European Journal of Logistics Purchasing and Supply Chain Management
Vol.3, No.1, pp.29-43, March 2015
Published by European Centre for Research Training and Development UK (www.eajournals.org)

VIRTUAL LABORATORIES- A SOLUTION FOR TERTIARY SCIENCE EDUCATION IN BOTSWANA?

***[1]Chaurura Pearson, [2]Chuma Kudzai**
1. Botho University
Department of Health Information Management
Gaborone, Botswana
2. Botho University
Department of Accounting
Gaborone, Botswana

ABSTRACT: *The aim of this survey was to evaluate the suitability and acceptability of virtual laboratories as alternatives or supplements to the traditional physical laboratories in the teaching of graduates in laboratory-driven science disciplines in Botswana. Participants were drawn from three universities in Gaborone, Botswana. The majority of respondents (66.7%), were faculty staff members and the rest (33.3%), were postgraduate students or recent graduates (0-5 years) at Masters or PhD level in a laboratory-driven science discipline. The majority of respondents (55.6%) believed that the physical laboratories at their universities were not adequate to deliver effective training to postgraduate students in laboratory-driven science disciplines. Despite this, most respondents (52%) were confident that graduates in laboratory-driven science disciplines trained using current laboratory facilities at local universities were equipped to meet industry performance expectations. A significant proportion of respondents (75%), believed that virtual laboratories have a role to play in postgraduate teaching of laboratory-driven science disciplines in Botswana. In terms of the preferred implementation model, the vast majority (94.4%), of respondents favored the hybrid model combining the use of both virtual and physical laboratories as a permanent set up in the teaching of graduates in laboratory-driven science disciplines.*

KEYWORDS: Virtual laboratory, physical laboratory, laboratory-driven science discipline,

INTRODUCTION

The field of science, in its broadest contemporary sense, makes some of the most valuable contributions to the general welfare of humanity. It is not an overstatement to say that the level of scientific activity in a country or region can be directly correlated to the level of development and quality of life in that region or country. Indeed the widely used descriptors "*first world countries*" and "*third world countries*" are direct references to the levels of development and quality of life these places. Level of productive scientific activity is one of the distinguishing factors between the developed and developing countries. One of the various reasons advanced by third world countries for this difference is a lack of resources to effectively teach and train scientists in the various disciplines. This boils down to the lack of adequate laboratory facilities. This challenge has to be addressed against a background of a proud history of incorporating the physical laboratory experience as an indispensable and integral part of teaching and training scientists. However, the

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

capital requirements of setting up a fully equipped physical laboratory have been and continue to be a deterrent for effective science teaching and training in the developing countries. Consequently, Africa and many of the third world countries have, to date, continued to lag behind their first world counterparts in terms of scientific activity and quality of life. Advancements in the information and communication technology has opened up real opportunities for developing nations to narrow the gap between them and the developed nations. Of particular interest to this study is to evaluate the potential use of virtual laboratories to augment or replace traditional physical laboratories in the training of scientists in Africa.

Problem Statement

Third world countries have struggled to adequately teach and train professionals in the science field primarily due to a limited access to adequate resources in the form of physical laboratory facilities and laboratory consumables. The traditional emphasis on hands-on laboratory experience as an indispensable part of 'proper' and adequate training in the science disciplines has meant that third world countries have lagged far behind their first world counter-parts in terms of the quality of training, research and general quality of life. Technological advancements have created opportunities for the augmentation and or complete replacement of physical science laboratories in the teaching of science graduates. However, the acceptability and suitability of these alternatives have remained contentious issues and only the bravest and most liberal institutions have so much as dared to discuss let alone try to incorporate them in their curricular. There is need, at this juncture, to explore the suitability and acceptability of virtual laboratories as potential alternatives or supplements to the expensive traditional physical laboratory facilities in the third world context exemplified by Botswana.

Justification

Finding and adopting a viable alternative(s) to the use of expensive-to-equip traditional physical laboratories can help the third world countries to significantly improve the teaching and training of science graduates. This can lead to increased scientific research output and improved quality of life in third world countries.

General Objective

The aim of the study was to evaluate the suitability and acceptability of virtual laboratories as alternatives or supplements to the traditional physical laboratories in the teaching of graduates of laboratory-driven science disciplines in Botswana.

Specific Objectives

1. To evaluate the adequacy of current physical laboratory resources for the training of science graduates.
2. To evaluate the confidence of science academics and postgraduate students in the ability of the current training, using physical laboratories, to satisfy industry expectations.
3. To evaluate the acceptability of the virtual laboratory as an alternative to the physical laboratory for the training of scientists in Botswana.
4. To make recommendations concerning virtual laboratories as a potential tool for enhancing tertiary science education in developing countries.

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

LITERATURE REVIEW

What is a Virtual Laboratory?

Definitions abound about what a virtual laboratory really is. Captured here are some of the definitions in existence:

1. "Virtual laboratories use computers to provide highly interactive virtual reality simulations of laboratory exercises." www.cnx.org/content/m18036/1.1.
2. "A virtual laboratory is one where the student interacts with an experiment or activity which is intrinsically remote from the student or which has no immediate physical reality." www.web.phys.ksu.edu/icpe/Publications/teach2/Hatherly.pdf
3. " A laboratory experiment without real laboratory with its walls and doors…" Harry and Edward (2005).
4. "Virtual labs use the power of computerized models and simulations and a variety of other instructional technologies to replace face-to-face lab activities." Scheckler (2003).
5. "Virtual studying and learning environment that simulates the real laboratory." Babateen (2011).
6. "A virtual laboratory is a computer-based activity where students interact with an experimental apparatus or other activity via a computer interface." www.web.phys.ksu.edu/icpe/Publications/teach2/Hatherly.pdf

A distilled definition of the virtual laboratory that is consistent with the ideas advanced in this research is given below:

"A virtual laboratory is a set-up consisting of computer hardware and software designed to simulate, as closely as possible, traditional physical laboratory activities for the purpose of imparting comparable knowledge and skills to learners."

Hatherly (www.web.phys.ksu.edu/icpe/Publications/teach2/Hatherly.pdf) makes an important distinction between simulations, computer-controlled experiments and a remote-controlled experiment. The simulated experiment involves a student interacting with programmed-in behaviours.

Computer-controlled experiments involve a student directly controlling an apparatus in his/her vicinity via a computer interface.

Remote-controlled experiments involve a student interacting with **real apparatus** via a computer link, yet the student is remote from that apparatus.

Simulations and remote-controlled experiments create the opportunities being sought for resource-poor third-world countries. Computer-controlled experiments create the same challenges related to physical laboratories since physical laboratory equipment will still be required within the immediate vicinity of the student. Remote controlled experiments provide an opportunity for developing countries to create partnerships with resource-rich first world countries whereby students in third world countries could remotely work with apparatus located in first world countries through the use of advanced information and communication technologies available today. Remote-controlled experiments overcome the biggest criticism against virtual laboratories in that learners use the power of information technology to **operate actual/real equipment/apparatus** located in remote/different geographic location. Simulation, though simpler and easier to use suffer from many setbacks including a detachment from reality and other such limitations.

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The Components of a Virtual Laboratory

The Benefits of the Virtual Laboratory

The benefits of using virtual laboratories vary from author to author but some of the more prominent ones are outlined below.

1. Increased accessibility of laboratory activities for students prevented by some reason from being able to access a physical laboratory. Such limit may emanate from a student's reduced dexterity, physical disability, or geographic distance (www.web.phys.ksu.edu/icpe/Publications/teach2/Hatherly.pdf).
2. Improved safety in the case of hazardous experiments (www.web.phys.ksu.edu/icpe/Publications/teach2/Hatherly.pdf).
3. Provision of training and practice for new or high risk experiments (www.web.phys.ksu.edu/icpe/Publications/teach2/Hatherly.pdf).
4. Virtual laboratories do not suffer from the constraints of space requirements as do physical laboratories (www.eprints.oum.edu.my/119/1/Merits_and_Demerits.pdf)
5. Low set-up and maintenance costs (www.eprints.oum.edu.my/119/1/Merits_and_Demerits.pdf)
6. Reduced complexity in carrying out experiments using a virtual laboratory (www.eprints.oum.edu.my/119/1/Merits_and_Demerits.pdf)
7. The technology-rich environment of the virtual laboratory greatly enhance the modern students' motivation (Babateen, 2011)

Disadvantages of Virtual Laboratories

The following are some of the criticisms against the use of virtual laboratories to train scientists:

1. Students need to possess prior knowledge of computers and the internet (www.eprints.oum.edu.my/119/1/Merits_and_Demerits.pdf).
2. Special hardware and networking requirements such as multimedia capabilities and high-speed servers may limit the utilization of the virtual lab concept by those who most need it e.g remote users (www.eprints.oum.edu.my/119/1/Merits_and_Demerits.pdf).
3. The possibility of virtual lab software become obsolete fast thereby causing high replacement costs (www.eprints.oum.edu.my/119/1/Merits_and_Demerits.pdf).

In the final analysis, the choice of whether to use physical laboratories or virtual ones is guided by a comparison of the benefits and disadvantages.

METHODOLOGY

Approach, Rationale and Study Population

The laboratory-driven science disciplines considered were Chemistry, Biological Sciences, and Engineering. A questionnaire designed to evaluate the participants' views on the adequacy of current physical laboratories, satisfaction with training provided/acquired using current physical laboratories, and the possibility of using virtual laboratories to augment or completely replace traditional physical laboratories. The collected data analysed using SPSS. It is hoped that information from the study will help evaluate the preparedness of learners and educators to adopt virtual science laboratories and the acceptability of this mode of teaching and learning in the

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

context of Africa in general and Botswana in particular. The study took a survey approach involving three groups of people: 1) current postgraduate students in laboratory driven disciplines (chemistry, environmental science, physics and biological science, etc), 2) postgraduate holders in the same disciplines (0-5 years) who are not members of the academic staff of a tertiary institution and 3) members of the academic staff involved in teaching laboratory-driven courses at a tertiary institution in Botswana (Senior Lecturers, Lecturers, Teaching Assistants and Laboratory Technicians). The first two groups were chosen to provide insight into student views and opinions on the research topic. Having gone through (or currently going through) university education they have first-hand experience with university laboratory resources at both undergraduate and postgraduate levels and can therefore provide insight into student experiences in an African setting. The third group was chosen to provide views and opinions of trainers and educators on the research topic.

Survey Tool

The survey tool was a questionnaire designed to evaluate the students' views on the adequacy of current resources in the physical laboratories of the university, students' satisfaction with their training using current laboratory resources at the university, students' views and opinions on the possibility of using virtual laboratories to augment or completely replace traditional physical laboratory sessions, trainers' views on the adequacy of current resources in the physical laboratories of their university, trainers' confidence in their students trained using current laboratory resources at their university, trainers' views and opinions on the possibility of using virtual laboratories to augment or completely replace traditional physical laboratory sessions.

Analysis of data

Data was analysed using the SPSS package.

RESULTS

7.1 Profile of Respondents

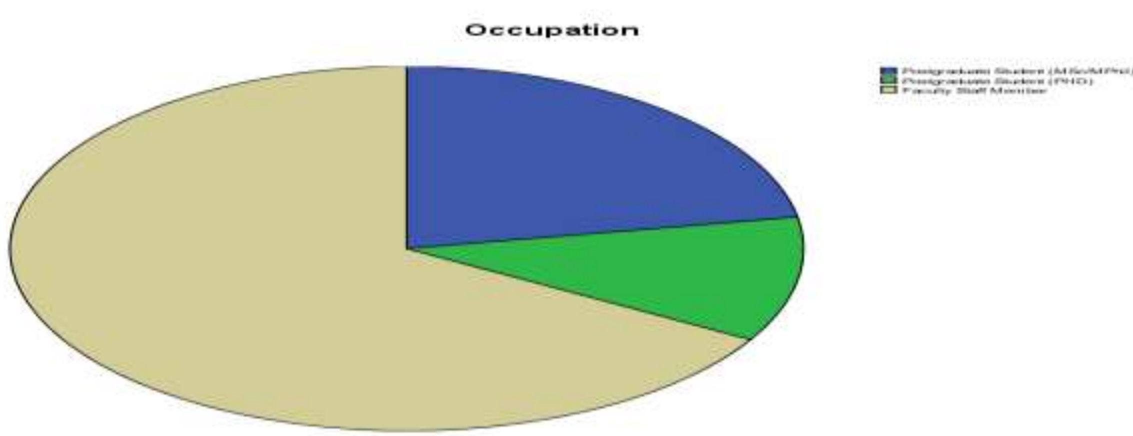

Figure 1. The proportions of survey respondents by occupation

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

The majority of respondents (66.7%) were faculty staff members at universities in Gaborone Botswana. The rest (33.3%) were postgraduate students, that is, current or recent graduates Masters or PhD level in a laboratory-driven science discipline.

Adequacy of Current Laboratory Facilities for Science Training

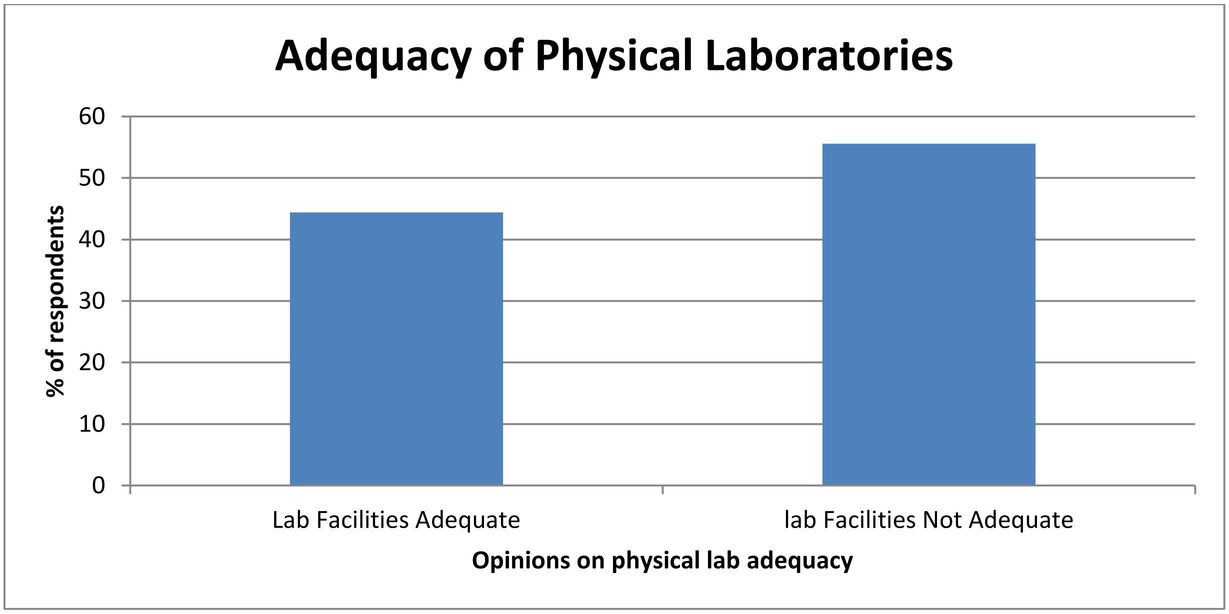

Figure 2a. Overall opinions on the adequacy of current physical laboratories.

The majority of respondents (55.6%) do not believe that the physical laboratories at their university are adequate to deliver effective to postgraduate students in laboratory-driven science disciplines.

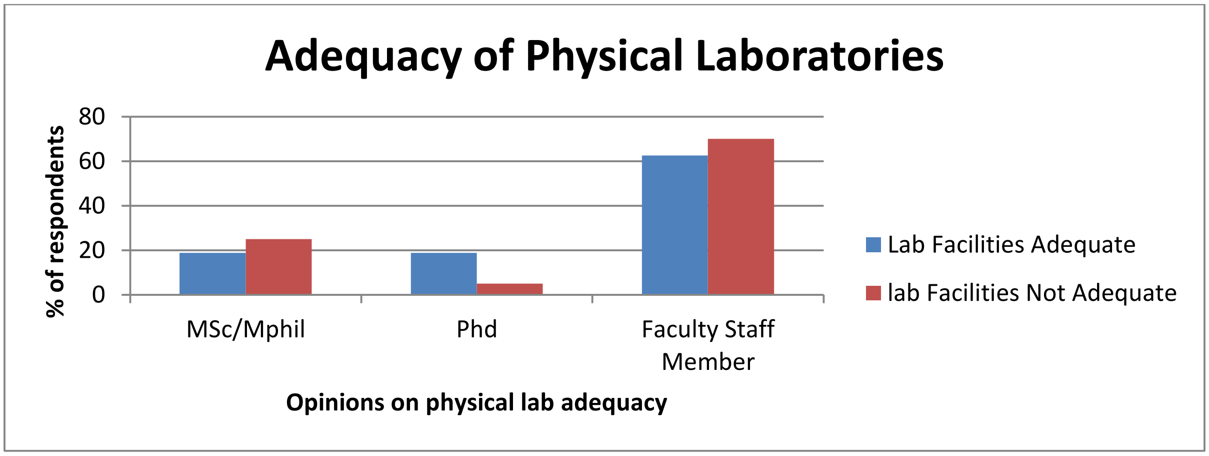

Figure 2b. Opinions on the adequacy of current physical laboratories by respondent category.

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

70% of faculty staff members and 30% of postgraduate students believed that the current physical laboratories at their universities were not adequate for the teaching of postgraduate science students.
62.5% of faculty staff members and 37.5% of postgraduate students believed that the current physical laboratory facilities at their universities were adequate for the teaching of postgraduate science students.

7.3 Confidence in the Ability of Science Graduates to Meet Industry Expectations.

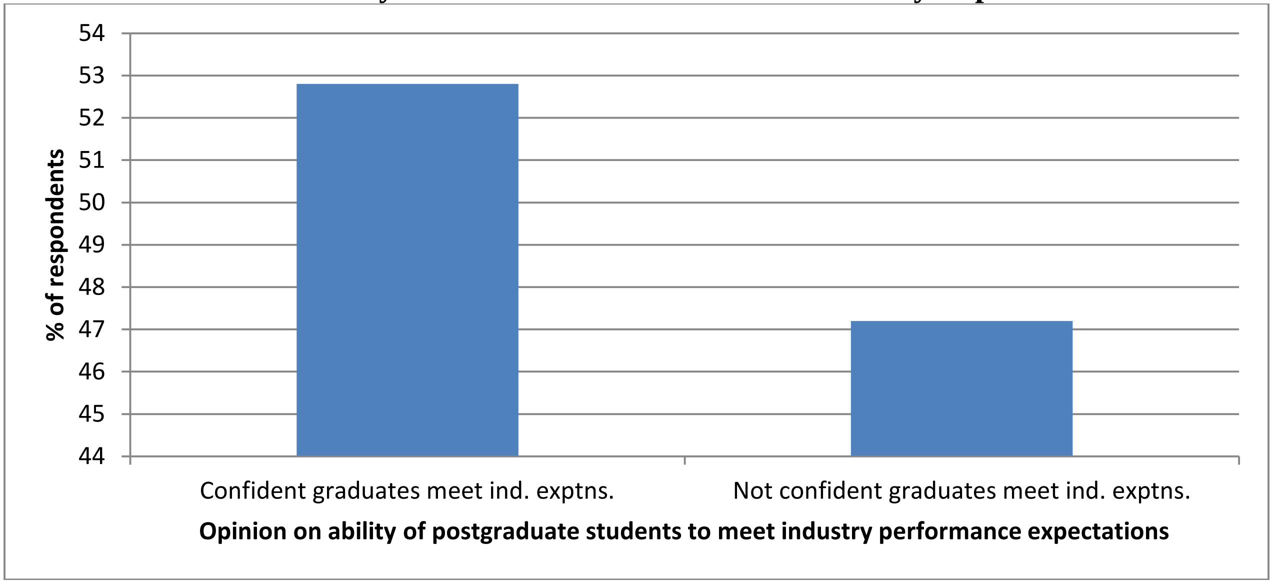

Figure 3a. Overall opinion of respondents on the ability of science graduates to meet industry performance expectations.Most respondents (52.8%) were confident that graduates in laboratory-driven science disciplines trained using current laboratory facilities will be able to meet the performance expectations of industry.

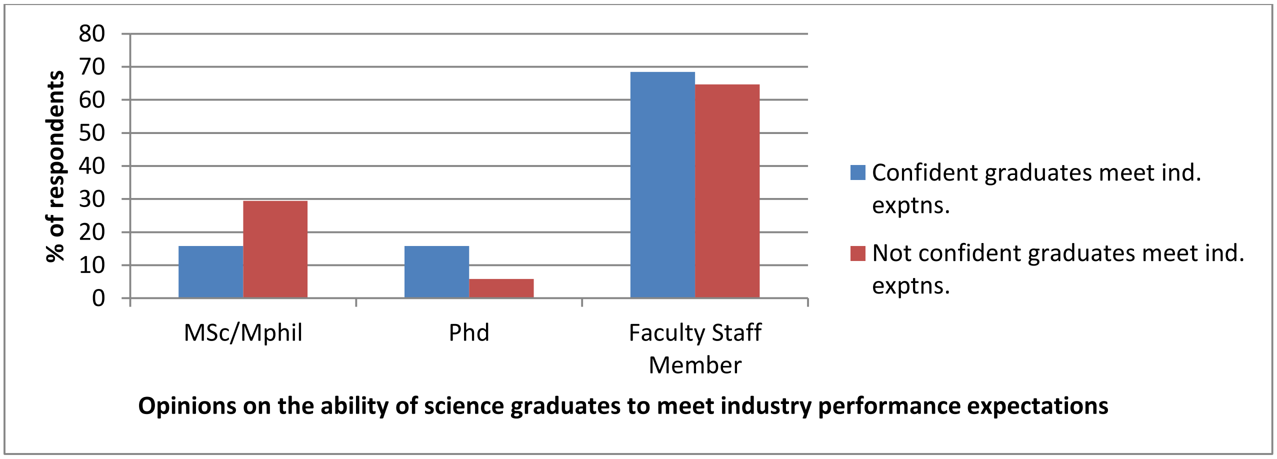

Figure 3b. Opinions of respondents, category-wise, on the ability of science graduates to meet industry performance expectations.

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

68.42% of faculty staff members and 31.58% of postgraduate students were confident that science graduates trained with current laboratory facilities can meet industry performance expectations. 64.71% of faculty staff members and 35.29% of postgraduate students were not confident that science graduates trained with current laboratory facilities can meet industry performance expectations.

7.4 Need for virtual laboratories in postgraduate science education in Botswana

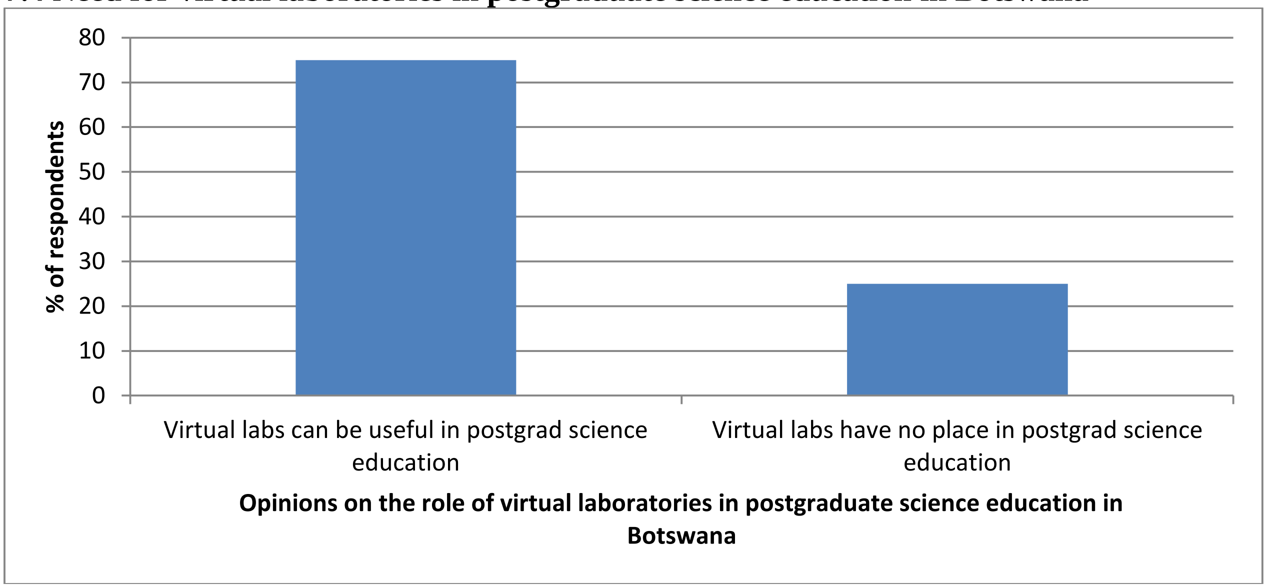

Figure 4. Opinions on the potential role of virtual laboratories in science education in Botswana.

An overwhelming majority of respondents (75%) believe that virtual laboratories have a role to play in postgraduate teaching of laboratory-driven science disciplines.

Implementation of virtual laboratories for postgraduate science education.

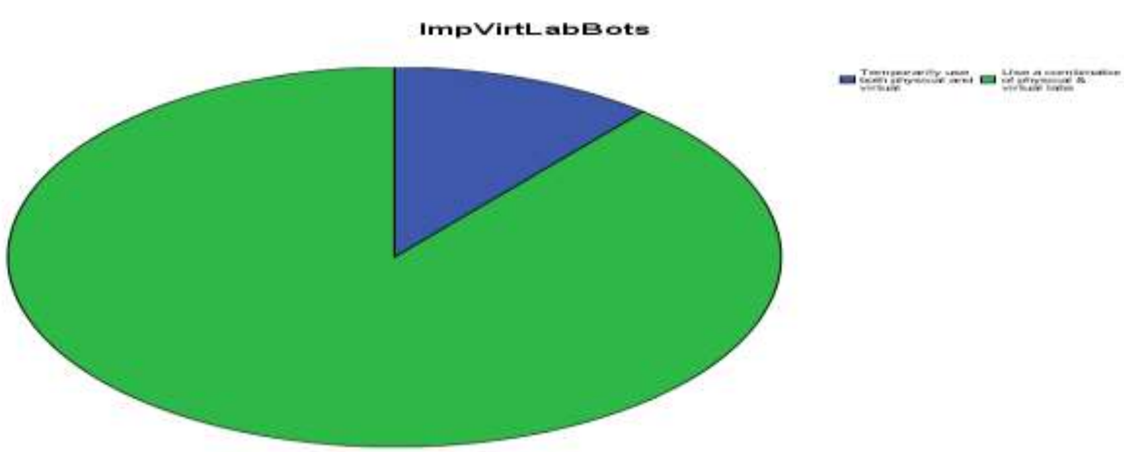

Figure 5. Preferred Implementation Plan for Virtual Laboratories in Botswana

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

The vast majority (94.4%) of respondents preferred the use of both virtual and physical laboratories as a permanent set up in the teaching of graduates of laboratory-driven science disciplines.

DISCUSSION

The aim of this survey was to evaluate the suitability and acceptability of virtual laboratories as alternatives or supplements to traditional physical laboratories in the teaching of graduates in laboratory-driven science disciplines at postgraduate level (masters and/or PhD) in Botswana. The participants in the study included faculty staff members in laboratory-driven science disciplines (Chemistry, Biological Sciences and Physical Sciences) at universities and postgraduate students or recent graduates (0-5 years) at Masters or PhD level in these disciplines at universities in Gaborone, Botswana. These respondents were deemed competent to provide expert opinion in the matter under investigation. The faculty staff members provided the opinions of the training provider and the postgraduate students provided the opinions of those being trained in the laboratory-driven science disciplines.

With regard to the adequacy of current physical laboratory facilities at the universities involved in the survey, of the 40 respondents who felt that the facilities were not adequate 28 (70%) were faculty staff members and 12 (30%) were postgraduate students. Of the 32 who felt that the laboratory facilities were adequate, 20 (62.5%) were faculty staff members and 12 (37.5%) were postgraduate students. Overall, 55.6% of the respondents believed that the traditional physical laboratory facilities at their universities were not sufficient to deliver effective training to postgraduate students in laboratory-driven science disciplines compared to 44.4% who believed the contrary. These results indicate a general dissatisfaction with current physical laboratory facilities used in the teaching of laboratory-driven science disciplines in universities in Gaborone, Botswana. This provides a fairly strong argument for the need for alternative approaches that may be used to boost teaching in laboratory-driven science disciplines.

Despite the general dissatisfaction with the adequacy of physical laboratory facilities for training postgraduate students in laboratory-driven disciplines, 38 respondents (52%) were confident that graduates of laboratory-driven science disciplines trained using current laboratory facilities at local universities were equipped to meet industry performance expectations. Of these 26 (68.42%) were faculty staff members and 12 (31.58%) were postgraduate students. This result suggests that university faculty staff members have more faith in the outcome of current training than the postgraduate students trained, 35.29% of whom believe that the training is not adequate. This difference of opinion needs to be understood since the student is the client in the educational setting and his/her satisfaction level with the services rendered must be taken into account particularly if the students are paying from their pockets.

A significant proportion of respondents (75%), believed that virtual laboratories can play a role to play in postgraduate teaching of laboratory-driven science disciplines in Botswana. This is particularly important given the above-mentioned dissatisfaction with the adequacy of current laboratory facilities in universities. Virtual laboratories can indeed mitigate the problem of

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

insufficient laboratory facilities and open up new opportunities for postgraduate teaching that are currently not available. In terms of the preferred implementation model, the vast majority of respondents (94.4%), favored a hybrid approach that combines the use of virtual laboratories and physical laboratories as a permanent approach in the teaching of graduates in laboratory-driven science disciplines. This approach enables lecturers and learners to switch between the two as the situation demands. It is also important to note that both virtual and physical laboratory approaches have their limitations therefore using both as appropriate allows one to take advantage of the strengths of both approaches. Proponents of this approach also stated that virtual laboratories are ideal when dealing with large classes, a common feature of university education. Another idea which came through from respondents is that virtual laboratories will give students in remote locations access to laboratory training which they would otherwise not get. Virtual laboratories are also ideal for experiments that take a long time to do or that are risky. In the later situation, students are able to practice without the risk of exposure to harm.

Other respondents, albeit the minority, felt that Botswana is not yet ready for the adoption of virtual laboratories in the training of postgraduate students in laboratory-driven science disciplines. These respondents seem to align themselves with the traditional view that science cannot be learnt without practical exposure to hands-on laboratory sessions. In this, they err in that they insist on holding on to a teaching model that is not delivering to expectations. One thing is clear, and that is there is need for an intervention and intervention may well be the adoption of virtual laboratories in science education.

CONCLUSION

Rather than continue to fight the concept of virtual laboratories in the teaching of natural sciences, regulatory bodies need to accept it as a viable alternative to traditional physical laboratory laborites. The accreditation process should then focus on evaluating the different virtual laboratories that will be developed against set criteria designed to assess the virtual laboratory's resemblance to reality, flexibility for different outcomes, functionality, user friendliness and other such important criteria.
From the expert opinions of university lecturers and postgraduate students, it appears sensible to adopt a hybrid approach that combines virtual laboratories and traditional physical laboratories in the teaching of postgraduate students in science disciplines.

RECOMMENDATIONS

Universities in Botswana should explore the possibility of adopting virtual laboratories in the teaching of laboratory-driven disciplines. In particular, they should try to access suitable virtual laboratories for those areas where they lack equipment or other resources. The economic and academic benefits may well be phenomenal.

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

1. http://eprints.oum.edu.my/119/1/Merits_and_Demerits.pdf
2. http://cnx.org/content/m18036/1.1.
3. http://web.phys.ksu.edu/icpe/Publications/teach2/Hatherly.pdf
4. Harry E.and Edward B. (2005). Making Real Virtual Lab. *The Science Education Review.*
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6. Babateen H.M. (2011). The Role of Virtual Laboratories in Science Education. *5th International Conference on Distance Learning and Education IPCSIT* **12**:100-104.

Appendix

Table 1. Occupational Profile of survey respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Postgraduate Student (MSc/MPhil)	16	22.2	22.2	22.2
	Postgraduate Student (PHD)	8	11.1	11.1	33.3
	Faculty Staff Member	48	66.7	66.7	100.0
	Total	72	100.0	100.0	

Table 2. Preferred Implementation Plan for Virtual Laboratories in Botswana

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Temporarily use both physical and virtual	8	11.1	11.1	11.1
	Use a combination of physical & virtual labs	64	88.9	88.9	100.0
	Total	72	100.0	100.0	

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)

Table 3. Comparison of opinions of respondent groups on adequacy of physical laboratory facilities

Count					
		Occupation			Total
		Postgraduate Student (MSc/MPhil)	Postgraduate Student (PHD)	Faculty Staff Member	
AdPhyLabTr	Disagree	6	0	4	10
	Strongly Disagree	4	2	24	30
	Agree	6	6	20	32
Total		16	8	48	72

Table 4. Comparison of opinions of respondent groups on confidence that science graduates trained using current lab facilities meet industry performance expectations.

Count					
		Occupation			Total
		Postgraduate Student (MSc/MPhil)	Postgraduate Student (PHD)	Faculty Staff Member	
ConWplDelv	Disagree	6	0	4	10
	Strongly Disagree	4	2	18	24
	Agree	6	6	26	38
Total		16	8	48	72

ISSN 2054-0930 (Print), ISSN 2054-0949 (Online)