ADOPTATION OF VIRTUAL LABORATORIES AS NEW TECHNOLOGIES IN THE NIGERIAN EDUCATIONAL SYSTEM FOR STEM TEACHING AND LEARNING

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Abstract
Science and engineering subjects at pre-tertiary and tertiary education levels are important for any country's socio-economic and industrial development; however, they are difficult for students to understand and apply. The rapid development of information and communication technology (ICT), especially in educational technology, has brought new possibilities in science, technology, engineering, and mathematics (STEM) subjects. Educational technology such as virtual laboratories is being considered as a sustainable solution to growing concerns related to physical laboratory training due to the cost of maintenance, shortage of infrastructure and insufficient or lack of laboratory expertise, apparatus, and reagents. Virtual laboratories have been proposed to minimize costs and build up students' experiences and enthusiasm towards learning STEM subjects. A virtual laboratory is a very useful tool for learning STEM-related practical skills not only in schools without laboratories but also in schools with laboratories, and it should be adopted by all pre-tertiary and tertiary schools in Nigeria.

Keywords: Information and communication technology, virtual laboratory, physical laboratories, learning outcomes, STEM education.

Introduction

Education is one of the most expensive investments any country can make in its human development. This is more challenging in developing countries due to the low gross domestic product and the ever-increasing economic challenges facing the educational sector. Nigeria is classified as a developing country and hence suffers the same fate as other developing countries where most of its citizens do not have sufficient resources to acquire quality education. However, the Nigerian government is committed to ensuring that its citizens have access to education through the provision of basic and functional literacy. There are still many challenges facing or affecting the development of

the educational sector, such as poor funding, high unemployment, and poverty, which to an extent pose a threat to access to formal education (George and Kolobe, 2014). This is despite the introduction of universal access to primary and secondary education, as advocated by the World Bank and United Nations. The major challenges of the educational system are financial, given that school ownership is either public or private.

Teaching science and technology-related subjects such as biology, mathematics, agriculture, chemistry, and physics requires a lot of investment in resources such as laboratories, studios, equipment, chemicals, and other facilities. The non-availability or limited resources of these facilities, necessary materials, and sometimes a shortage of qualified science teachers hinder the teaching and learning of science subjects in schools. These conditions create some level of anxiety and poor confidence in the students, hence generally affecting their performance in pre-tertiary and tertiary education because most students have either not performed any experiments by themselves or seen demonstrations by their teachers, while some reportedly have not been inside a laboratory (George and Kolobe, 2014). The challenges facing effective teaching and learning of science-based subjects due to a lack of infrastructure and equipment can be addressed by the adoption of Information and communication technology (ICT) in the educational sector in order to improve poor-quality laboratory education.

Information and communication technology is widely accepted in all areas of human activity, especially the educational system. Currently, there is a global trend towards achieving twenty-first-century educational skills, and digital literacy is one of the core aims of the United Nations Sustainable Development Goals (SDGs). There is an increasing concern about introducing more educational technology into the classroom for effective teaching and learning (Byukusenge *et al*., 2022). Globally, scholars believe that educational technology can transform the teaching and learning processes by providing teachers and students with access to relevant modern resources when integrated into teaching. However, the introduction of information and communication technology into teaching and learning can be deemed successful when it enhances the achievement of learning objectives because effective technology should enable students to achieve critical thinking by creating a shift from memorizing factual knowledge to understanding principles and applications.

Teaching Theory and concepts through experimentation in laboratories is fundamental to Science, Technology, engineering, and Mathematics (STEM) education. These laboratories and their furnishings are expensive to build, maintain, and expand, especially in developing countries. This has caused many schools, mostly government-owned schools, to engage in the theory of STEM-related subjects without any experiments. This deprives the students of the knowledge gained from performing experiments, such as arousing interest in science subjects, and they find it difficult to connect sometimes abstract theory to the real world (George and Kolobe, 2014). This situation has led to students losing interest in, eventually, the sciences and engineering-related courses. Hence, these challenges encountered in performing physical experiments can be solved by adopting information and communication technology via a virtual laboratory in the form of Video demonstrations, animations, and other internet-based resources as used in the developed world (Baker *et al*., 2013). Based on our experience in teaching science-related subjects to undergraduate students, we noticed a lack of confidence and knowledge in carrying out simple laboratory experiments; therefore, this scholarly article is to highlight the need for the adoption of virtual laboratories in the Nigerian educational system.

Virtual Laboratory

Virtual learning is the latest learning approach for the information and Communication technology-based educational system. Basically, virtual learning methods are developed to overcome problems in teaching conditions that demand high costs, high imagination, resourceful learning materials, and long hours (Baker *et al*. 2013). Virtual laboratories are developed to overcome challenges encountered in conventional classes and the conduct of harmful science experiments.

The virtual laboratory has been adopted as a new teaching method that is less expensive and less demanding but capable of retaining the students' interest in learning objectives.

A virtual laboratory is an interactive practical environment in which students and teachers can perform scientific simulated experiments while improving their abilities, skills, interest, and understanding of science and engineering ideas (Abdelmoneim *et al*., 2022; Redel-Macias *et al*., 2016). A virtual laboratory is an alternative learning environment that seems to contribute to the achievement of meaningful learning. The adoption of the virtual laboratory, which uses information and communication technology to solve educational problems for teachers and learners, has led to its growing presence in the educational system. It is gaining popularity in science and engineering education. There are various ICT-enabled learning tools for educational applications, including computer-assisted physical and chemical simulations and copying natural phenomena and conditions of an experiment (Bortnik *et al*., 2017). A virtual laboratory is a computer simulation that allows the essential activities of laboratory experiments to be performed on computer software. A virtual laboratory was developed to supplement conventional laboratory experiences and make them highly valuable and interesting. It enhances conceptual understanding and problem-solving skills, opens up new learning perspectives that cannot be explored in a regular laboratory, and produces learning outcomes that are equivalent to traditional hands-on laboratories (Abdelmoneim *et al*., 2022; Jimenez *et al*., 2021).

Adoption of Virtual Laboratory in STEM Education

The adoption of technology in science, technology, education, and Mathematics (STEM) education will play an essential role in enhancing the learning processes and increasing their understanding and applications. Laboratory courses constitute a mandatory part of STEM education because STEM courses are generally connected to technological development, both cognitively and practically. Therefore, educational professionals have considered the importance of integrating information and communication technology in STEM education, mostly virtual laboratories, in order to facilitate studying many scientific phenomena that cannot be studied in a physical laboratory due to its danger, poor laboratory facilities, or lack of time to complete the experiment (Gwozdz-Lukawska *et al*., 2015). A virtual laboratory will help the student achieve the main aims of STEM education through investigation and further searching in their various disciplines. The activities involved in virtual and physical laboratories can improve the learning environment and make it more constructive. However, there are differences between virtual laboratory and physical laboratory based on the nature of students' learning conditions; for instance, students in physical laboratory will focus on how to use the physical equipment and the possible outcomes, while students in virtual laboratory direct their attention to variables and the interaction of the variables that produce the outcomes (Widodo *et al*., 2017; Toth, 2016).

The fields of electronic learning are diverse, including virtual laboratories, which are considered the main idea in practical electronic learning, seeing that virtual laboratories closely resemble physical laboratories. Moreover, a technology-enriched environment would greatly enhance students' motivation and develop a positive attitude towards studying STEM courses. There are several emphases on the fact that the adoption of virtual laboratories in STEM education will help enhance academic performance, improve students' awareness of scientific concepts, and modify misconceptions attached to learning STEM-related subjects. An experiment takes the form of a simulation when a real experiment is replaced by a computer model. Virtual laboratories enable students to perform experiments in an online environment, and they can be used alone or in combination with other physical laboratories (Hamed & Aljanazrah, 2020). The instructional design of a virtual laboratory involves the use of video demonstrations, simulation tools, animation, and interactive presentations to improve students' understanding of macroscopic, sub-microscopic, and symbolic levels of scientific demonstration. There are numerous web-based resources for teaching and experimental demonstrations for

STEM core subjects, such as Beyond Labz, Virtlab, the Chemistry Collective, Royal Society of Chemistry demonstration videos, molecular workbench, Merlot, and PBS NOVA Concord Consortium, to Mention but a few. Moreover, these resources still need some investment in terms of procuring access licenses, dealing with software glitches, and internet access, especially in low-income countries (George & Kolobe, 2014). This limitation can pose a serious challenge to the adoption of virtual laboratories in STEM education.

The adoption of Virtual laboratories will ease the pressure brought on pre-tertiary and tertiary education in terms of the cost and maintenance of physical laboratories while utilizing the extensive technological knowledge of students in their present condition. Studies have shown that properly planned and executed virtual laboratories increase students' knowledge, skills, and performance in examinations while reducing limitations posed by geography, health, safety, cost, and availability of materials (Lewis, 2014). Virtual laboratories are perceived as mere additions to traditional laboratory set-ups with the potential to provide an equal and enhanced learning experience to the students, with many benefits that traditional physical laboratories cannot offer. The model of a virtual laboratory component of organic chemistry and molecular biology experimental session are presented in Figure 1 and 2.

Figure 1. Screenshot of Molecular biology environment in the virtual laboratory (adopted from Beyond Labz)

Figure2. Screenshot of organic chemistry environment in the virtual laboratory (adopted from Beyond Labz)

Prospects of Virtual Laboratories

Laboratory experience is an important component of technical and scientific education. Laboratory practices give students the confidence to deal with real issues in realistic environments. Therefore, there is a need to enhance their motivation and enthusiasm for STEM subjects through large-scale initiatives to ensure that enough graduates meet the employment needs of society (De Jong *et al*., 2014). Virtual laboratories have been proposed to reduce the cost and maintenance of laboratory facilities while offering students a safe environment to build up experience and enthusiasm for STEM subjects.

The major prospects of a virtual laboratory in addition to a physical laboratory are the following:

1. Virtual Laboratories are viewed as learner-centred and inquiry-based simulations that promote higher levels of thinking and retention. It allows students to receive immediate feedback and correct their faulty understanding of a concept they believe to be abstract (Smetana & Bell, 2012).
2. Virtual laboratories offer a solution to the challenges of physical practical classes in STEM education by providing conducive environments for students to interact with each other through the use of virtual objects and apparatus through a software interface that is connected to hardware in one centralized place (Wolf, 2010).
3. Virtual laboratories allow students to develop their reasoning, innovative, critical thinking, and creative skills without the usual limitations of resources, time, and space since educational reforms emphasize inquiry-based learning (Wang *et al*., 2015).
4. Virtual laboratories are easy to set up, use, and maintain, with appreciable cost and time reductions.
5. Virtual laboratories offer more possibilities for simulating and virtualising quite a number of complex scientific concepts. It helps students increase their knowledge regarding unobservable molecular-level phenomena and acquire better conceptual understanding (Bortnik *et al*., 2017).
6. Students develop a positive attitude towards the use of computers for learning. Simulation of laboratory experiments helps in motivating and creating a lot of experience among students as it supports them in the accomplishment of cognitive tasks and enhances their learning processes.
7. Virtual laboratories will allow teachers to capture students' attention and ensure their engagement and motivation towards STEM subjects.
8. Virtual laboratories will help students learn at their own pace as they can prepare and carry out laboratory experiments at any time and place.
9. Virtual laboratories will help teachers and students to explore topics that could be unachievable in conventional physical laboratory.
10. Virtual laboratories allow the sharing of resources between geographically distributed educational institutions and users.
11. Virtual laboratories have been affirmed to lessen financial burdens related to laboratory equipment, space, and maintenance experience in the setting up of physical laboratories.
12. Virtual laboratories have proven helpful when conducting experiments that could involve dangerous substances and apparatus.
13. Virtual laboratories allow students to learn from mistakes without causing any real damage to themselves or others.
14. Virtual laboratories allow students to repeat experiments multiple times, providing them with the chance to change the parameters of their experiments to enable them to understand a variety of lesson types and topics.
15. Virtual laboratories are asset tools required to mitigate the challenges of

insufficient laboratory equipment needed in the teaching of STEM subjects, especially in developing countries.

16. Virtual laboratories benefit disabled students greatly as they are not exposed to the physical limitations found in physical laboratories.

Challenges of Virtual Laboratories

Considering the prospects and adoptions of virtual laboratories, e-learning-based virtual laboratories cannot replace traditional or physical laboratories but can respond to the existing challenges faced by physical laboratories and optimize the teaching and learning process. Virtual laboratories have the potential to revolutionize the teaching of STEM subjects, but gaps between their recognized potential and their actual application still exist. There are major virtual laboratories in our educational system.

1. Virtual laboratories have come under criticism due to their lack of a real-life feel and the fact that they do not teach laboratory safety to students.

2. Virtual laboratories make students unable to feel, smell, or touch materials and chemicals as in a physical laboratory.

3. Virtual laboratories do not allow students to handle real equipment and apparatus, which makes them feel as if they are missing out on some stages of practical training available in physical laboratories.

4. The incorporation of virtual laboratories into the education process always requires an adjustment or extension of existing resources that are available within the laboratories. This is a major challenge for teachers, as they are required to at least understand the underlying technology behind virtual laboratories to be able to input new content.

5. The emergence of virtual laboratories has created doubts about the need for social interaction among students while using virtual laboratories for the learning process.

6. The drawback of virtual laboratories is that they diminish direct communication among students, instructors, or teachers in the laboratory.

7. It increases the risks associated with physical laboratory work.

8. The high cost and lack of qualified human resources involved in the development and expansion of virtual laboratories have been identified as major obstacles.

CONCLUSION

The article lays the groundwork for adopting virtual laboratory technology to leverage the quality of the learning process and advance the Nigerian educational system through theory and practice. The findings conclude that virtual laboratories are more effective in teaching difficult and abstract STEM topics. Conceptual understanding of STEM subjects is the learning outcome, which is mostly enhanced when using virtual laboratories. This article x-rays the prospect of adopting virtual laboratories in the Nigerian educational system and affirms that virtual laboratories provide students with practical experience in STEM subjects while reducing the costs and hazards associated with physical laboratories. Furthermore, virtual laboratories improve students' motivation, self-efficacy, and attitudes towards learning STEM subjects. This article also discusses the challenges of adopting virtual laboratories in teaching and learning in the Nigerian educational sector. The effectiveness of virtual laboratories, like any other instructional tool, may be largely affected by how they are used in the classroom. The authors observed that virtual laboratories deserve the attention of researchers, teachers, and instructional designers because of their potential as a means of actively involving students in safer and more cost-effective scientific inquiry. Thus, we recommend further studies on the prospects and challenges of adopting virtual laboratories in teaching and learning in the Nigerian educational system.

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