# Human and Infrastructure issues in the Development of Web-based laboratories in challenged Environments.


- **D. Olowokere***; L. Kehinde**; O. Jonah*; O. Osasona*; E. Ajayi*; K. Ayodele***
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- *Obafemi Awolowo University, Ile-Ife, NIGERIA
- ** Texas Southern University, Houston. USA
- ***University of Alabama at Birmingham, USA



**Abstract**

*Web-based laboratories (WBL) not only involve hardware and software but human and infrastructure development. For sustainable WBL, it is important to ensure that the laboratories not only are the able to satisfy pedagogical needs; they should also ensure that designers and developers are well trained to adapt basic experiment infrastructure to suit a range of experiments. Training will include hardware and software development. An important aspect of WBL is how much hardware should be replaced with software. This aspect becomes especially relevant in cash-strapped environments and in many institutions where deficient funding leads to constraints in the acquisition of equipment. Of note also is how WBL can be tailored to suit cases where adequate bandwidth is an important issue.*

*In this paper, the experience of developing WBL especially in a fund and bandwidth-limited environment is presented. The basic training for acceptable skill requirement of technical staffs are identified. In doing this, consideration is given to issue of ratio of hardware to software for optimal result in an economy with financial constraint. Suggestions are made for relevant collaboration between staff of institutions separated by distance as well as student exchange to evolve a critical mass of developers at each institution. The difficulties encountered in specific situation are enumerated and solutions proffered. The development of WBL that has synergy with curriculum and which can engender curriculum development is also considered.*



**Keywords:** web-based laboratories, experiment, human, hardware, software, Challenges.


## 1. INTRODUCTION

Remote web-based experimentation which enables students and researchers access the laboratory anytime via the Internet, is becoming an increasingly attractive way to complement or even in a few situations, replace traditional laboratory sessions.[2] Interfacing a video camera and microphone with equipment and apparatus to capture what is actually happening in the laboratory allows the images and audio data to be streamed to the client side. Researchers in different countries can share equipment and conduct researches cooperatively and remotely. The use of laboratory experiments is a critically important aspect of engineering education. Experience in teaching has shown that a complementary approach, combining theoretical and practical exercises is vital for effective learning. Increasingly, some teaching institutions are offering remote access to web-based laboratories as part of an overall e-learning strategy.[9] Remote experimentation provided as part of a web-based learning approach affords a number of benefits, allowing flexible access to on-campus resources free of time or geographical constraints. In the context of full distance learning, it may sometimes be the only realistic method of performing experiments. However, adapting and redeveloping existing software and hardware resources to this purpose is both time consuming and expensive

There are numerous human and infrastructural challenges to the development and deployment of web-based laboratory, particularly in the challenged environments of many developing countries. These and other unpredictable circumstances inhibit its success in these environments. Web-based laboratories may allow students to have full access to existing off-campus laboratory resources remotely but without substantial implementation and development overheads incurred by the providers. This is achieved through increased functionality and extended utilisation of existing assets.

## 2. NATURE OF THE WEB-BASED LABORATORY

A web-based laboratory consists of several components. Many of the components are illustrated in fig 1. A data acquisition measurement system comprising of data acquisition hardware, digitizer, signal conditioning components, driver software and the computer system, is connected to the physical phenomena and the Internet for access from the web. The fig 2 illustrates more details of the layout of a web-based laboratory (WBL).The *measurement block* is where the experiments are performed and data acquired. The acquired data is stored in a *database* on a computer. The *web server* provides remote web access for the administrator and users through the Internet while the *network interconnections* provide network access to the laboratory through the Internet or network. The *laboratory experiment* contains the interconnection of experiment hardware and switches and connections to the lab are made through the *client block*. The *Service Broker* is a server that controls and keeps track of all activities while the *Lab Server* is responsible for circuit switching activities. The hardware and software components work closely to achieve the desired result. More details about hardware and software components are as provided in later sections.

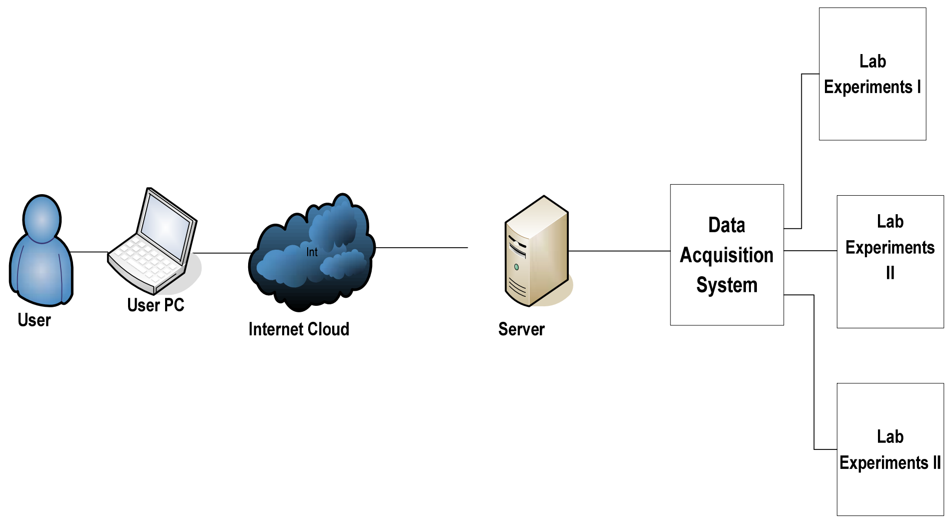


Fig 1 A Typical web based laboratory system

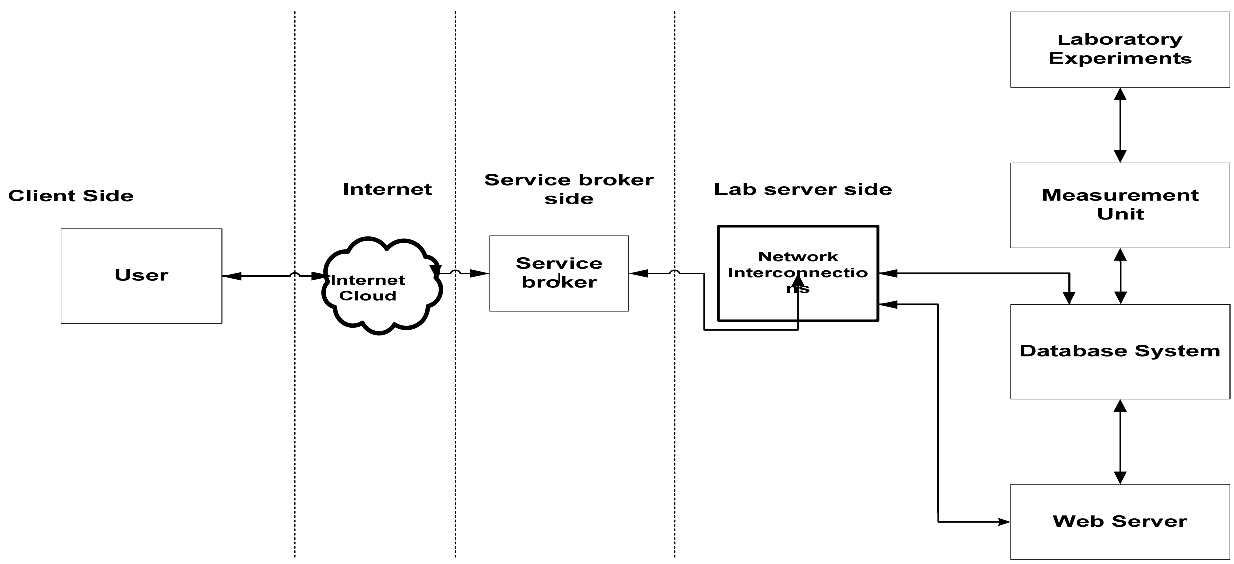


Fig 2 The Basic layout of the web based Laboratory (WBL) based on MIT iLab shared Architecture[1]

The ***hardware components*** may include:

- **Equipment containing a Suite of virtual instruments**: this has several instruments that can be used for performing and analysing laboratory experiments.
- **Data acquisition card**: It is used to acquire electrical signal from physical phenomena.
- **A switching matrix**: It has several switches that are used to configure several experiments at different times.
- **Prototyping board**: The circuit experiments are set up on this board and can be easily modified or changed as desired.
- **Experiment circuits**: These are the circuit experiments. In our present case, these are operational amplifiers and logic gates.

- **Webcam**: An Internet-based mini camera to capture the experiment setup and stream in real-time over the network.

A block diagram representation is shown in fig 3 where a National Instrument's switching matrix SCX11-1169 [7] and suite of virtual instruments (NI-ELVIS)[6] are employed.

The ***software component*** resides on the Lab Server and Broker[1] and this may include:

- **Software for the suite of virtual instruments**, which has several measuring equipments such as oscilloscope, signal generator bundled in a suite of instruments.
- A **data acquisition software** module for acquisition of data from the laboratory experiments, and storage in a computer system.
- **The switching matrix module software** which, is used to configure the experiment to be performed at any particular time, by switching ON or OFF circuit components.
- **A measurement software** for adding, configuring and general management of lab experiments measurement, along with a database of all experiments requests and results.
- **The webcam software** module to capture laboratory experiment setup and transmit in real-time over the network.

A diagrammatic representation of the hardware interconnections and software interaction paths is shown in fig 3 and fig 4 respectively.

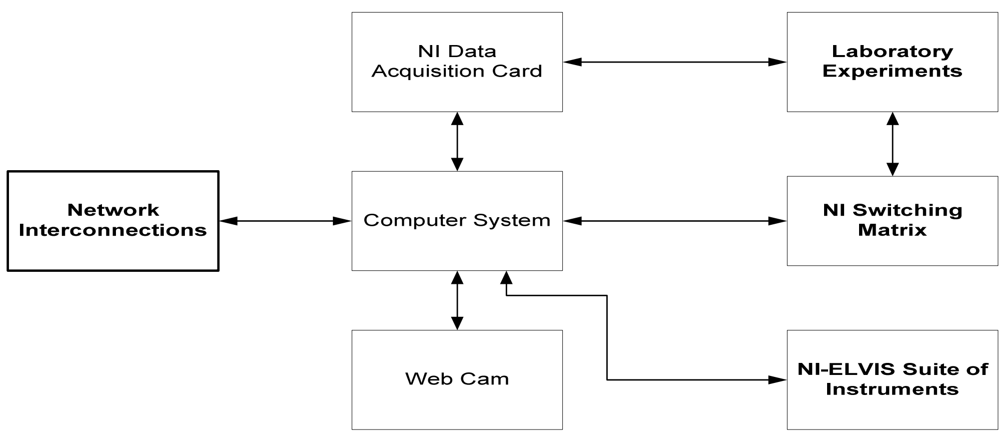


Fig 3 Block diagram representation of the web based lab Hardware interconnection.

The software components are embedded in the computer system for measurement, storage, and processing and network access.

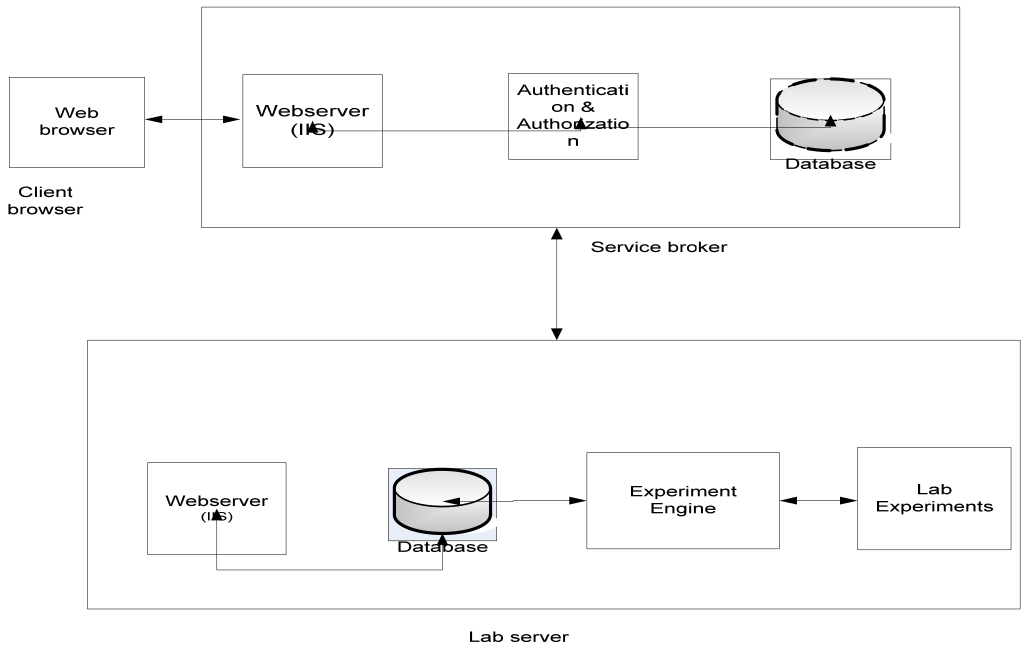


Fig 4 Block diagram representation of the web based lab software interaction paths.

In summary, the WBL is a network-based system for performing laboratory experiments. It involves selection and performing experiments, data acquisition, storage, analysis and transmission of performed experiments. Computers remotely connected to the Internet can access this online laboratory from anywhere in the world. The WBL is designed to handle a myriad of computer-based data acquisition laboratory experiments.

## 3. RELATED WORKS.

### i. MIT iLabs

Massachusetts Institute of Technology (MIT) has developed several Internet-based laboratories which are in use in a number of departments for students' online laboratory works, some of which. Some of these are as follows:

1. Department of Electrical Engineering and Computer Science(EECS) has two online laboratories namely :

    a. The Microelectronics Weblab for experiments on electronics device characterization.
    b. The dynamic system lab for experiment on feedback systems

The MIT Microelectronics WebLab or "WebLab" is a remote microelectronics device characterization laboratory. It enables users to measure the current-voltage characteristics of various microelectronics devices at any time, from any physical location, using a Java-enabled web browser. WebLab is one of the MIT laboratories available under the MIT-iLabs project which is dedicated to the proposition that online laboratories i.e., real laboratories accessed through the Internet - can enrich science and engineering education by greatly expanding the range of experiments that students are exposed to in the course of their education.[8]

The major goal of the WebLab project is to deliver the educational benefits of typical hands-on microelectronics experimentation to students anywhere, at any time over the Internet. Students are able to enjoy the complete laboratory experience which can be delivered to any conventional Java-enabled web browser. Today, web browsers are ubiquitous and therefore, through WebLab, students can take current-voltage measurements on transistors and other devices in real time from anywhere and at anytime. In addition, expensive equipment and educational materials associated with lab experiments are shared as broadly as possible within higher education and beyond. Some of the devices available for I-V characterization include pn diodes, NMOS/PMOS Field Effect Transistors, and NPN/PnP Bipolar Junction Transistors. The user is able to change the operating conditions of the experiment such as bias voltages and currents, compliance values, voltage and current sweep ranges, etc using a simple graphical interface. The results of the experiments are immediately displayed as graphs in the Weblab applet console, and can be downloaded as a comma separated file for post processing using Matlab or any spread sheet application.[2]

The others are:

2. The “**shake table**” for experiments on vibrations developed by the Department of Civil engineering and EECS.
3. The “**heat exchanger**” laboratory for experiments on heats developed by the Department of Chemical engineering and EECS.

### ii. OAU iLabs

The research group at Obafemi Awolowo University, Ile-Ife, Nigeria (OAU) has developed two ilabs namely, Operational Amplifiers (OpLab) for the demonstration of numerous uses of the operational amplifier and Logic gates design Lab (LogiLab) for the demonstration of several application of de-Morgan’s theorems, both of which are based on MIT iLab shared architecture. These have been used by over three hundred students of Science and Engineering in the past two academic sessions. As with MIT architecture, the main objective is to provide laboratory experiments to many students from different geographical region at all times, with access to the Internet. Two additional experiments are presently being developed using a robotic Arms and in Advanced Electronics.

The development of a web-based OpLab (WBL) by the authors has been carried out using operational amplifiers. The system consists of five modules consisting of: Experiment Circuits, Circuit Switching and Data Acquisition System, Network Interface, Data Storage and

Presentation. The lab server controls an operational amplifier based experiments set up on prototyping board, high precision data acquisition, NI-ELVIS, switching matrix and card network transfer software. The DAQ card has several analog/digital input channels, a signal conditioning module and analog/digital outputs channels. The outputs of the DAQ card are connected to PCI/PCMCIA bus of the computer system. When an experiment is selected, instructions are sent to the hardware, which configures the desired circuit by the switching matrix, perform the experiment and acquire the experiment data. This is then transferred to the computer, stored in the database and then sent over the network to the remote person that initiated the experiment through his web browser. A snapshot of the oplab is shown in fig. 5. The LogicLab follows similar concept and uses logic gates to design and prove Boolean laws as well as design simple combinational circuits.

Fig 5 OAU Operational amplifier lab

The system Architecture of the operational amplifier web-based laboratory is shown below

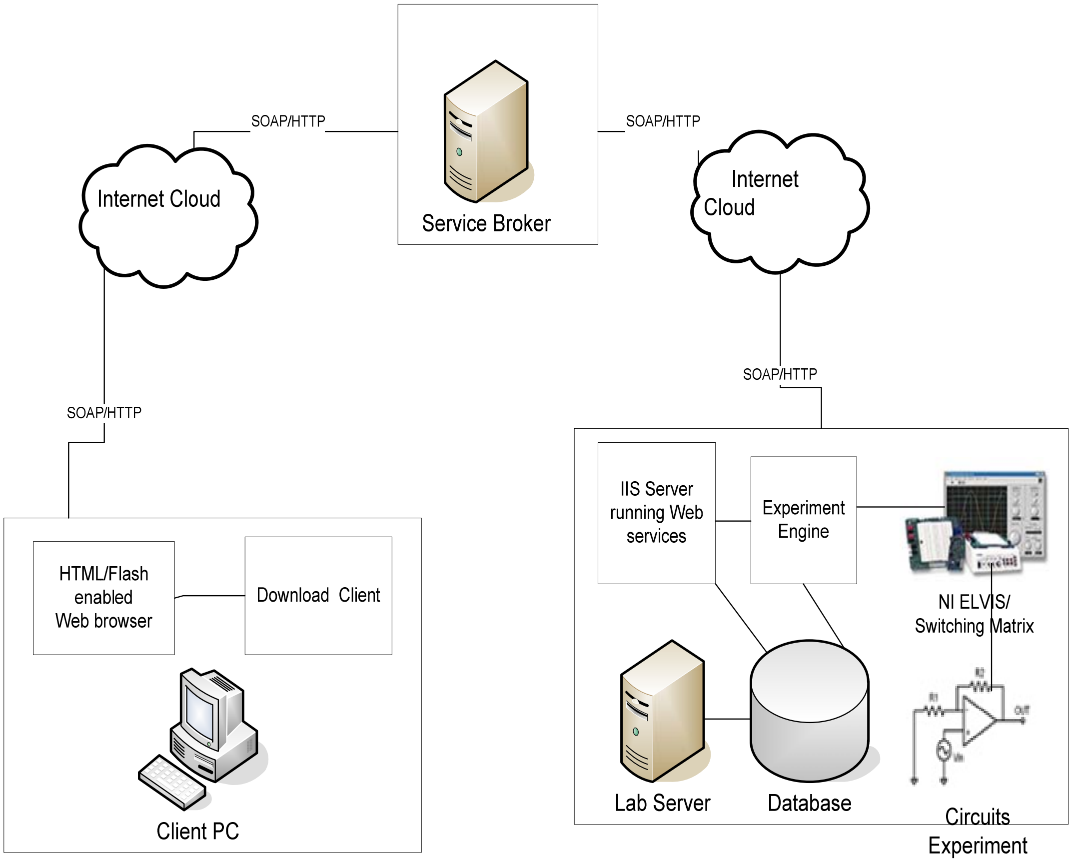


Fig 6: The System Architecture.

The MIT iLab design was based on a variety of Lucent and Agilent technologies equipments interfaced to the computer through the GPIB bus, the equipments are very expensive and not affordable here, therefore the need for a different approach. NI-ELVIS[6] approach was selected as the core hardware because it is equipped with several virtual instruments such as Oscilloscope, Dynamic Signal Analyzer, Digital Multimeter, Bode analyzer, and Current-Voltage Analyzers e.t.c, and it cost just a few thousands US dollars. In addition, the NI PCI 6024E[10] data acquisition card was selected based on a compromise of functionality and cost, some of its features are high sampling rate (200 kSamples/s) and other good features. This work makes use of the “dozen impedance operational amplifier circuits”[11] which makes it necessary to close/open several switches in order to be reconfigure a single operational amplifier circuit for several desired operational amplifier experiments, hence the need for a switch matrix, the NI SCXI 1169[12], 100 relay, low impedance switch was selected, these equipments together with a few accessories (switch chassis, connecting block, cables) and a computer system comprises the web-based Laboratory (WBL) in this case, the equipments mentioned above makes up the hardware components.

The software component can be divided into three categories, namely the hardware drivers, MIT iLab batched Architecture codes (re-written and modified locally for this purpose) and software developed basically for this purpose, these all work together for the actualization of this research work. XML[13], DTD[14] and web services[15] were used to implement the software component of the Laboratory. Web services is extensible to allow description of endpoints and their messages regardless of what message formats or network protocols are used to communicate, the transparency of web services makes this technology an obvious choice to integrate our distributed application framework. All the above factors collectively influenced the choice of hardware and software for this work. The hardware and software interaction responsible for accessing the Laboratory, selecting experiment, performing experiment and retrieval of result is as shown in fig 3 and fig 4 respectively.

## 4. O.A.U'S EXPERIENCES AND CHALLENGES

From the time the OAU team commenced usage of the MIT iLab[1] and later developing new WBL, we encountered numerous challenges. The team was able to overcome most of them, and are working on the outstanding issues. Some of these challenges are:

- **Funding**: At the onset, OAU's funding was a subset of a grant MIT secured to disseminate ilab architecture in developing countries. This has been going on for about 3 year and gave the impetus to acquire relevant skill, replicate some of the technology implemented at MIT and develop new labs.

- **Training:** A lot has been gained by the OAU team from the experience MIT has acquired over time. Before the MIT-OAU collaboration a in developing online laboratory. There is a technical exchange programme through which OAU staffs visit MIT and vice versa on technical and pedagogical issues relating to development of new lab. MIT has provided OAU with the complete software codes of the iLab architecture. This has gone a long way in aiding OAU's development of new lab within a relatively short period of time.

- **Contentions**: The ilab developmental work contends with primary assignments in the university. Since most ilab members academic or technical staffs, it requires a feat to combine these duties. Each member of the team therefore needs to work out equitable sharing formula for duties within the system.

- **Equipments & Infrastructure**: The funds available to the team for the purchase of equipments were inadequate. It was initially planned to use Agilent-based equipment for functionality, but after a thorough analysis of equipments cost and budgets the team opted for National Instruments because the former was not within its buying power. The team found the National Instruments equipments purchased very versatile and dependable. Most of OAU's laboratories are deployed on National Instruments hardware.

- **Power supply issues.**

  Many developing countries have erratic supplies of electricity. Hence there is a need to put into place alternative supplies, e.g. inverters, solar power etc. These are non issues in the more developed countries but they pose great problems to developing countries where apart from downtimes, transients can cause damage to expensive equipments. The team employed the use of inverters and a solar system and this gave adequate backups.

**b. Relevant skill acquisition**

**i. Skilfulness in hardware design**

Hardware is an essential component of the system, and the appropriate design and choice of equipments must be arrived at the early stage of the laboratory design. The lack of a proper design and the right choice of equipments to implement the laboratory experiments of choice might jeopardize the entire laboratory. In order to optimise the meagre fund available, the design should be within the financial limit of the available fund

**ii. Skilfulness in software development**

Software development is the core of the web-laboratory development; without which the entire hardware setup will be useless. The software developers should be well skilled in software development, particularly hardware communications database programming (data retrieval, storage and processing), ASP.NET (Web Services) so as to surmount any software related challenges that might arise in the process of setting up the laboratory. Relevant training must be mounted for staff at regular intervals.

**c.Software vs. Hardware paradigm in WBL development.**

**d.** Are there limits for the ratio of hardware-to-software to be utilised in setting a WBL? There are no known standards. It is possible to increase software contents to take the place of expensive hardware. This is an issue being considered by a staff of MIT as well as some of the staff of OAU. Many times, for developing countries, it is cheaper for staff to develop software than for the institution to afford the hardware cost. The two components should have a well-planned synergy for optimal performance of the laboratory.

**d. Collaborations between institutions.**

The cost of developing a WBL, which may not be great in the developed world, is daunting in some part of the developing world where problems emanate from financial, technical bureaucracy and logistic issues. Hence, it important for the developing countries have a collaborative synergy on the use of WBL since this sharing of the available developed laboratory will enhance the quality of laboratory experiment in many ways. Joint decisions on which experiment each institution will set up will enhance collaboration and standardize curriculum. The institution can leverage on the expertise of other more experienced institutions in development, deployment and usage of the system. Students' exchanges between Institutions are also very useful for appropriate sharing of experiences.

**e. Tailoring WBL for low bandwidth Environments.**

Many of the tertiary Institution in developed countries have very limited bandwidth, which must be used judiciously. The ilab architecture has put into consideration these peculiar requirements by using web services[4] for all the communication between the servers at all time. Designs should be such that take into account bandwidth optimisation techniques. It may also be necessary sometimes to restrict students' experimentation times to "after-office" periods.

**f. WBL and curriculum development.**

The development and deployment of web-based laboratory comes with the need to update the curriculum, to provide for the numerous changes that might be necessary in the pedagogical system. For effective cooperation, those universities with deficient curricula must rise to the challenges involved with cooperation so that they can perform ilab experiments set up by other more-advanced institutions.

**g. Student Grading Techniques**

The present OAU iLab system does not have provision for online grading of student laboratory report, though it can set time limit and monitor student access. There is the need for an improved design that allows for online grading of students laboratory report. This we hope to develop in our future deployments.

**h. Pedagogical standard**

There are standards in setting up educational and instructional activities, in order to get the best out of the laboratory setup. These ranges from the client interface which the user interacts with when performing the laboratory to the experiments being performed and how they are setup. These should be intuitive and should reinforce theoretical knowledge acquired in the class about the experiments

**i. The need for sustainability of lab**

WBL have enormous benefits in the developing world. .It affords the use of remote laboratory situated at other campuses without incurring any local additional cost. Expensive ilab set ups do not have to be duplicated in all campuses. Hence developing labs that others do not have will enhance sustainability. Adequate training of ilab staff must be ensured.

## 5. FUTURE WORK

The web-based lab (WBL) is a new frontline in laboratory experiment, which comes with many challenges ranging from hardware to software. Despite the use of high precision data acquisition card and all other relevant hardware, the experiment results data were not free of spikes from the switching matrix; this can be surmounted by using high quality solid state switches. Also, the lab is not as interactive as compared to conventional laboratory, more work need to be done in developing a web client that can compare very well with running experiments in the conventional laboratory. The web cam used has a low resolution, which does feed the lab user with a low resolution streaming video of the laboratory. A high resolution web cam with more features and flexibility should be used.

## 6. RECOMMENDATION AND CONCLUSION

Online laboratory has the potential of allowing students from different environments have access to rare and expensive hardware and be able to perform experiments on a myriad of laboratory experiments set up anywhere in world once it is accessible by the Internet. Universities should form partnerships and leverage on their strength and weaknesses to provide online laboratories to complement the aging and hardly available laboratory experiments in our ivory towers. This will not only make innumerable laboratory experiments available to our students but also bridge the digital divide between the developed and developing countries, in terms of the quality of laboratory experiments

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