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Immersive Learning in Chemistry: A Review on the Role of Virtual Laboratory in Modern Nigerian Education

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ABSTRACT

The inadequacies in laboratory infrastructure, overcrowding, and lack of resources in some Nigerian schools continue to hinder effective Chemistry education. As Chemistry is practical and concept-driven, there is a need to adopt innovative strategies that can bridge the gap between theoretical instruction and hands-on experience. Immersive learning, particularly through virtual laboratories, offers a solution. This paper explores the potential of virtual laboratories (VLs) to transform Chemistry education in Nigeria, where inadequate infrastructure and limited resources hinder practical instruction. It examines the pedagogical benefits of VLs, including enhanced engagement and conceptual understanding, safety, flexible delivery and access to experimental content, supported by global and local empirical evidence. This paper reviews various international and local studies that have implemented VLs in the classroom. It evaluates the impact of VLs across different educational settings, and examines the barriers to implementation in Nigeria. The paper strategies for integrating virtual labs into Nigeria Chemistry education, emphasizing the need for policy reform, public-private partnerships, and localized platform development.

Keywords: Chemistry education, digital tools, immersive learning, virtual laboratory.

INTRODUCTION

Chemistry is essential for understanding and recreating our environment. It plays a major role in addressing global challenges such as climate change, drug development, food security, and renewable energy [1]. Chemistry is crucial to Nigeria's national development. Therefore, effective chemistry education is critical for equipping students with the skills to tackle global and local challenges. However, chemistry education in many Nigerian secondary and tertiary institutions remains largely theoretical, limited by a lack of functional laboratories, overcrowded classrooms, outdated curricula, and underfunded infrastructure [2,3].

The nature of chemical concepts makes it more difficult for learners to gain a profound understanding. As a result, there is an increasing demand for creative educational practices that go beyond standard chalk-and-talk methods and foster deeper, more engaged learning.

Immersive learning has emerged as one such approach. Immersive learning is the utilization of technology enhanced environments, which are frequently digitally simulated or augmented, to provide learners with immersive, engaging, and context-rich experiences [4,5]. Immersive learning strategies include virtual reality (VR), augmented reality (AR), mixed reality (MR), 3D simulations, and virtual laboratories (VLs), are designed to create interactive spaces where students can explore, manipulate, and visualize scientific phenomena. Among these strategies, virtual laboratories have shown promise in the field of chemistry education.

Virtual laboratories have emerged as transformative in modern education, facilitating experiential learning through interactive simulations that enable students to conduct experiments and explore scientific concepts online. This innovative approach to education bridges the gap between theoretical knowledge and practical application, particularly in fields such as science, technology, engineering, and mathematics (STEM) education [6]. Virtual laboratories are computer generated simulations that replicate physical laboratory environments, enabling learners to conduct experiments safely and repeatedly, manipulate variables, and observe results without the constraints of time, resources, or risk [7]. They are important tools in modern pedagogy because they provide adaptable, accessible, and resource efficient learning settings that respond to varied student needs and learning styles [8].

This paper seeks to address the significant gap in literature that exists regarding the contextual implementation of VLs within the Nigerian education system. It aims to provide a comprehensive overview of the structure and functions of virtual chemistry laboratories; assess their relevance and educational impact; and critically analyze the opportunities and challenges surrounding their adoption in Nigeria. The paper also offers practical recommendations for policymakers, educators, and curriculum developers on how virtual laboratories can be effectively integrated into chemistry instruction to improve learning outcomes and foster 21st -century science competencies among students.

LITERATURE REVIEW

Virtual laboratories have become an increasingly prominent tool in science education, offering simulations of real lab environments where learners can conduct experiments, manipulate variables, and receive immediate feedback. Globally, these labs are used to supplement or, in some cases, replace physical laboratories, especially where resources are limited. VLs are built on simulation-based learning principles and are often integrated into learning management systems or operated through specialized software or mobile apps.

Several international studies have shown that virtual labs contribute to a better understanding of abstract scientific concepts, improved learner autonomy, and increased accessibility to practical learning. Su and Cheng [9], investigated the influence of a virtual chemistry laboratory on students' academic achievement, focusing on the relationships between self-efficacy, cognitive load, and learning motivation. Their findings showed that experiential learning through the virtual laboratory significantly enhanced students' learning motivation and academic performance. Specifically, students who engaged with the virtual chemistry lab scored higher on post-tests compared to pre-tests, confirming a positive relationship between learning motivation and academic achievement.

Another research carried out by Peechapol [10], investigated the effect of virtual lab simulation in chemistry on the learning achievement, self-efficacy, and learning experience of first-year undergraduate students. The results demonstrated that the virtual lab simulation had a positive impact on student's learning achievement and self-efficacy. The student who learned chemistry through a traditional lecture supplemented by virtual lab simulation had higher scores of knowledge and self-efficacy than learning with only a traditional lecture. It also stated that the virtual lab simulation-based learning contributed to students' motivation in learning and helped them understand complex concepts in chemistry, as well as preparing to perform in a real laboratory experiment that could connect theory with practice.

Gungor *et al.* [11], examined the impact of virtual reality applications on undergraduate students' self-efficacy, self-concept, interest, and laboratory anxiety in an introductory chemistry course. Their results showed that the use of virtual reality had a generally positive effect, enhancing students' confidence, interest, and perception of their abilities, while also reducing feelings of anxiety. Notably, students who initially felt anxious about performing laboratory tasks reported a significant decrease in anxiety after engaging with the virtual reality simulation.

These findings highlight the value of virtual laboratories in higher education settings, particularly where access to physical laboratories is limited or where distance learning is necessary. In Nigerian educational institutions, there is limited empirical evidence assessing the implementation, effectiveness, and contextual challenges of VLs.

Adeyemi *et al.* [12] investigated the effects of virtual laboratories on the attitudes of chemistry students towards quantitative analysis in Colleges of Education in Oyo State, Nigeria. The study found that students taught using virtual laboratories achieved significantly higher academic performance compared to those taught through conventional methods.

Another study was conducted to evaluate the use of a virtual laboratory on improving students' attitudes toward practical chemistry [13]. The findings revealed a statistically significant difference in attitude ratings between students exposed to the virtual laboratory strategy and those taught using traditional face-to-face laboratory methods, favoring the virtual laboratory group. The study also identified a gender related disparity, with male students demonstrating more positive attitudes towards virtual chemistry practical than their female counterparts.

A research on the effects of virtual laboratory on the achievement levels and gender of secondary school chemistry students in individualized and collaborative settings in Minna, Nigeria showed that students exposed to chemistry virtual laboratory package in collaborative learning setting outperformed their counterparts in individualized setting [1].

Nathaniel *et al.* [14], investigated the effect of combining virtual and real laboratories on students' achievement in practical chemistry. Their findings revealed that the integration of virtual laboratories as a supplement to hands-on activities significantly improved students' performance compared to the use of physical laboratories alone, suggesting that a blended laboratory approach may be more effective for enhancing practical chemistry learning outcomes.

Several studies have demonstrated that the use of virtual laboratories, either as a replacement for or supplement to physical laboratories, is highly beneficial, particularly in developing countries like Nigeria, where public schools often face numerous challenges.

Benefits of Virtual Laboratories in Nigerian Chemistry Education

The adoption of virtual laboratories in chemistry instruction presents numerous pedagogical, infrastructural, and cognitive benefits, particularly in Nigeria, where the education system is under-funded. These benefits are supported by both global research and local pilot studies.

Increased Accessibility and Equity

One of the foremost advantages of virtual laboratories is their potential to increase access to quality science education. In Nigeria, many schools lack functional laboratories due to poor funding, infrastructural decay, or overcrowding. VLs offer a scalable alternative by eliminating the need for physical reagents, laboratory assistants, or expensive equipment. Digital platforms can host simulations that mirror real life experiments, giving students in rural or underserved schools access to the same quality of instruction as those in urban, better funded institutions [1].

Enhanced Conceptual Understanding

Virtual laboratories enable visualization of abstract concepts that are often difficult to grasp through traditional instruction alone. For example, chemical bonding, reaction mechanisms, and molecular geometry become more comprehensible when represented through interactive 3D simulations [15,16]. These visual cues aid in mental modeling and cognitive processing, especially among students with limited prior exposure to practical science. Nigerian students have also demonstrated better learning outcomes and reduced misconceptions after engaging with localized virtual lab content [1,14].

Safety, Cost Efficiency, and Repeatability

Laboratory safety is a persistent challenge in Nigerian schools, many of which lack adequate supervision or safety equipment. VLs mitigate risks associated with hazardous chemicals or glassware, allowing students to experiment freely without the fear of accidents. They also eliminate the recurring costs of consumables like acids, bases, and indicators, making them a cost-effective alternative for schools with limited budgets [6].

Additionally, VLs offer repeatability. Students can revisit simulations as often as needed, reinforcing their understanding and confidence. In traditional labs, opportunities to repeat experiments are often constrained by time and material scarcity.

Promoting Resilience in Education

Virtual laboratories enhance the resilience of the educational system, a vital feature in the post-pandemic era. The COVID-19 crisis exposed the vulnerability of physical only laboratory instruction and emphasized the need for hybrid and digital solutions [3]. VLs offer a way to continue practical instruction during emergencies, school closures, or environmental disruptions.

Nigeria's aspiration for a resilient, technology-driven education system, as reflected in national digital policy frameworks, makes virtual laboratory integration both timely and strategic.

Challenges and Limitations of Implementing Virtual Labs in Nigerian Schools

Although virtual laboratories offer a promising solution to the chronic underfunding and infrastructural deficits in Nigerian science education, their implementation is constrained by several practical, systemic, and socio-economic challenges.

Infrastructural Limitations

A primary obstacle to virtual laboratory implementation in Nigeria is the inadequacy of infrastructure, particularly in terms of electricity, internet connectivity, and access to digital devices. Many public secondary schools and tertiary institutions, especially in rural and peri-urban areas, still operate without reliable power supply or broadband access [17]. This digital divide significantly impairs the potential for seamless integration of virtual lab platforms. Additionally, access to digital devices such as laptops, tablets, or smartphones which are essential for operating virtual labs, is limited among both students and teachers [18].

Lack of Teacher Training and Digital Competence

Another critical limitation is the low level of digital literacy among teachers. Many science educators in Nigeria have not received formal training on integrating educational technologies into their teaching practices, including virtual laboratories. Studies have shown that even when virtual tools are provided, the absence of adequate training often results in poor utilization and resistance to adoption [18].

Curriculum Rigidity and Assessment Constraints

The Nigerian senior secondary school chemistry curriculum emphasizes practical work but does not yet formally incorporate digital laboratory alternatives. As a result, teachers may feel constrained by assessment structures (such as WAEC and NECO practical exams) that still rely on traditional laboratory setups [18]. Integration efforts may remain peripheral or tokenistic without curriculum reforms that recognize and validate virtual laboratory work as equivalent or supplementary to physical practical.

Socioeconomic and Equity Gaps

The introduction of virtual labs also risks widening existing educational inequities. Urban schools, private institutions, and students from comfortable backgrounds are more likely to benefit from virtual labs due to better infrastructure and resource access. Meanwhile, students in remote or low-income areas may be left behind, thus widening the learning divide [17,18].

Moreover, gender disparities in technology access and usage may also affect female students more adversely, especially in patriarchal or rural communities where boys are prioritized in digital learning opportunities [19].

Implementation Strategies for the Nigerian Context

To harness the transformative potential of virtual laboratories in Nigerian chemistry education, a multifaceted implementation strategy is essential.

Curriculum Integration and Policy Reform

The successful deployment of virtual labs must begin with formal recognition within Nigeria's national chemistry curriculum. The Federal Ministry of Education, in collaboration with curriculum agencies should revise existing science curricula to incorporate virtual lab components alongside conventional practical. Such reforms would legitimize the use of VLs for formative and summative assessments and encourage wider institutional adoption.

Additionally, examination bodies like WAEC and NECO should pilot hybrid practical exams that include digital simulations, particularly for schools lacking physical laboratory infrastructure. This will incentivize schools to adopt virtual labs while also easing the burden on traditional lab resources.

Development and Deployment of Locally Relevant VL Platforms

Investing in the design and development of virtual lab platforms is critical. Rather than relying solely on foreign platforms, locally developed solutions can address curriculum-specific content, operate offline contextualized, low-bandwidth, and use languages or interfaces that are culturally relevant.

Teacher Training and Professional Development

Equipping teachers with the skills and confidence to integrate virtual labs into instruction is indispensable. Pre-service and in-service training programs must embed digital pedagogical skills, especially for STEM teachers. Teacher training institutions should revise their curriculum to include immersive learning design, digital assessment, and classroom integration of virtual simulations. Workshops, boot camps, and continuous professional development programs can be delivered in partnership with NGOs, EdTech firms, and teacher to scale capacity building efforts.

Infrastructure Support and Public-Private Partnerships

To bridge the infrastructure gap, strategic public-private partnerships are essential. Telecommunications firms, tech companies, and donor agencies can support the deployment of solar powered digital labs, subsidized data access, and donation of devices to under-resourced schools.

Pilot Projects and Scalable Models

Pilot implementation in select schools can serve as a testing ground to refine approaches and measure effectiveness. These pilots should be geographically diverse, representing urban, semi-urban, and rural areas. Data collected can inform evidence based policymaking, scaling decisions, and context specific adaptations. Providing incentive for schools through grants, recognition awards, or performance-based funding could also motivate principals and administrators to experiment with virtual lab integration.

Addressing Socioeconomic and Gender Barriers

To ensure equity, implementation strategies must target underserved populations, including girls, students with disabilities, and learners in rural areas. Providing inclusive interfaces, local-language support, and gender-sensitive training can promote wider participation. Interventions should involve parents, community leaders, and education stakeholders to foster a culture of support around digital learning.

CONCLUSION

From a review of recent literature, this paper highlighted the pedagogical advantages of virtual labs. Case studies and empirical evidence showed that students using VLs demonstrated improved academic performance, higher retention of knowledge, and stronger conceptual. These outcomes are critical in the Nigerian education landscape, where traditional laboratories are underfunded, poorly maintained, or nonexistent in many secondary schools.

Despite the benefits of virtual labs in chemistry education, there several challenges to the adoption of VLs. Strategic implementation, including curriculum reforms, capacity building, localized VL development, and targeted infrastructure investments can aid in overcoming these challenges. Ultimately, virtual laboratories represent a resilient innovation aligned with the broader vision of educational access, technological integration, and national development.

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