Virtual Laboratories for STEM in Nigerian Higher Education: The National Open University of Nigeria Learners' Perspective

Juliana Ngozi Ndunagu[1], Kingsley Eghonghon Ukhurebor[2], Adewale Adesina[1]

[1] *National Open University of Nigeria, Abuja, Nigeria*
[2] *Edo State University Uzairue, Edo State, Nigeria*

Abstract

Virtual Laboratory (VL) has revolutionized STEM programs in higher education, and there is an increasing demand for VL education to replace or to focus on an integrative technique in the resolution of real-life issues with the utilization of technology. The high and growing demand for VL education is to replace or complement remote, feasible, and equitable hands-on practical learning, and this will support ubiquitous learning from any place at any time in a flexible environment. A VL allows access via an internet connection and offers learners the required infrastructure to complete laboratory tasks without attending physical laboratory facilities from anywhere and anytime. NOUN is an open and distance learning (ODL) institution with 110 study centres. It is very difficult to duplicate physical laboratories in all the centres for STEM students. Currently, NOUN conducts physical education, or hands-on practical, for students in only thirteen centres, and students from other centres are expected to join the nearest study centre for the exercise, but previous exercises showed that the attendance had been very low due to obvious constraints. However, there is little information on how virtual laboratories are being developed and used, and more research on how virtual laboratories can be effectively used to address equity and access issues in STEM education is needed. This research paper presents a survey study that aims to explore the implementation of virtual laboratories in STEM courses at the NOUN from the perspective of students. This study applied an online survey design by using a Google form to collect data from STEM NOUN students (undergraduate and postgraduate). The study surveyed 4570 students enrolled in STEM courses, and data were collected through an online questionnaire. The questionnaires were distributed using the students' WhatsApp numbers and consisted of five (5) sections of open- and closed-ended questionnaires. Statistical Packages for Social Sciences (SPSS) was coded in spread sheets to analyse responses from independent variables among the demographic data collected. The overall result showed that 49% opted for physical laboratories, 21% selected VL, 12% picked collaboration with other universities, 08% adopted hybrid, and 09% chose no idea. NOUN practices remote learning and already has an existing Learning Management System (LMS) website, which allows learners to access it by utilizing their internet connections and a web browser, from anywhere and anytime. This means that the integration of VL, when developed, can easily be plugged into the NOUN's existing LMS. VL are known to keep learners' interest up, have the ability to generate a lot of data for learning analytics, and are cost effective. The introduction of a VL in NOUN will drastically reduce the rate of attrition among NOUN STEM-based learners. Generally, developed VL for STEM can be shared with STEM courses in other Nigerian higher education institutions since both the conventional and non-conventional modes of learning in Nigeria have the same curriculum.

Keywords

Nigerian higher education, virtual laboratory, NOUN, ODL, STEM

Proceedings of the Technology-Enhanced Learning in Laboratories workshop (TELL 2023), April 27, 2023, Online.
EMAIL: jndunagu@noun.edu.ng (A.1); ukeghonghon@gmail.com (A.2); aadesina@noun.edu.ng (A.3)
ORCID: 0000-0003-2018-089X (A.1); 0000-0001-7595-3939 (A.2); 0000-0003-2491-7289 (A.3)

1. Introduction

The term “virtual laboratory (VL)” describes a way of delivering content in which all experiments and content are presented in a virtual setting using simulations and videos. It is widely acknowledged that the learning component of Science, Technology, Engineering, and Mathematics (STEM) classes is an essential part of the educational process. These experiences can take many different forms, such as lab sessions and project design [1]. The higher education industry needs to embrace ubiquitous learning (U-Learning), which enables learning to take place using any device in a flexible environment of time, place, and speed [2].

The adoption of VL, which uses internet technology to deliver educational solutions to the learners with a network system and an emphasis on on-demand learning, supports STEM learning in the modern era [3]. The desired learning outcomes are varied and include cognitively simple objectives like applying concepts and principles learned in class, working in a laboratory, and performing data analysis [4]. A virtual environment must be developed in order to create a VL, and this can be done using either publicly available platforms or platforms that have been specifically built for the purpose [5].

Since VL includes a variety of activities, they will retain students' attention. Since the VL files and executables can be distributed to students in a variety of ways, including online and offline media in the form of CDs, downloadable web applications, and a dedicated server system stored locally or remotely on the cloud, the VL is cost-effective [6, 7]. Through the use of remote laboratories, physical facilities that can be accessed over a network connection, related software, and unlimited internet access, virtual learning gives students the chance to put their theoretical knowledge into practice [8].

Although VL lacks physical facilities, they do have online tools, such as hardware and software, that can be accessed [9]. Users can access the internet concurrently based on the elasticity of the laboratory facility and go beyond what a physical laboratory can provide thanks to the virtual character and remote access of the laboratory resources. In order to develop the skills required by the industry, STEM higher education students must put their academic knowledge into practice. Additionally, VL offers collaborative opportunities, flexible learning opportunities, and a setting that serves as a prelude to actual laboratories [10].

Technology use is a benefit for preparing graduates for future jobs [11, 12, 13, 14, 15], because it allows them to access and interact with VL. Based on the technology and material used for delivery, the VL needs to be properly designed, and a choice needs to be made with knowledge. It's crucial to offer students a virtual space where they can engage with and view animations of physical simulations that have been conducted to create the desired virtual experiment [16].

Nigeria's higher education institutions have had a number of difficulties throughout the years, which have resulted in low educational quality and graduates who are unable to meet corporate expectations. These issues in scientific and engineering-related courses include crammed lecture halls, overcrowded workshops, and laboratories, a lack of lab space, inexperienced staff, and inadequate laboratory equipment [17]. Higher education in Nigeria has deteriorated over time, and graduates have had trouble meeting expectations in their fields. These issues are common in scientific and engineering-related professions. In light of these financial constraints, institutions must look for a practical and long-lasting solution to alleviate infrastructural problems. Therefore, this proposal suggests converting some of the physical infrastructure, like physical laboratory (PL) into a VL. According to Redel-Macas et al. [18] software-based infrastructure is more dependable and less expensive than physical infrastructure. The National Universities Commission (NUC) is actively investigating open and distance learning (ODL) as a way to increase access to postsecondary education in Nigeria without compromising quality [19]. ODL has become widely accepted as a substitute for traditional education, claims [20]. There are currently more than 10 educational institutions in Nigeria with permits to offer ODL programs, although very few of them offer engineering or science-related courses. Despite ODL's benefits and potential, learning science in Nigeria is still exceedingly challenging because print media still predominates in the educational landscape.

Open Distance Learning (ODL) requires students to complete their coursework online rather than face-to-face as in the traditional method. The ODL system is flexible and accessible, and facilitators are physically separated from the learners. The National Open University of Nigeria (NOUN) is one of the open and distance learning institutions in Nigeria, with over 500,000 students across 110 study centres within the country. There are eight (8) faculties, of which four are STEM-based, with laboratory practical as a prerequisite for graduation. The challenges for ODL learners, especially STEM-based learners, are how to overcome the problems associated with VL components of courses [21]. However, studies have shown and affirmed that the major challenge of ODL institutions is the high rate of attrition of students, and it remains a major concern for many educational institutions [22].

It is difficult for ODL institutions to practice hands-on practical due to the dispersed nature of the students [21], and this has contributed to the high rate of dropout, especially among STEM-based learners [23, 24]. This study has investigated students' views on the proposed introduction of virtual laboratories in NOUN with the following research questions:

1. What percentage of students are working while studying in the sample at the NOUN?
2. How effective do students perceive virtual laboratories to be in enhancing their understanding and skills in STEM subjects at NOUN?

Laboratories are indispensable in university structures, especially in STEM education [25]. This experiment suggests that integrating VL into the ODL curriculum will be a more effective way to give ODL students a practical education. Students will have the opportunity to get the information and real-world experience they need to compete with peers attending conventional universities thanks to this. Since the experiment description contains all necessary instructions, instructors are not required in VL [26].

The constructivism learning theory, also known as learning by observation and practice, acknowledges the value of traditional laboratory work in raising students' levels of cognitive understanding. However, in order to comprehend scientific phenomena and further explore the underlying scientific concepts, scientific experiments are regarded as crucial methodologies and processes [27]. Virtual technology may be used to share specialised, expensive, scarce tools and resources that only have a limited number of users due to geographic time and place. It might be a method to put underutilised facilities to their best use. A wider number of students can access the practical with the use of VL [26]. Potential risks that could arise in an actual experiment are eliminated by VL. A high-risk coefficient makes it hard to teach and exhibit some experiments (radioactive, high-power voltage, concentrated acidic liquids, etc.) for educational purposes. VL is a platform for experimentation and demonstration that eliminates risk and safety [18]. Insufficient reagents and equipment, inadequate technical support, time restraints, worries about their personal safety, and equipment limitations are just a few of the challenges faced by students in PL. These might make students less enthusiastic about practical subjects or fields of study. Less than 40% of students who enrol in STEM disciplines are unable to do so for this reason [28].

Students' experiments in real laboratories play important roles in teaching and learning because laboratory work improves students' motivation to learn based on acquired soft skills, particularly in STEM. The conventional approach of setting up physical laboratories is both expensive and time-consuming, though effective delivery of courses through VL is highly necessary in STEM-based disciplines [21].

Nigerian higher education consists of conventional and non-conventional modes of learning. The conventional and non-conventional institutions have the same curriculum and are under the same regulatory body, the National Universities Commission (NUC). ODL institutions practice a non-conventional mode of learning. For those students who don't take on-campus classes, ODL provides distance learning. The dispersed nature of ODL students has contributed to a high rate of attrition, especially among NOUN learners. NOUN is one of the foremost ODL institutions in Nigeria, with over 500,000 students and 110 study centres; learners also practice hands-on practical in only twelve study centres. Learners from other studies are expected to join for the practical exercise, but the turnout has always been very low due to some obvious constraints. It will be very difficult to duplicate laboratories in the 110 study centres due to the high cost of equipment for hands-on practical. The connectivism learning theory is hosting this study, which examined and evaluated VL in comparison to physical laboratories. The applications are in STEM. Evidently, higher education STEM programs have been transformed by VL, and there is a growing need for VL education to replace or concentrate on an integrative approach in the resolution of real-life problems with the use of technology. In order to replace or supplement remote, practical, and equitable hands-on learning, there is a high and expanding demand for VL education. This will enable ubiquitous learning from any location at any time in a flexible setting. A VL provides learners with the necessary infrastructure to carry out laboratory tasks without physically visiting real laboratory facilities at any time or place and enables access via an internet connection. Hence, this study is aimed at analysing VL for STEM in Nigerian higher education from the NOUN learners' perspective in order to project how VL can complement teaching by replacing experiment equipment and potentially reducing dangerous laboratory exercise. The research used a Google form to collect information from STEM NOUN students (undergraduate and postgraduate) using an online survey design. The five (5) parts of the questionnaires, which were open- and closed-ended, were distributed using the students' WhatsApp numbers. To evaluate responses from independent variables among the gathered demographic data, spreadsheets with Statistical Packages for Social Sciences (SPSS) coding were used.

Generally, the introduction of virtual laboratories in over 200 Nigerian higher education institutions, which comprise federal universities in Nigeria, state universities in Nigeria, and accredited private universities in Nigeria, will complement the physical laboratories. The other sections of this paper include Section 2, which is for the literature review; Section 3, which is for the methodology; Section 4, which is for the results and discussion; and Section 5, which is the conclusion of the paper.

2. Literature review

2.1. Conceptual review

The virtual learning environment (VLE) or remote learning system used by NOUN and in relation to STEM is a launch pad for the proposed VL, and in order to embark on VL, the strength and coverage of NOUN internet must be upgraded. The readiness to introduce a VL is measured in terms of its perceived usefulness, awareness, and how respondents perceive the new system [29].

The difference between respondents who believe that NOUN is ready to embark on a VL and those who do not believe in the new system when it is launched should be run together with the existing physical laboratory system, which is a blending of digital learning with traditional learning for better comprehension [30].

2.2. Theoretical review

In higher education settings, behaviourism, cognitivism, constructivism, humanism, and connectivism are the five main theories of learning that have been applied [31]. The four fundamental learning theories that govern instructional settings are behaviourism, cognitivism, constructivism, and humanism. Connectivism theory places a strong emphasis on connecting with students online. The knowledge-learning paradigm known as connectivism was created for online learning environments [32]. To encourage discussion and flexible learning possibilities, connectivism is combined with online collaboration and LMS integration in the creation of VL.

In their studies, Jou and Wang [33] outlined the advantages of using virtual environments in the education space and the use of VL to teach practical modules as being extremely important because they allow STEM courses to be taught and practical to be carried out in ODL institutions without the need for the students to be physically present. Distance learning institutions teach courses remotely, and as a result, using VL in these institutions to teach practical skills in STEM-based courses and other hands-on courses is a necessity [21]. The challenge of teaching laboratory components is more complicated at NOUN based on the capital-intensive nature of replicating laboratories in the 110 dispersed study centres across the nation, coupled with the expected rigor by students and facilitators in accessing those centres [34, 35].

The use of VL can aid ODL institutions in cutting down on the costs of laboratory setup and maintenance [21]. Thus, a ubiquitous (VL) alternative approach becomes necessary. The proposed approach is to leverage the potentials of cloud computing infrastructure, services, and platforms in creating simulated virtual practical environments that can be accessed by all NOUN STEM-based students, irrespective of their geographical locations. Such opportunities will increase study activities, motivate students, and allow learners to conduct practical experiments individually, repeat them multiple times if needed, and are minimum instructor-dependent [36, 34].

2.3. Empirical review

A VLE called “velnet or meiro” was specifically developed for VL in diverse fields, such as computer networking and computer graphics. Consequently, VLE ameliorates the competence of students in diverse fields of learning and is used stand-alone or as a plug-in for the LMS [37].

Tsihouridis et al. [38] analysed the order in which students in the electronics module should carry out real experiments, such as the real experiments before the virtual experiments. The outcomes showed the order in which the real or VL used affected learners.

VLE or remote learning systems were evaluated based on the “Unified Theory of Acceptance and Use of Technology (UTAUT)”. These were cases of teaching at one school of public health, an empirical study in Turkey and the UK [39, 29]. In their research, West and Veenstra [40] discovered that, despite liking the convenience of a virtual experience, 97% of physiology students did not want the physical experiments converted to computer simulations because they valued the opportunity to directly manipulate animal tissue.

In their study, Dalgarno et al. [41]examined the efficiency of a VLE in a chemistry lab as a tool to get online chemistry students ready for residential school on-campus. The outcome showed that VL can be used to give students confidence and help them overcome anxiety by familiarizing them with the experiments before they carry them out in their physical form. According to the paper's findings, detailed instructions and scaffolding must be integrated for certain tasks in the experiments if there is to be a significant improvement in the effectiveness of using a VL to teach remotely.

In their research, Coleman and Smith [42] used a VL simulation to teach health and safety to students in a bioscience module. Their findings demonstrated that the students had gained a deeper comprehension, more information, and the confidence to carry out physical experiments in the real world. Tan et al. [43] combined chemistry and computer science knowledge to create a fully automated remote titration experiment. The possibility of sharing expensive equipment between various departments and organizations is also made possible by this delivery method.

3. Methodology

This is an investigative study that sought to understand the impact of VL delivery system against physical laboratory system. There are no longer many traditional forms of instruction that require in-person participation, such as lectures and laboratories, so educators are modifying their methods of instruction while still meeting the needs of their students [44, 45, 15]. It can take many different forms, such as reducing the amount of coursework required, switching to online modes for traditional content delivery, interaction, and assessment, and transforming practical instruction into virtual, remote, or hybrid experiences [46]. Massive Open Online Courses (MOOCs) [47, 15] and Education Technology [48], are examples of pedagogical trends and tools from space that can offer the resources and know-how required to adopt courses for online/remote delivery. It also used open-ended question method to collect responses from the students for a designed and developed practical laboratory teaching system that would improve learning experience and outcome.

This study also evaluated and assessed 4,570 NOUN students in terms of the proposed VL by using a survey technique. The experiments and projects that are carried out in teaching laboratories vary greatly between disciplines, and this study introduced three packages for evaluation in order to achieve the desired results.

Hands-On: Practical STEM practice should emphasize hands-on skills because they help students become accustomed to tools or environments and give them tactile information that affects their cognitive and psychomotor development.

Virtual: Students apply their theoretical knowledge in real-world experiments or in situations where equipment is used but is not the main goal of the experiment in virtual experiential learning. Students’ knowledge is not always necessary for these activities, but it is used as a tool to gather information or complete a task.

Hybrid: Combining hands-on and simulations, hybrid experiential learning activities use simulations as their main mode of experimentation. These are experiments that can cover a wide range of topics by visualizing molecular mechanisms, protein dynamics, and time scales without the use of any physical equipment.

4. Research analyses

4.1. Research instrument and method

This research used an online survey design and a Google Form to collect data from NOUN students (undergraduates and postgraduates). The questionnaire was distributed through the students' WhatsApp numbers. The questionnaire consisted of 5 sections made up of open- and close-ended questions. The responses were coded in a spreadsheet and analysed using SPSS.

4.2. Data analysis

Table 1 depicts the frequency distribution of demographic objects as well as a test of association between demographic data and age, gender, and field of study. Then, a response variable that captured each of the 4,570 respondents' responses suggested three ways practical teaching should be structured. The result yielded 13,710 suggestions. These responses were regrouped into five sub-groups, and the responses of participants assigned to these five groups were used for SPSS tests. Tables 1 and 2 showed the association test result of demographic variables Age, Gender, and Faculty cross-tabbed with open-ended statements on how NOUN practical teaching should be structured. These analyses were highly tailored to the experiment, with features such as simple measurement, data recording, and automatic report generation. The data analyses and outcomes were provided by students in codified manners such as off-line media and CD.

Figure 1 shows the frequency distribution of suggestions on how students want NOUN practical teaching to be structured. The 2,240 (49.02%) students want a continuation of the face-to-face method because a stand-alone virtual system is not feasible. Collaboration with established institutions received 570 (12.48%) responses. Participants who supported virtual learning were 980 (21.44%). Both blended and no idea had 390 (8.53%) each.

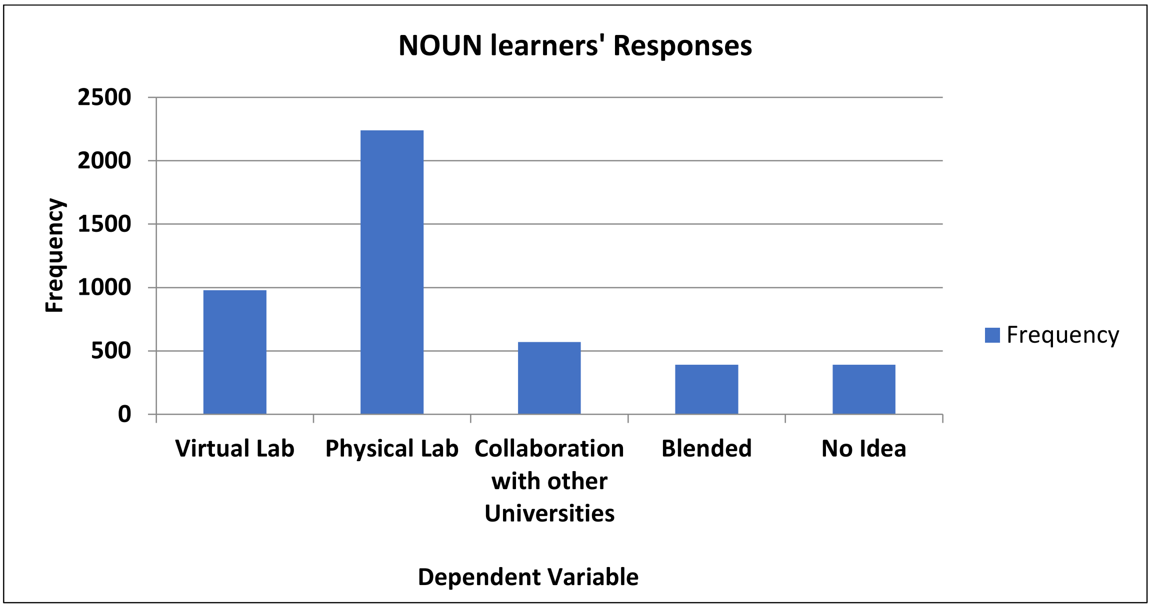

Figure 1: The Frequency distribution of suggestions on how students want NOUN practical teaching to be structured.

Table 1
Socio-demographic frequency

S/N	Variables	Frequency	Percentage (%)
i.	**Gender**		
	Male	1,830	40
	Female	2,740	60
	Total	**4,570**	**100**
ii.	**Age**		
	17-19	120	03
	20-22	460	10
	23-25	540	12
	>25	3,450	75
	Total	**4,570**	**100**
iii.	**Are you working and studying**		
	Yes	3,810	83
	No	590	13
	Indifferent	170	04
	Total	**4,570**	**100**
iv.	**Faculty**		
	Arts	30	01
	Science	3,960	87
	Education	10	00
	Others	570	12
	Total	**4,570**	**100**
v.	**Present NOUN practical teaching**		
	Physical/Face-to-face	4,520	99
	Missing system	50	01
	Total	**4,570**	**100**

Table 2
Frequency distribution of subgroups

S/N	Dependent variable (user defined how NOUN practical teaching should be structured)	Frequency	Percentage (%)
i.	VL	980	21.44
	Physical laboratory	2,240	49.02
	Collaboration with other Universities	570	12.48
	Blended	390	08.53
	No Idea	390	08.53
	Total	**4,570**	**100**

5. Findings/results

NOUN students assembled in six geopolitical locations across the country for hands-on practicals, but low turnout was evident due to obvious constraints, and it has not created the expected impacts in terms of acquired soft skills [24]. The experience of the NOUN in this regard is not different, and since both virtual and physical laboratories provide students with the same level of access to laboratory content, virtual laboratories are suggested as an extension of the existing virtual learning environment (VLE) [27].

Liu [27] incorporated a 3D virtual learning platform that was designed and implemented into an open and distance learning platform and is considered an inexpensive option for institutions and students. This agrees with the responses and various demands made by the respondents in the open-ended survey conducted for data collection. This ranges from requests for increased internet strength, free data, and the cost effectiveness of the proposed system.

NOUN has an integrated, dedicated online learning management system (LMS) and also dedicated communication channels that, if moderated, can offer educators flexibility and control in terms of setting deadlines and providing feedback mechanisms. According to the results, the majority of the 2,240 participants (49.02%) believe that NOUN is not yet ready to embark on VL because the institution lacks the financial resources to support the implementation structure. The challenges that students may face in VL include technical issues, inadequate guidance, and limited interaction with instructors and peers. Also, the 2,240 students had no prior experience with virtual laboratories to know the plethora of advantages.

The difference between Categorized Remote Learning, which NOUN currently practices, and Categorized VL, as perceived by 980 (21.44%) respondents, believes that a Remote Learning system is required for maximum VL success. Only 390 students opted for hybrid practical, this is also due to the fact that the students had not prior experience with using both virtual laboratories and physical laboratories, where the virtual laboratories serve as a prelude to the physical laboratories. Viitaharju et al. [5], in their study showed that students can learn with a deep knowledge and make links between scientific theory and its practical applications in technology through hybrid virtual and hands-on activities. This improves the ability of learned knowledge and abilities to be applied outside of the classroom to address engineering problems encountered in the real world.

6. Conclusion/recommendations

Virtual simulation-based laboratories have been developed, and technological advancements can be employed in ODL institutions, while NOUN should take advantage of these advancements to make a significant impact and establish a standard VL for academic and result-oriented laboratory results. Before virtualizing the laboratory aspect of learning, the remote learning system or VLE should be upgraded in terms of hardware, software, internet resources, and qualified resource persons.

VL is generally feasible in ODL institutions and can cmplement real laboratories. NOUN is an ODL institution, but due to the diverse nature of the mode of ODL, it is difficult for STEM-based students to practice traditional (real or physical) laboratory. However, because most ODL institutions deliver courses via VLEs, it is sufficient to plug the designed and developed content of the practical on the field into the ODL institution's VLE. VL implementation in ODL institutions will benefit both students and institutions in terms of cost effectiveness, convenience, and coverage, regardless of geopolitical location. Though the practice of both the virtual and traditional laboratories will increase students' knowledge in the field of concern.

7. References

[1] W. Chen, U. Shah and C. Brechtelsbauer, "A framework for hands-on learning in chemical engineering education—Training students with the end goal in mind," *Educ. Chem. Eng.,* vol. 28, pp. 25-29, 2019.

[2] B. Gros and M. Kinshuk Maina, "The Future of Ubiquitous Learning- Learning Designs for Emerging Pedagogies. Lecture Notes in Educational Technology. The Future of Ubiquitous Computing.," Springer Nature, Berlin/Heidelberg, Germany., 2016.

[3] M. Rosenberg, E-Learning: Strategies for Delivering Knowledge in the Digital Age, New York, NY, USA: McGraw-Hill Education, 2000.

[4] M. Xie, P. Inguva, W. Chen, N. Prasetya, A. Macey, P. Dimaggio, U. Shah and C. Brechtelsbauer, "Accelerating students' learning of chromatography with an experiential module on process development and scaleup," *J. Chem,* pp. 1-28, 2020.

[5] P. Viitaharju, K. Yliniemi, M. Nieminen and A. Karttunen, "Learning experiences from digital laboratory safety training," *Educ. Chem. Eng.,* vol. 34, pp. 87-93, 2021.

[6] B. Kyaw, P. Posadzki, G. Dunleavy, M. Semwal, U. Divakar, V. Hervatis and L. Car, "Offline digital education for medical students: systematic review and meta-analysis by the digital health education collaboration," *J. Med. Internet Res.,* vol. 21, pp. 1-16, 2019.

[7] R. Alvarez, T. Mirzoev, A. Gowan, B. Henderson and S. Kruck, "Learning laboratories as services in private cloud deployment," *J. Comput. Inf. Syst.,* vol. 59, pp. 354-362, 2019.

[8] S. Kurukunda, C. Trigona and S. Baglio, "Laboratory Activity during COVID- 19 as a "Virtual Experience": Restriction or Chance?," in *17th International Multi-Conference on Systems, Signals Devices (SSD)*, Sfax, Tunisia, 2020.

[9] S. Bermejo, "Cooperative electronic learning in virtual laboratories through forums," *IEEE Trans. Educ.,* vol. 48, pp. 140-149, 2005.

[10] R. Vasiliadou, "Virtual laboratories during coronavirus (COVID-19) pandemic," *Biochem. Mol. Biol. Educ.,* vol. 48, p. 482–483, 2020.

[11] M. Asanga, U. Essiet, K. Ukhurebor, A. Afolorunso and P. Hussaini, "Social media and academic performance: a survey research of senior secondary school students in Uyo, Nigeria," *International Journal of Learning, Teaching and Educational Research,* vol. 22, no. 2, pp. 323-337, 2023.

[12] E. Odinakachi, O. Mbalisi, K. Ukhurebor, J. Opateye and E. Leonard, "Accessibility of instructional materials for effective teaching: outlook from high schools in Eleme, River State, Nigeria," *Cypriot Journal of Educational Sciences,* vol. 18, no. 2, pp. 456-469, 2023.

[13] A. Olusegun, E. Uranta, K. Ukhurebor, G. Jokthan, A. Bello and D. Nalwadda, "Appraisal of e-learning and students' academic performance: a perspective from secondary schools," *Cypriot Journal of Educational Sciences,* vol. 18, no. 1, pp. 351-367, 2023.

[14] E. Emeka, J. Okoza, K. Ukhurebor, G. Onwodi, F. Bayonle and J. Nyagblordjro, "The impact of internet use on tertiary institution students' academic performance: an exploratory study," *Cypriot Journal of Educational Sciences,* vol. 18, no. 1, pp. 253-267, 2023.

[15] C. Nneji, R. Urenyere, K. Ukhurebor, S. Ajibola and O. Onaseso, "The impacts of covid-19-induced online lectures on the teaching and learning process: an inquiring study of junior secondary schools in Orlu, Nigeria," *Frontiers in Public Health,* vol. 10, no. 1054536, 2022.

[16] C. Garcia, J. Naranjo, E. Alvarez-M and M. Garcia, "Training virtual environment for teaching simulation and control of pneumatic systems," in *Augmented reality, virtual reality, and computer graphics*, Springer Nature, 2019, pp. 91-104.

[17] O. Nsikan, I. A. Anayo and E. E.O, "Engineering Education and Development in Nigeria Beyond 2020," 2017.

[18] M. Redel-Macías., S. Pinzi, A. Cubero-Atienza, M. Dorado and M.-J. M.P, "Biorefinery Virtual Lab-Integrating E-learning Techniques and Theoretical Learning," in *International Joint Conference, CISIS'12-ICEUTE´12-SOCO´12*, Heidelberg, 2013.

[19] NUC, "Approved Programmes of Distance Learning Centers," NUC- National Universities Commission, 2019.

[20] L. Flowers, "Investigating the Effectiveness of Virtual Laboratories in an Undergraduate Biology Course," *The Journal of Human Resource and Adult Learning,* vol. 7, no. 2, pp. 110-116, 2011.

[21] P. Umenne and S. Hlalele, "Evaluation of the effectiveness of virtual laboratory's for Electronics in the Open distance learning Context," in *2020 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD)*, Durban, South Africa, 2020.

[22] A. Yilmaz and S. Karataş, "Why do open and distance education students drop out? Views from various stakeholders," *International Journal of Educational Technology in Higher Education,* vol. 19, no. 28, 2022.

[23] J. Ndunagu, E. Ukwandu, M. Ezema, C. Olebara, M. Ugwu, J. Igwe, D. Oyewola and S. Fapohunda, "Future of remote learning: the virtual laboratory perspective," *University of Ibadan Journal of Science and Logics in ICT Research,* vol. 8, no. 1, pp. 55-68, 2022.

[24] S. Utami, I. Winarni, S. Handayani and F. Zuhairi, "When and who dropouts from distance education?," *Turkish Online Journal of Distance Education,* vol. 21, no. 2, p. 19, 2020.

[25] J. Brinson, “Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research,” *Computers & Education,* vol. 87, pp. 218-237.

[26] T. Budai and M. Kuczmann, “Towards a Modern, Integrated Virtual Laboratory System,” *Acta Polytechnica Hungarica,* vol. 15, no. 3, 2018.

[27] D. Liu, P. Diaz, G. Riofrio, Y. Sun and R. Barba, “Integration of virtual labs into science e-learning,” in *International Conference on Virtual and Augmented Reality in Education, 75, 95-102.*, 2015.

[28] P. Ari-Gur, P. Ikonomov, R. Rabiej, P. Thannhauser, M. Hassan, D. Litynski and R. Schwartz, “Transforming Undergraduate Engineering Education with 3D Virtual Reality Laboratory,” in *ASEE Annual Conference & Exposition*, Atlanta, Georgia, 2013.

[29] M. Camilleri and A. Camilleri, “The students’ acceptance and use of their university’s virtual learning environment,” in *11th International Conference on E-Education, E-Business, E-Management, and E-Learning, (IC4E)*, Osaka, Japan, 2020.

[30] C. Olebara, “Mobile devices as tools for implementing digital classroom in Nigeria,” *Journal of Emerging Technologies,* vol. 2, no. 1, 2022.

[31] H. Kapici and H. Akcay, “Cognitive Theories of Learning on Virtual Science Laboratories,” in *Education Research Highlights in Mathematics, Science and Technology*, Ames, IA, USA, ISRES Publishing, 2019, p. 107–126.

[32] J. Goldie, “Connectivism: A knowledge learning theory for the digital age?,” *Med. Teach.,* vol. 38, p. 1064–1069, 2016.

[33] M. Jou and J. Wang, “Investigation of effects of virtual reality environments on learning performance of technical skills,” *Comput. Human Behav.,* vol. 29, no. 2, 2013.

[34] K. Aljuhani, M. Sonbul, A. M and M. Meccawy, “Creating a virtual science lab (VSL): the adoption of virtual labs in Saudi schools,” *Smart Learning Environments,* vol. 15, no. 6, 2018.

[35] R. D, S. K and P. J.P, “A review on cost-efficient virtual laboratory: a teaching aid,” in *2017 International Conference on Computing Methodologies and Communication (ICCMC)*, 2017.

[36] R. Radhamani, “Virtual laboratories in biotechnology are significant educational informatics tools,” in *International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, Bangalore, India, 2018.

[37] M. Lekova and P. Boytchev, “Virtual learning environment for computer graphics university course,” in *12th International Technology Education and Development Conference*, 2018.

[38] C. Tsihouridis, G. Ioannidis, D. Vavougios and A. Alexias, “The effect of teaching electric circuits switching from real to virtual lab or vice versa – A case study with junior highschool learners.,” in *International Conference on Interactive Collaborative Learning (ICL)*, Florence, Italy, 2015.

[39] O. Kurt and O. Tingoy, “The acceptance and use of a virtual learning environment in higher education: an empirical study in Turkey and the UK,” *International Journal of Educational Technology in Higher Education* , vol. 14, no. 26, 2017.

[40] J. West and A. Veenstra, “Cane toad or computer mouse? Real and computer-simulated laboratory exercises in physiology classes,” *Australian Journal of Education,* vol. 56, p. 56–67, 2012.

[41] B. Dalgarno, A. Bishop, W. Adlong and D. Bedgood, “Effectiveness of a virtual laboratory as a preparatory resource for distance education chemistry students,” *Computers and Education,* vol. 53, no. 3, pp. 853-865, 2009.

[42] S. Coleman and C. Smith, “Evaluating the benefits of virtual training for bioscience students,” *Higher Education pedagogies,* vol. 4, no. 1, pp. 287- 299, 2019.

[43] S. Tan, P. Naraharisetti, S. Chin and L. Lee, “Simple visual-aided automated titration using the python programming language,” *J. Chem. Educ.,* vol. 97, p. 850–854, 2020.

[44] Z. Almarzooq, M. Lopes and A. Kochar, “Virtual learning during the COVID-19 pandemic,” *J. Am. Coll. Cardiol.,* vol. 75, p. 2635–2638, 2020.

[45] J. Crawford, K. Butler-Henderson, J. Rudolph, B. Malkawi, M. Glowatz, R. Burton, P. Magni and S. Lam, "COVID-19: 20 countries' higher education intra-period digital pedagogy responses," *J. Appl. Learn. Teach.,* vol. 3, pp. 4-13, 2020.

[46] J. Glassey and F. Magalhães, "Virtual labs – love them or hate them, they are likely to be used more in the future," *Educ. Chem. Eng.,* vol. 33, p. 76–77, 2020.

[47] W. Zhang, Y. Wang, L. Yang and C. Wang, "Suspending classes without stopping learning: China's education emergency management policy in the COVID-19 outbreak," *J. Risk Financ. Manag.,* vol. 13, p. 55, 2020.

[48] R. David, A. Pellini, K. Jordan and T. Phillips, "Education during the COVID-19 crisis: Opportunities and constraints of using EdTech in low-income countries," 2020.