A Review of Virtual Laboratory and Justification for Adoption in Nigeria Tertiary Educational Institutions

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***Abstract*—Physical laboratory (PL) is widely considered to be essential to learning and teaching science and engineering related courses. However, developing countries including Nigeria have struggled to provide quality training to students in the above fields due to inadequate laboratory facilities. The need to finding and adopting viable alternatives has become necessary. This paper proposed the adoption of virtual laboratory (VL) as a standard e-learning tool to complement the inadequacies of PL in Nigeria tertiary educational institutions. The paper reviewed several successful application of VL, comparison between VL and PL were made and suggestions on some justifications for adoption outlined. It concluded that, just like the digital libraries is complementing University physical libraries, VL could also be adopted to complement PL used in teaching and learning science and engineering courses whether on face-to-face or Open and Distance Learning (ODL) mode. The great potential that lies in VL offers the possibility of it being an alternative/ replacement of PL in most science and engineering disciplines in future, especially for those experiments learner decisions or actions are not based on tactile or olfactory sensory cues.**

***Keywords*—Inadequate Laboratory Facilities, Virtual Lab Adoption, Virtual Laboratory versus Physical Laboratory.**

I. INTRODUCTION

Developing countries have struggled to adequately teach and train professionals as well as students in the science and engineering fields primarily due to limited access to adequate laboratory facilities and consumables [1].

Physical laboratory (PL) for practical is widely considered essential to learning science and engineering related courses, because laboratory provides students opportunity to develop hand-on experience with physical equipment and materials [2][3].

The emphasis on hands-on laboratory experience as an indispensable part of proper and adequate training in the science and engineering disciplines has meant that developing countries have lagged far in terms of quality of training and research [1]. However, providing students with high quality laboratory facilities can be very expensive, dangerous, difficult, or time-consuming [2]. Educational institutions are not able to keep up-to-date laboratory facilities with the rapidly growing technology. [4] noted the fast development of technology had become an issue for educational institutions to keep up with the pace.

Physical laboratory (PL) is however, also constrained, as it is only open at scheduled class hours. In most cases, access to scarce and expensive equipment is very restricted, leading to low students utilization [5].

Considering financial constraints, the need to finding and adopting a viable alternative(s) to the use of expensive equipment in PL can help developing countries to significantly improve the teaching and training of graduates has become necessary [1]. [3][6] proposed the use of computer-aided tools. This paper therefore, proposed the need for tertiary educational institutions in developing countries including Nigeria to adopt the use of VL to complement the inadequacies of their PL.

The paper reviewed the successful application of VL in science and engineering disciplines in tertiary educational institutions globally. Several researches have proven the suitability and acceptability of VL as alternatives or supplements to the traditional PL in the teaching of undergraduates and postgraduates of laboratory-driven science and engineering disciplines.

II. SCIENCE AND ENGINEERING EDUCATION

One of the distinct features of science and engineering education is the hands-on laboratory experience entrenched in its curriculum [7].

When student pursue a degree in science and engineering disciplines in tertiary institutions that does not offers adequate hands-on laboratory experience, it raises concerns of the kind of graduates that such institution will inject into the society.

In a global perspective, there are several expectations from science and engineering programmes. According to [8], specifically, engineering programmes must have student outcome that prepares graduates to attain the programme educational objectives. Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors that students acquire as they progress through the program. The student outcomes outlined are: (i) an ability to apply knowledge of mathematics, science, and engineering (ii) an ability to design and conduct experiments, as well as to analyze and interpret data (iii) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (iv) an ability to function on multidisciplinary

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teams (v) an ability to identify, formulate, and solve engineering problems (vi) an understanding of professional and ethical responsibility (vii) an ability to communicate effectively (viii) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (ix) a recognition of the need for, and an ability to engage in life-long learning (x) a knowledge of contemporary issues (xi) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Conventionally, the technical related aspects of the student outcome are literally expected to be acquired through hands-on practical activities on the physical laboratory. Hence, one will ask, can these be acquired through e-learning mode such as virtual laboratory as advocated by this study?

Several concerns is been raised when studying science and engineering disciplines using e-learning mode rather than the conventional way. However, in recent time, technology had advanced and this skeptics is gradually fading away. According to [7][9], engineering education will need the use of information and communication technology (ICT) to advance the learning process, hence, making learning more effective and universal. In affirmative, [8] noted that the objectives for engineering laboratory is largely met through e-learning mode [10]. [11] noted that with technological advancement and universal nature of education, there is likelihood that in near future, technical courses like engineering would be fully taught online including access to practical.

III. PERSPECTIVE ON VIRTUAL LABORATORY (VL)

A virtual laboratory can be defined as an environment in which experiments are conducted or controlled partly or wholly through computer operation, simulation, and/or animation either locally or remotely via the internet [12]. It is a computer or device aided environment for teaching, practicing and performing experimental activities without physical contact.

Advancements in the ICT have opened up real opportunities for developing nations to narrow the gap between them and the developed nations [1].

VL is evolving to be a cost effective and sustainable way of delivering quality hands-on laboratory experiment compared to physical laboratory. This provides financially depressed institutions the opportunity to continually provide quality education for its students by complementing its physical laboratory through such innovation.

VL may become critical in institutions that lack adequate and functional facilities as well as where technologist are lacking, less experience or find little time to supervise large student population in laboratory activities.

VL allows students the opportunities to practice experiments, especially those that may not be easily replicated due to resources, time and safety issues [12]. It main purpose is to familiarize students with practical procedures and exercises without physical contact with the equipment [4].

Figure 1. Sample Virtual Lab. Source [13]

In this paper, we categorized VL into two forms. Namely remote laboratory and simulated laboratory.

A. Remote Laboratory (RL)

Remote Laboratory is designed to allow users to remotely conduct physical experiments across the Internet. The experimental laboratory space, materials and operating equipment are in one geographical location, while the user is controlling experiments from a different or sometimes very distant location [14]. RL offer a range of benefits that can significantly improve pedagogical success: (1) they adapt to the pace of each student (2) an experiment may be concluded from home, if the time available at the lab was not sufficient (3) it can be repeated to clarify doubtful measurements obtained at the lab (4) the student may improve the effectiveness of the time spent at the lab by rehearsing the experiment beforehand (5) safety and security are improved, since there is no risk of catastrophic failures [15]. In this paper, we consider remote lab as virtual from the perspective of the third party user. The user at the other end does not have physical access to the equipment, hence it is virtually accessed.

B. Simulated Laboratory (SL)

Simulations are now widely used in education and training in a variety of high risk professions and disciplines, including the military, commercial airlines, nuclear power plants, business and medicine [16].

Simulated laboratory provides object-based 2D or 3D virtual environment that enable users practice experimental concept. According to [17] it is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables in the simulation, predictions may be made about the behavior of the system.

SL enables the students to learn and acquire new skills in a relatively shorter time. Students can repeat a set of actions and exercises as many times as they want [18].

IV. CASE STUDIES

VL have been developed for several aspect of science and engineering disciplines. In this section, we examine few VL initiatives and projects that have been fully implemented and serving purpose.

Table 1. List of some VL initiatives and projects.

VL Name	**Description**	**Affiliation**	**Discipline**	**Reference**
Advanced Medical Simulation Laboratory	The lab comprises of a human patients simulation system, child and infant simulator, Cardiac Cathereizton Lab., Endo simulators, Minimal access surgery simulator, USG and Echo simulator and also the task trainers which helps the young interns to acquire practical skill of intubations, IV insertions, ICD tube drainage and tracheostomy.	D.Y. Patil University	Medical	[18]
Clinical Simulation Laboratory	The lab brings together individuals, groups and teams for hands-on learning experiences enhanced by the integration of standardized patients and advanced technology in settings that reflect actual trauma, operating room, in-patient and ambulatory settings.	University of Vermont	Medical	[20]
Radioactivity iLab	It is a remote lab that enables students' measure radiation from a sample of strontium-90 since working with radioactive materials is dangerous. Student can control a Geiger counter to measure samples, and could watch what happened over a live video.	Northwestern University	Physics	[21]
PhET Interactive Simulations	PhET offers several chemistry-based simulations.	University of Colorado	Chemistry	[22]
MERLOT	MERLOT is a collection several discipline-specific learning materials and simulations.	California State University	Major Science and engineering discipline	[23]
ChemCollective	ChemCollective is a collection of virtual labs, scenario-based learning activities, tutorials, and concept tests.	Carnegie Mellon University	Chemistry	[24]
LABVIEW Virtual Laboratory	It provides a virtual environment for students to operate a series of graphical units, each represents an instrument or experimental object. Students can conduct remote virtual experiments at any time by a local machine or by a remote machine via the internet.	University of Hong Kong	Electrical and Electronic Engineering	[12]
Virtual Labs Project	It is aimed at providing access to users who do not have access to good lab-facilities and/or instruments, share costly equipment and resources, which are otherwise available to limited number of users due to constraints on time and geographical distances.	Ministry of Human Resource Development, Government of India	Major Science and engineering discipline	[25]

Next-Lab	Provides access to hundreds of virtual and remote science laboratory, inquiry learning applications and Inquiry Learning Spaces organized by scientific domains and age groups.	European Union's Horizon 2020 Research and Innovation Programme	Science	[26]
Ocean Virtual Laboratory	The main objective of the project is to develop a virtual plateform to allow oceanographers to discover the existence and then to handle jointly, in a convenient, flexible and intuitive way, the various co-located EO datasets and related model/in-situ datasets over dedicated regions of interest with a different multifacet point of view.	European Space Agency	Oceanography	[27]
Mechanical Engineering Virtual Labs	A comprehensive mechanical engineering virtual labs in the following areas: Mechanics of Solids, Wind Energy, Solar Thermal Energy, and Energy Storage. Each lab consists of 8 to 10 experiments all accessed over the internet	Amrita University	Mechanical Engineering	[28]
UTS Remote Laboratory	UTS Remote Laboratory facility enables students and researchers to remotely control laboratory equipment and to perform experiments – similar to what they would do in a classroom setting, but over the internet. The lab uses real, physical equipment that has been instrumented with cameras and connected to the internet.	University of Technology, Sydney	Major science and engineering disciplines	[29]

V. VIRTUAL LABORATORY (VL) VERSUS PHYSICAL LABORATORY (PL)

From our study, Table 2 suggests the comparison between virtual laboratory and physical laboratory.

Table 2. Comparison between virtual laboratory and physical laboratory

Parameters	**Virtual Laboratory**	**Physical Laboratory**
Number of users	A large number of users	Small number of users
Accessibility	Could be anytime and from anywhere	Within a location at the scheduled time
Usage time	Long period	Short period
Setup and Maintenance Cost	Relatively Cheaper	Expensive
Safety and Security	Very safe	Could be unsafe
Teaching Method	Student-Centered	Teacher-centered
Practical Sensation	Immersive/ Intangible	Physical/ Tangible
Practical Experience	Virtual hands-on	Real hands-on
Technology Support	Fully technology based	Might not be technology based
Space Confined	Open	Close
Plagiarism Risk	High	Low
User Precaution	Not safety conscious	Safety conscious
Resource Sharing	Easy	Complex
User Distraction	Higher distraction due to game like UI	Minimal distraction
IT Literacy	Required	Might not be required

VI. JUSTIFICATION FOR VIRTUAL LABORATORY ADOPTION

1. Improve Student Performance:

Research shows that VL could improve student learning performance and attitude compared to PL [30][31][32]. Students who participated in VL believe they generally learn more concept compared to PL [35][33][4]. [32] asserted that students learn twice as much with VL. VL therefore, can be used to prepare students for practical experience, skills and self-confidence necessary to solve real problems and succeed industrial trend and demands.

2. Infrastructure Inadequacies

Nigeria tertiary institutions over the years had suffered several issues resulting to poor quality of education as well as inability of graduates to meet industry expectations. In science and engineering related disciplines, these issues includes inadequate laboratory facilities, inadequate workshop/laboratory space, in-experience personnel, over populated classrooms/workshops/laboratory, obsolete curriculum etc [34][11][36]. These factors are hinged on insufficient funding of institutions from their proprietor. [37] asserted, there will hardly be a time government budget allocation will be enough for federal and state owned tertiary institutions in as much that education is not the only sector in Nigeria.

In the face of this financial constraints, institutions must seek cost-effective and sustainable approach to solving infrastructure inadequacies. Hence, this paper suggests the transformation of some of the physical infrastructure such as PL into a VL. [6] noted that the use of software based infrastructure is more robust and cheaper than physical infrastructure.

VL could help mitigate infrastructure issues by replicating PL components in virtual platform using 2D or 3D modelling and game engine. The platform, can be hosted on a cloud server to enable mobility and accessibility from anywhere and anytime, without institutional physical infrastructure or space. VL offers the opportunity of bringing laboratory facilities closer to students. Through VL, students can develop relevant industrial competency and skills required to succeed after graduation. [38] stated that VL enables institutions to do everything from preparing student better for lab exercise, to taking entire degree programme online.

3. Cost Effective and Sustainable Platform

In a large student population, teaching very basic practical course could take several days for each student to directly participate. The situation may worsen if equipment malfunction as a result of over usage or if there arise the need to replenish shortage of reagent or replace wear equipment. VL does not suffer the above constraints, hence, fixed and variable expenditures is reduced. Budai and Kuczmann, (2018) stated that VL does not age nor wear out which lowers its operational cost. According to [14] transforming physical experiment into virtual ones requires relative effort and then you have it as long as you want.

VL is an emerging trend for technical courses. Student can conduct experiment through the computer in a time-efficient and cost-effective way [12]. It allows Science, Technology, Engineering and Mathematics (STEM) students experiment in expensive labs at a fraction of cost hence, providing cost saving benefit [38]. Students can repeatedly practice or experiment and also they are unable to cause damage to the platform as a result of making mistakes, this makes it sustainable.

VL may not require any additional infrastructure if its web based, users access the platform using internet enabled computer or a Virtual Reality (VR) headset. It is not confide to location, time and space hence, its accessibility, flexibility and scalability is more or less limitless. It is also more economical setting up and maintaining VL. It provides educational institutions the opportunity to keep up and adapt laboratory with practical requirements inline with technological and industrial development.

4. Enhance Open and Distance Learning (ODL):

Open and distance learning is one of the avenues National Universities Commission (NUC) is currently exploring to increase access to tertiary education without compromising quality in Nigeria. [34] noted that ODL has become widely accepted as an alternative mode of education.

Currently, there are over 10 tertiary institutions in Nigeria that have been granted license to offer ODL programmes with very few science related courses and non in engineering [39]. Despite the benefits and promises of ODL, learning science through ODL is still very challenging in Nigeria as instructional materials are dominated by print media. In the case of National Open University of Nigeria, practical sessions take place in laboratory at the study centres or in laboratory of their partner universities [40][34].

This approach hampers flexibility and self-pace learning as promised in ODL mode as students are expected to be in the location within the scheduled time. In addition, several other issues earlier mentioned confronting face-to-face mode of leaning in conventional universities will arise.

This paper suggests integrating VL into ODL programme will be a better approach to delivering practical to ODL students. This will enable students to develop skills and hands-on experience required to compete with colleagues in conventional universities.

In VL, instructors are not needed, instead the necessary guidance are presented in the experiment description. Material guide are created to give narratives during virtual experiments (Budai and Kuczmann, 2018). Institution offering ODL programmes can conveniently increase access to practical facilities for their geographically disperse students using VL.

VL can be used to facilitate fully online programme in science and engineering related fields without compromising quality.

5. Sharing Expensive Equipment:

Virtual technology could be used to share specialized, scares and expensive equipment and resources which are limited to number of users due to geographical time and space. It could be a form of opening up underutilized facilities for optimal use.

VL provides the possibility to break out from the physical constraints of PL and make practical available to a wider audience of students (Budai and Kuczmann, 2018).

6. Maintain Flexible Curriculum:

Obsolete curriculum had been mentioned as one of the factor responsible for poor quality graduates in Nigeria [36][11]. [42] asserted the need to reshape Nigeria tertiary education curriculum in other to cater for current industrial development. [11] noted that the general reason for refusing curriculum review is because of the fast pace the various fields are changing. The author however, encouraged Nigeria to embrace changes like other developed countries had done. [36] ague Nigeria to seek development through maintaining flexibility in educational program and continually adapt them to technological changes.

This study suggests that one way this can conveniently be achieved is through software aided approach to teaching and learning. In technical courses, rather than seeking to provide several equipment for practical exercise, which can be very expensive and difficult to adapt/ upgrade when curriculum changes, this study advocate that virtual platforms will better cater for the need.

7. Eliminate Risk and Safety Concerns:

VL eliminate possible risk that could occur in real experiment. Some experiment (radioactive, high power voltage, concentrated acidic substances etc) have a high risk coefficient which makes them impossible to be taught and demonstrated in the cause of teaching. VL is an idea platform for demonstrating and experimenting such experiment thereby avoiding risk and safety concerns. In addition, VL enables students to practice different concept and procedures before engaging in real experiment. This reduces the possibilities of manhandling or damaging equipment.

Students can make mistakes with VL with no consequence. [6] noted that it allows students represent some situations that are not reproducible in the laboratory because they require costly and complex equipment.

8. Increase Student Engagement:

In PL, students face several challenges which includes: limited equipment/ reagents, inadequate technical support, time constraint, personal safety, equipment restriction etc. These could affect students' zeal for practical courses or disciplines. [43] noted that fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree.

[44] affirmed that one reason undergraduate choose to leave engineering fields is loose of interest as a result of inadequate motivation. However, the author argues that engaging students in investigation by means of 3D VL, interest and concomitant retention can be aroused. [38] stated that VL is aimed at increasing student engagement and excitement for STEM careers.

VII. CONCLUSION

The lack of inadequate laboratory facilities and several other issues earlier mentioned had over the years led to the fallen standard in science and engineering education in developing countries including Nigeria. Finding urgent cost-effective and sustainable solutions will salvage further decadence.

This paper therefore, propose the adoption of VL as a standard e-learning tool to complement the inadequacies of PL.

This paradigm shift holds the future of science and engineering education especially in a time like this were most tertiary educational institutions are faced with tight financial constraint.

Technological advancements have created opportunities for an alternative to PL through VL in teaching and learning. However, the acceptability and suitability have remained contentious issues [1].

We believe that if VL is adopted by Nigeria government and tertiary institutions accreditation bodies, as a standard e-learning tool to complement PL inadequacies, just as we have the digital libraries is complementing University libraries, teaching and learning science and engineering courses whether on face-to-face or ODL mode will be greatly improved and exciting.

From this study, great potential lies in VL. Although we advocate VL as a complementary tool, we do not doubt the possibility of VL being an alternative/ replacement of PL in most science and engineering disciplines in future. Especially for those experiments learner decisions or actions are not based on tactile or olfactory sensory cues, with the fast development of artificial intelligence (AI) and its application in every aspect of automation, the replacement is certain.

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