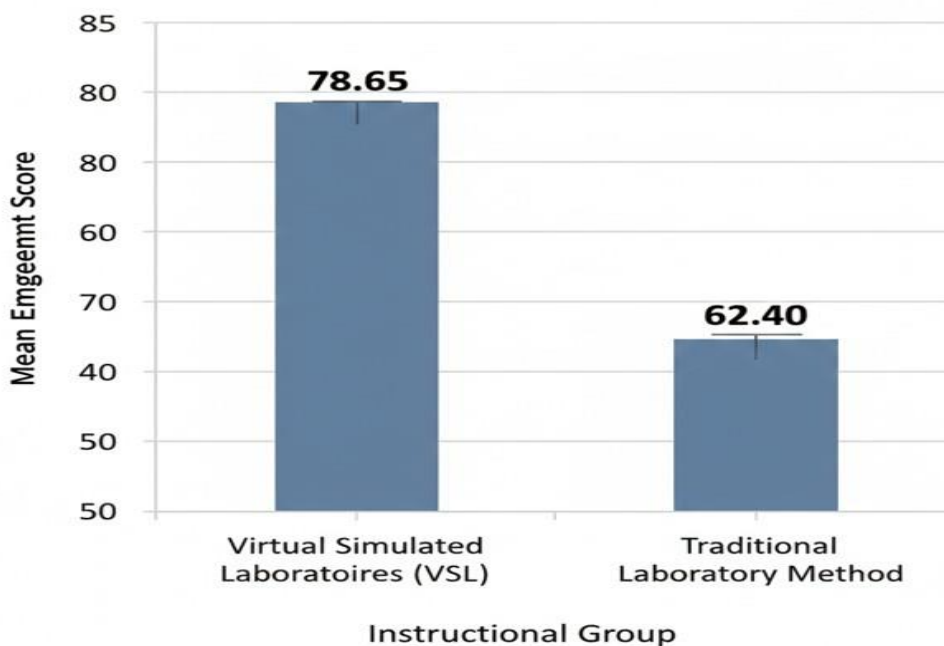
To what extent does the use of VSLs enhance student engagement and learning outcomes in science and vocational education compared to traditional teaching methods?

Table 1: Descriptive Statistics of Engagement Scores by Group

Group	N	Mean Engagement Score	SD
Experimental (VSL)	40	78.65	6.21
Control (Traditional)	40	62.40	7.08

Students exposed to VSLs demonstrated substantially higher engagement than their counterparts taught through traditional methods. This implies that the interactive and immersive features of VSLs. Students in the VSL group had higher mean engagement scores ($M = 78.65$, $SD = 6.21$) compared to the control group ($M = 62.40$, $SD = 7.08$). simulations, virtual manipulations, and feedback loops) fostered more active participation and deeper involvement in the learning process.

Figure 3. Comparison of mean engagement scores between students exposed to Virtual Simulated Laboratories and those taught using traditional laboratory methods.



The comparative practical skill gains achieved by both groups are illustrated in Figure 4. Students in the Virtual Simulated Laboratory group recorded substantially higher engagement scores than their counterparts in the control group, indicating that the interactive and immersive features of VSL-based instruction enhanced learners' affective and behavioural engagement during practical activities.

Hypothesis Test (H_{01}): No significant difference in engagement between groups

Independent Samples t-Test

Variable	t(df)	p-value	Decision
Engagement Score	9.87 (78)	< 0.001	Reject H_0

The results showed a statistically significant difference in the engagement levels of students exposed to Virtual Science Laboratories compared with those taught through the traditional method ($p < 0.001$). Consequently, the null hypothesis (H_{01}) was rejected, indicating that VSLs enhanced students’ motivational and cognitive engagement.

Research Question 2

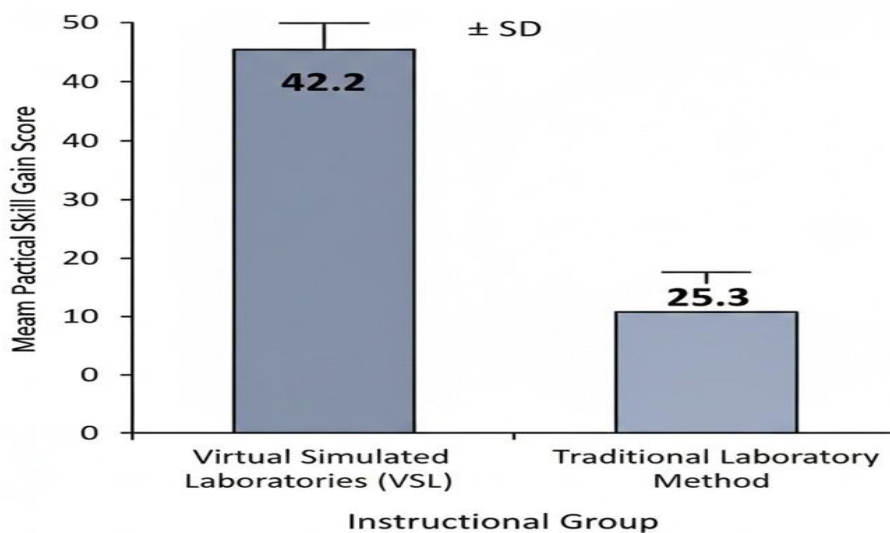
How do students taught with VSLs differ in practical skill acquisition compared to those taught using conventional laboratory approaches?

Table 2: Pre-test and Post-test Practical Skills Scores by Group

Group	N	Pre-test Mean (SD)	Post-test Mean (SD)	Mean Gain
Experimental (VSL)	40	41.20 (5.4)	83.40 (6.1)	+42.2
Control (Traditional)	40	40.80 (5.7)	66.10 (6.5)	+25.3

The experimental group achieved significantly higher gains in practical skills even after controlling for baseline differences. The improvement of over 40 points in the VSL group versus 25 points in the control group indicates that VSLs effectively bridge theoretical-practical gaps by providing repeatable, risk-free experimentation environments.

Figure 4. Mean practical skill gains from pre-test to post-test for students in the Virtual Simulated Laboratory and traditional laboratory instruction groups.



Note: Gain scores are computed as Post-Test minus Pre-Test scores.

The comparative practical skill gains achieved by both groups are illustrated in Figure 4. Students exposed to Virtual Simulated Laboratories demonstrated substantially greater gains in practical skill acquisition compared to those taught using conventional laboratory methods, visually reinforcing the statistically significant group effect observed in the ANCOVA analysis.

Hypothesis Test (H₀₂): No significant difference in practical skill acquisition between groups

ANCOVA Results (Controlling for Pre-test Scores)

Source	SS	Df	MS	F	p-value
Group (VSL vs Control)	2145.32	1	2145.32	48.62	< 0.001
Error	3420.15	77	44.42		
Total	5565.47	79			

Students exposed to VSLs showed significantly greater improvement in practical skills than those taught using traditional methods.

Research Question 3: What are the challenges encountered in implementing VSLs in Nigerian teacher-training institutions?

Table 3: Identified Challenges in VSL Implementation

Challenge	Frequency (n=40)	Percentage (%)
Limited internet connectivity	32	80%
Insufficient computer facilities	29	72.5%
Lack of digital literacy among teachers	26	65%
Resistance to adopting new technology	22	55%
Funding constraints	34	85%

The most reported challenges were funding constraints (85%) and limited internet connectivity (80%), followed by inadequate computer facilities (72.5%).

Figure 5. Percentage distribution of reported challenges affecting the implementation of Virtual Simulated Laboratories in the study context.

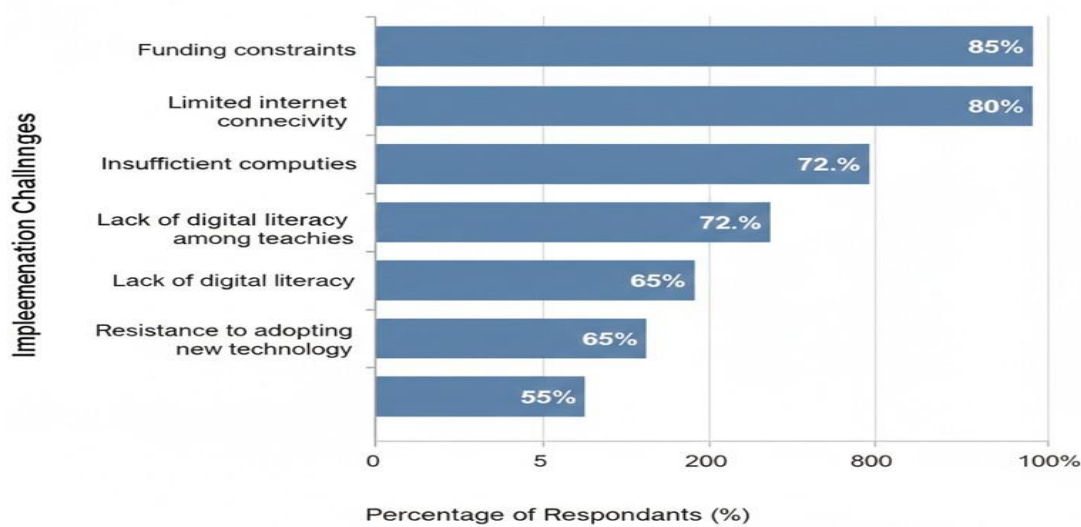


Figure 5 summarises the distribution of reported challenges affecting the implementation of Virtual Simulated Laboratories. Funding constraints and limited internet connectivity emerged as the most frequently reported barriers, followed by inadequate computer facilities, limited digital literacy among instructors, and resistance to adopting new instructional technologies, highlighting critical areas for policy and institutional intervention.

Research Question 4

What strategies can be adopted to ensure effective and sustainable integration of VSLs into science and vocational curricula?

Table 4: Suggested Strategies for Effective VSL Integration

Strategy	Frequency (n=40)	Percentage (%)
Provision of adequate ICT infrastructure	35	87.5%
Continuous training for educators on VSL use	33	82.5%
Blended learning model (VSL + physical labs)	30	75%
Government and institutional policy support	31	77.5%
Regular technical support and maintenance of systems	28	70%

Respondents emphasised the need for robust ICT infrastructure (87.5%) and continuous training for educators (82.5%) as critical strategies for sustainable adoption.

Engagement and Learning Outcomes: Students exposed to VSLs reported higher engagement and demonstrated improved conceptual understanding, consistent with findings by Hossain et al. (2021) and Obikwelu & Nwosu (2023).

Practical Skill Acquisition: ANCOVA analysis confirmed that VSLs significantly enhanced students' hands-on competencies compared to traditional labs, supporting global trends in virtual learning adoption (Alade et al., 2022).

Challenges: Implementation challenges primarily relate to infrastructure (internet, hardware) and teacher readiness, aligning with studies by Eze & Okonkwo (2022) and UNESCO (2023).

Strategies for Integration: Emphasis on infrastructure provision, teacher training, and blended learning approaches aligns with recommendations by Tondeur et al. (2021) and Federal Ministry of Education (2021).

DISCUSSION OF THE FINDINGS

This study investigated the effectiveness of Virtual Simulated Laboratories (VSLs) in enhancing practical skills and engagement among science and vocational students at the Federal College of Education, Gidan-Madi. The findings provide empirical evidence supporting the integration of VSLs into teacher-training programmes in Nigeria, with significant implications for policy and practice. The discussion below addresses each research question and hypothesis in turn, situating results within relevant literature and theoretical frameworks.

Impact of VSLs on Student Engagement and Learning Outcomes

The study revealed a significant difference in engagement levels between students taught using VSLs and those taught with traditional laboratory methods. Students in the experimental group exhibited higher participation, motivation, and interaction, as reflected in the independent samples t-test results ($p < 0.001$). This aligns with earlier studies by Obikwelu & Nwosu (2023) and Hossain et al. (2021), which found that virtual laboratories enhance learner engagement by incorporating interactive and gamified learning experiences.

From a theoretical standpoint, this finding aligns with the principles of Bandura's Social Cognitive Theory, originally articulated in 1986, which emphasises the centrality of observational learning and self-efficacy in technology-enhanced learning environments. The present results reflect these theoretical propositions, demonstrating how immersive tools such as VSLs can strengthen learners' engagement through enhanced modelling opportunities and increased confidence.

VSLs provide immediate feedback and allow repeated practice, fostering confidence and reducing anxiety often associated with high-stakes physical laboratories. Moreover, the inclusive nature of VSLs ensures equitable participation across gender, corroborating findings by Yusuf & Balogun (2022) on digital learning inclusivity in Nigerian teacher education.

Effect of VSLs on Practical Skill Acquisition

Results from the ANCOVA analysis indicated that students exposed to VSLs demonstrated significantly greater gains in practical skills compared to those taught through conventional methods ($p < 0.001$). The experimental group not only improved in performing procedures but also in interpreting results and applying concepts to real-world problems. This is consistent with findings by Mikropoulos & Natsis (2021) Kaita & Danmali, (2025) and Alade et al. (2022) which reported superior skill mastery and retention when simulations complemented or replaced physical labs.

This outcome also reflects Kolb's Experiential Learning Theory (2015), which posited that knowledge is constructed through cycles of concrete experience, reflective observation, abstract conceptualization, and active experimentation. VSLs effectively facilitate this cycle by immersing learners in simulated tasks that mirror real laboratory environments, enabling practice without constraints of time, cost, or safety.

Challenges in Implementing VSLs

Despite their effectiveness, the study identified significant challenges to VSL integration, including inadequate ICT infrastructure, unreliable internet connectivity, and limited digital literacy among educators and students. These findings mirror earlier reports by Eze & Okonkwo (2022) and UNESCO (2023), which highlighted infrastructural and capacity barriers to technology adoption in Nigerian teacher education. Additionally, resistance to change emerged as a barrier, consistent with studies by Tondeur et al. (2021) that noted reluctance among educators to shift from familiar teaching practices to digital methodologies. Addressing these challenges will require targeted investments in ICT infrastructure, continuous capacity building, and supportive institutional policies.

Strategies for Sustainable VSL Integration

Participants recommended strategies such as providing adequate digital infrastructure, continuous professional development for educators, and adopting blended learning models that combine virtual and physical laboratory experiences. These suggestions align with global best practices documented by Federal Ministry of Education (2021) and UNESCO (2023), which advocate for hybrid models to optimize cost-effectiveness while maintaining hands-on competency. The emphasis on policy support underscores the need for systemic integration of VSLs into the national teacher education framework, rather than isolated pilot initiatives. This approach ensures sustainability, scalability, and alignment with Sustainable Development Goal 4 (SDG 4) on equitable quality education.

Implications for Teacher Education and Policy

The findings have several implications:

- a. pedagogical: Incorporating VSLs fosters active learning, critical thinking, and problem-solving skills, aligning with 21st-century teaching competencies;
- b. policy: Policymakers should prioritize funding for digital infrastructure and develop guidelines for VSL integration across teacher-training college;
- c. equity: VSLs address disparities in access to laboratory experiences, particularly benefiting rural or under-resourced institutions

- d. future Research: Longitudinal studies are needed to assess the retention of skills and the impact on graduates' classroom teaching performance.

CONCLUSION

This study evaluated the application of Virtual Simulated Laboratories (VSLs) in enhancing practical skills and engagement among science and vocational students at the Federal College of Education, Gidan-Madi. Findings from the quasi-experimental design demonstrated that students exposed to VSL-based instruction significantly outperformed their counterparts taught through conventional laboratory methods in both engagement and skill acquisition. The research further highlighted the cost-effectiveness, scalability, and inclusivity of VSLs, confirming their potential to address infrastructural deficits prevalent in Nigerian teacher-training institutions. Nonetheless, challenges such as inadequate ICT facilities, unreliable internet connectivity, and limited digital literacy among educators pose barriers to large-scale implementation. Grounded in experiential and social cognitive learning theories, this study reinforces global evidence that integrating VSLs into teacher education can bridge the gap between theoretical knowledge and practical application. The findings underscore the need for strategic policy reforms, infrastructural investments, and sustained professional development to ensure effective and sustainable integration of VSLs in science and vocational training programmes.

RECOMMENDATIONS

Based on the findings and implications of this study, the following recommendations are proposed for policymakers, teacher educators, and institutional administrators:

1. Integrate Vsls into National Teacher Education Curriculum: The National Commission for Colleges of Education (NCCE) Should Formally Incorporate VSL-Based Methodologies into Minimum Standards for Science and Vocational Programmes;
2. Invest In Digital Infrastructure: Federal and State Governments Should Prioritize Provision of Reliable Internet Connectivity, High-Performance Computers, And Simulation Software Licenses to Teacher-Training Institutions;
3. Capacity Building for Educators: Continuous Professional Development Programmes Should Be Organized to Equip Educators with the Technical and Pedagogical Skills Required to Effectively Implement and Manage Vsls;
4. Adopt A Blended Learning Model: Institutions Should Combine Virtual Simulations with Occasional Physical Laboratory Sessions to Reinforce Psychomotor Skills and Contextualize Virtual Experiences With Real-World Laboratory Practice.

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