Online Laboratories: Enhancing the Quality of Higher Education in Africa

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Abstract

Online laboratories have been adopted by the Obafemi Awolowo University (OAU) - Nigeria, Makerere University (MAK) - Uganda and the University of Dar-es-Salaam (UDSM) -Tanzania to enhance the delivery and quality of higher education. Utilizing the Massachusetts Institute of Technology (MIT) iLabs Shared Architecture (ISA), grant-related teams at each of the three universities partook research into the development of online laboratories (iLabs) to support Science and Technology curricula. This has provided students with a low-cost, flexible, convenient and reliable experimentation platform. The iLab-Africa project has also opened up specific beneficial areas viz.: collaboration between universities, staff-student exchanges between these universities and MIT, funding opportunities, the possibility of collaboration between universities in different countries on the use of scarce laboratory equipment, and the collaboration of students between universities in different countries on specific laboratories. This paper discusses the application of iLabs in improving the teaching and learning processes at each of the partner Universities and highlights the offshoot advantages arising from the same. It thus lays a case for adoption of the technology throughout Africa to support curricula and promote inter-institutional collaboration.

Introduction

What are iLabs

Traditionally, experiments are performed by a person physically present in a physical laboratory. With advances in computing, networking and communication technologies in the last 20 years, a new niche of experimentation has opened up: online experimentation. An online laboratory is a lab in which the user is spatially removed from the experiment setup performs the experiments over a communications network (intranet or internet). There are two types of online labs: virtual labs and remote labs. Virtual labs are labs in which the experiment setup at the remote end is a mathematical model on a computer. In remote experimentation there is a physical laboratory setup at the remote end. Figure 1 illustrates an online laboratory setup.

iLabs are remote laboratories which make use of the MIT iLab shared architecture (ISA) [1], [2], [3], [4]. The ISA was developed by the Massachusetts Institute of Technology (MIT), Cambridge, USA for online experimentation. It is a three-tiered architecture. The ISA is shown in figure 2.

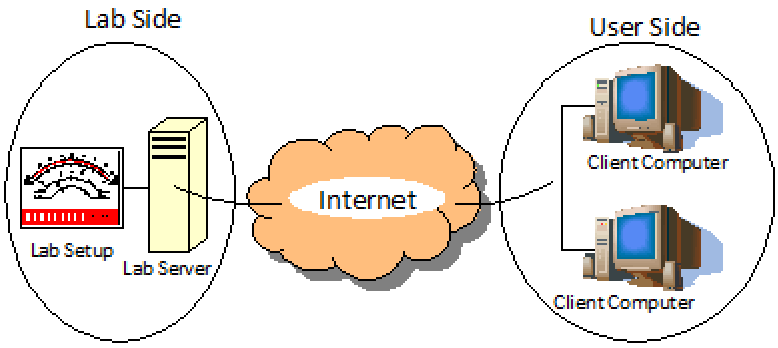

Figure 1: Typical structure for a remote laboratory [5]

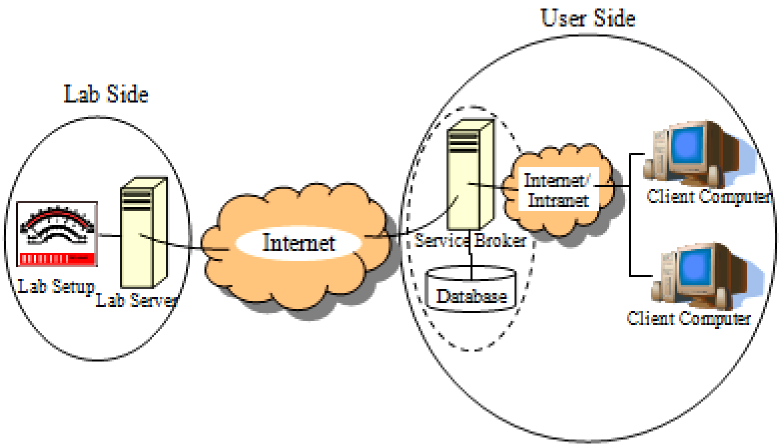

Figure 2: The three-tiered iLab shared architecture [5]

History of iLabs-Africa

In February 2004, the iLabs project was introduced to the then Faculty of Technology (now College of Engineering, Design, Art and Technology), Makerere University by Prof. Jesus del Alamo during his maiden visit. Subsequently, a memorandum of understanding was signed between MAK and MIT, leading to formation of the iLabs@MAK Project, under the umbrella of the iLab-Africa Project. To facilitate access to the online Microelectronics Device Characterization laboratory (WebLab) set up at MIT, an iLab Service Broker was set up at MAK. The MIT WebLab was then utilized by the first year students offering the Bachelors of Science in Electrical and Telecommunications Engineering Programmes over the next three years. In 2007, a team of three undergraduate developers embarked on research that led to the establishment of the comprehensive iLabs infrastructure at Makerere University. The project then embarked on continuous research and development to fully integrate iLabs into the local curricula, with formation of an agile research team as a key component of the process.

Prior to 2004, Science and Engineering education at the Obafemi Awolowo University were also disadvantaged by the shortage of laboratory equipment for laboratory work. In 2004, Prof. Jesus del Alamo introduced iLabs and MIT's OpenCourseWare to OAU. These were immediately embraced. A service broker was setup at OAU and MIT provided access to its

WebLab. In 2006, OAU began developing iLabs, setting up an operational amplifiers iLab, the first iLab in Africa.

The University of Dar-es-Salaam (UDSM), the oldest university in Tanzania, embraced the idea of iLabs when Prof. Jesús del Alamo visited in 2003. The iLab idea fit squarely within the efforts of the University to use alternative mode of delivery to enhance Higher Education and create a flexible learning environment. This scenario arises because of the ever increasing student population, putting pressure on the existing facilities. A number of Science and Technology institutions rely on UDSM's laboratory facilities to conduct experiments required in their curricula. UDSM thus has a key role to play in supporting many newly established universities in their early stages of growth.

Impact of the iLabs-Africa Project on Pedagogy

Development and Utilisation of Laboratories

When iLabs were introduced to MAK, the physical laboratories were in a dire state. The utilisation of the MIT WebLab could not fully address the curricula requirements of the target Programmes, and this eventually necessitated development of native laboratories. Although full integration of iLabs was envisaged, iLabs@MAK research initially targeted courses where inadequacy of equipment was particularly acute. Since 2008, iLabs have been developed in the fields shown in Table 1. Working in pairs and assisted by students from the lower levels, final year students derived the requirements specification for the iLabs from the curricula requirements of specific courses, and consultation with the respective technical personnel at MAK and MIT, course lecturers and professors. The developed laboratories have been used by over 2000 students and staff in relevant courses to date.

Table 1: iLabs Developed at MAK

Laboratory	Courses Supported
Amplitude and Frequency Modulation [6]	ELE 3204: Communication Engineering I ELE 4101: Communication Engineering II
The Pulse Code Modulation [6]	TEL 3101: Basic Telephony
Combinational Logic Circuit Analysis	ELE 1201:Introduction to Digital Electronics CMP 1202: Electronics II CMP 2203: Digital Logic
Fibre Optics Communication	TEL 3102: Internet Technology ELE 4103: Telecommunications Systems Engineering I ELE 4202: Telecommunications systems Engineering II
Control Systems	ELE 3202: Control Systems Engineering I ELE 4207: Control Systems Engineering II
Digital Signal Processing [7]	CMP 4101: Digital Signal Processing TEL3105: Basic Telephony CMP4205: Audio and Speech Signal Processing ELE3202: Instrumentation
FPGA [8]	CMP 2203: Digital Logic ELE 1201: Introduction to Digital Electronics ELE 3103: Advanced Digital Electronics

The iLab team in OAU has developed and deployed five remote laboratories with great support from the MIT iLab team, Carnegie Corporation and National Instruments (table 2). The OAU team also embarked on studies into the effect of realistic looking interfaces on the pedagogic value of remote laboratories [9], [10]. The introduction of iLabs had a three-way advantage: Firstly, each student could be required to perform the experiments personally as iLabs were made available round the clock. Hence, with one piece of laboratory equipment many students could be served. Secondly, students could be made to perform specific experiments at specific periods of the semester. Thus, it became possible to synchronize the lectures with the laboratory work. Thirdly, with the ease of setting up of remote laboratories with the iLab framework, it became possible to expand the experiment caches for courses and introduce laboratory into courses which previously had no laboratory exercises. These three advantages meant a major improvement in curriculum delivery.

Table 2: iLabs Developed at OAU

iLab	**Experiments**	**Platform**
Op-amp iLab [11], [12]	Inverting, non-inverting, summing, integrator, differentiator	NI ELVIS workstation. Switching matrix was built from the scratch
Logic Lab	De Morgan's law (digital electronics)	Built from scratch
Advanced digital lab [13]	Digital electronics experiments. Limitless number of experiments.	Altera DE-1 FPGA Development Board
Robotics iLab [5], [14]	Forward kinematics, inverse kinematics, gravity effect, trajectory planning	RA-01 robotic arm by Images SI Inc
Control Engineering iLab	Transient response (step response), system identification. Currently being expanded	Quanser DC motor control trainer on NI ELVIS

The iLab Team at UDSM has six developed laboratories in the field of electronics, based on the low-cost National Instruments Educational Laboratory Virtual Instrumentation Suite (NI-ELVIS) and Data Acquisition Interfaces. They address characterisation and application of electronics components like diodes and transistors. At the time of writing this paper ten conventional experiments have been converted into the iLabs, and more than ten new experiments, previously unavailable at UDSM are in the process of being introduced. Optical fibre communication experiments are typical example of iLabs which are in the process of being introduced.

Experiential Benefits of iLabs

The utilisation of iLabs has come hand-in-hand with offshoot benefits, which have contributed to capacity building at the partner institutions:

The sustainability of the iLabs@MAK Project has relied on establishment of an agile team comprising Members of staff, Graduate Fellows and Undergraduate students. The Undergraduate student members are recruited on merit from the BSc Electrical, Telecommunications and Computer Engineering programmes. The recruitment is in line with the University Strategic Plan on gender mainstreaming, offering equal opportunity to male and female students. At the time of authoring this paper, eight of the sixteen undergraduate student developers are female.

With mentorship from staff members, publications have accrued from the postgraduate and undergraduate research to-date. In building the technical capacity of the developers, iLabs have enabled the students utilize their time more effectively, get closer to their lecturers and develop effective reading habits. This has in turn translated into good academic performance. Two of the best students in the Electrical Engineering Department (Lea Musasizi and Cosmas Mwikirize) in the 2008/2009 academic year were final year researchers with the project. In 2009/2010, Michael Kyesswa was the best student in BSc Electrical Engineering.

Students also participate in exhibitions organized by private and public sector and in so doing improve their presentation and public speaking skills. Notably, iLabs@MAK represented the then Faculty of Technology at the Second Annual Kampala ICT expo and the East African Digital Revolution Forum 2010, where the project was recognized with an excellence award (Figure 3) for being the Best project nationwide, in ICT Research and Development.

Figure 3: Nicholas Mpanga (R) and Ephraim Malinga (L) after receiving the Award

At OAU, seven publications have accrued from iLab research to date. The pioneer researchers led by Kayode Ayodele have taken on academic career paths. Indeed, the motivation derived from iLab research has so far yielded three Masters theses, with one Masters and two PhD theses in view. The iLab community is a huge motivation to students at OAU and other Universities in Nigeria, toward undertaking research relevant to addressing national needs.

At UDSM, the development of new iLabs necessitated the establishment of a strong developer team. Three staff were identified and trained as developers and did their MSc dissertations on iLabs resulting in six locally developed iLabs experiments [15], [16], [17], [18], [19]. A few undergraduate students were also involved in the development of the iLabs, as part of their final year project. To date, fourteen students have done their final year projects on iLabs. The iLabs UDSM team gradually grew from three core members to twelve staff members. In order to strengthen higher education in sub-Saharan Africa, the retention and professional growth of talented junior faculty has been emphasized. Three of the new staff members received fellowship for their iLabs related MSc research. After organizing an international workshop in 2010, as part of the annual information exchange mechanisms among participating institutions in the iLabs project, two new students joined the team to pursue their MSc in iLabs.

iLabs: Supporting Student and Staff Exchanges in Africa

MAK, UDSM and OAU annually organise and participate in collaborative training workshops in which ideas about new development techniques, acquisition of skills, best utilisation practices and cross-cultural experiences are shared. Each of the Universities also organises an annual trip to MIT. The student and staff exchanges have gone a long way in fostering collaboration between these institutions.

iLab Outreach Programmes

The iLabs-Africa team is reaching out in efforts to afford the benefits of iLabs to high schools. This is being done by creating physics/science experiments for high schools and involving high school students in iLab activities.

As part of an initiative by the iLabs@MAK project to promote project-based learning in Ugandan Secondary Schools, secondary school students are encouraged to participate in elementary design projects to nurture their scientific minds at an early age. Some of the bench-marked activities include institution of Engineering Design Clubs in schools, an annual National Engineering Design Challenges and Mentorship Programmes between Makerere University and secondary schools. With financial support from the Presidential Initiative Project, Engineering Design clubs have been established at St. Mary's College Kisubi and Gayaza High School. The first challenge involving the two schools took place on April 2, 2011 where students exhibited creativity in programming LEGO Mindstorms NXT robots to solve real world problems. Figure 4 shows one of the Teams from Gayaza High School demonstrating the operation of a Fork Lift which they had designed using the NXT Toolkit.

Figure 4: Students from Gayaza High School Present at the Schools' Robotics Challenge 2011.

In February 2011 the OAU iLab team, in collaboration with the African Regional Centre for Space Science and Technology Education – English (ARCSSTEE) OAU, inaugurated a robotics club. This club is focused at introducing secondary school students and undergraduates to robotics and LabVIEW using Lego Mindstorms NXT kits. Three secondary schools are currently part of the programme: Adesina College, Ibadan, Ambassadors College, Ile-Ife and St. David's Grammar School, Ile-Ife.

<u>Creating an African Higher Education Space</u>

In an African Higher Education Space, it will be desirable to have educational content available for use across the continent. iLabs present this opportunity. As can be seen from the experience of the iLabs Africa team above, iLabs present the following advantages:

1. They provide the ability to share laboratories and experiments between institutions with no travel risks due to commuting and near-zero expense.
2. They could be used to foster student collaboration across universities on laboratory exercises.
3. They foster collaboration between institutions. This leads to a more comprehensive educational experience [20].
4. Cash-strapped institutions can give quality science and engineering education by making use of iLabs for laboratory exercises.
5. Ultimately, the cost laboratory education per institution is reduced and redundancy of laboratory equipment is reduced.

In creating an African Higher Education Space, the goal would be to create a structure for sharing educational resources between institutions of higher education. Resources which could be shared include library facilities, lecture notes and lecture materials and laboratory facilities. With iLabs, the sharing of laboratory facilities is almost trivial.

The main concerns which would rise from the use of iLabs in a higher education space are:

1. Provision of the iLabs
2. Terms of use of the iLabs
3. Facilities and equipment required for a user to use existing iLabs
4. Foreseeable challenges

Provision of the iLabs

There would be the need for the creation of a pool of iLabs from which institutions can request to use specific iLabs for their curriculum delivery.

Terms of use of the iLabs

Policy would need to be set up to determine the terms of use of the iLabs in the higher education space. There would ultimately be need to charge for access to the online laboratories as though little and dependent on the particular laboratories, there are running costs for maintaining an iLab.

Infrastructure Requirement for iLabs Use

Each participating institution would be required to own a Service Broker. In the ISA, the Service Broker is a server (web services) which handles the authentication of users logging on to it. With each institution owning and managing its own service broker, the iLabs pool would not need to know the individual students. The pool would only interact with the service brokers which would have been registered with it. In reality, the iLabs pool is merely a collection of service brokers which recognize each other and / or the various laboratory servers which host the laboratories. With the service broker, a layer of abstraction is put into the system so that each institution can handle the authentication, database and individual privileges of its own students / users and the lab provider can concentrate on providing the lab while being unbothered by these issues.

It goes without saying that any institution intending to participate in the Higher Education Space would need to have access to the internet for its students. iLabs, by placing a service broker in each user institution, minimize the amount of bandwidth needed for each experiment. Table 3 shows that very little data is transferred between the service broker and the lab server. Hence, with the service broker, most of the data is transferred over the university's intranet. The implication of this is that a good campus intranet is desirable to minimize the university's bandwidth requirement.

Table 3: Flow of control for performing an experiment using the ISA [21]

STEP	STUDENT	SERVICE BROKER	LAB SERVER
	Using Web Browser	**Using Web Application**	
1	Log in →		
2		← List student's groups	
3	Choose Group →		
4		← List available Lab Clients (i.e. experiments)	
5	Choose Lab Client →		
6		← Launch Lab Client	
	Using Lab Client & Web Services	**Using Web Services**	**Using Web Services**
7	→ Submit Expt Specs		
8		→ Submit Expt Specs	
9			← Submission Report
10		← Submission Report	
			Execute experiment
11			← Notify of completion
12		→ Retrieve Result	
13			← Result Report
Result is stored in service broker until student requests the result			
14	→ Retrieve Result		
15		←Result Report	

Foreseeable Challenges

In building the Higher Education iLab Space, there will be the need to address the following:

1. **Power Failure:** There will be a need for backup power supply for every iLab setup so that the iLabs are always available for use.

2. **Bureaucracy:** Bureaucracy will have to be minimized. In OAU's outreaches to other institutions, while the lecturers in the institutions were enthusiastic, it was often a big hassle to get the institution authorities to release necessary funds for the infrastructure necessary to enable them use the iLabs.

3. **Cost of Ownership and Cost of Use:** The required financing for each institution will be dependent on the goals of the institution. If the goal is simply to make use of iLabs developed by others, then financing is minimal (mostly purchase of one computer server to host its service broker). If the goal is however also to develop its own iLabs, a significant cost might be incurred. The expenses would be the purchase of a number of computer servers for its service broker and lab server, the cost of setting up the physical laboratory equipment and interfacing costs between the physical lab and the computer servers.

4. **Assessing the Quality of Developed iLabs:** At present, this is the grey area. There would be need for a lab accreditation system to verify that each developed iLab is of pedagogical value, and probably to rate its pedagogical value. This way, users of the lab can assess the quality of education being received from the labs and higher quality can be demanded.

Conclusion

iLabs have been of immense benefit to the Makerere University, OAU and UDSM. While there have been challenges in the development of iLabs, these can and are being surmounted. We recommend that iLabs and online labs in general are of great benefit to universities, particularly where laboratory education is presently deficient. The adoption of iLabs in all Universities in Africa, and hence creation of an iLabs pool, is a crucial step toward Strengthening the Space of Higher Education in Africa, drawing on the experience of the afore-mentioned institutions that have benefited greatly from using iLabs.

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