Role of ICT-enabled visualization-oriented virtual laboratories in Universities for enhancing biotechnology education - VALUE initiative: Case study and impacts

Authors contributed equally to the design, deployment, surveys and data analysis towards the results in this paper.
Corresponding author: shyam@amrita.edu

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Bipin Nair, Remya Krishnan*, Nijin Nizar*, Rakhi Radhamani*, Karthika Rajan*, Afila Yoosef*, Gopika Sujatha*, Vijilamole Radhamony*, Krishnashree Achuthan, Shyam Diwakar*,

Amrita Vishwa Vidyapeetham (Amrita University), Kerala, India

ABSTRACT. Information and Communication Technology (ICT) enabled virtual labs have been setup in order to facilitate and enhance higher education. VALUE Biotechnology virtual labs were implemented as part of an ICT initiative and tested between several students and teacher groups. In this paper, we discuss about the application of virtualizing concepts and experiments in biotechnology, one of the fundamental area of biological sciences to impart quality education to meet the necessities of students. We found virtual labs, enhanced attention and student performance in biotechnology courses. The paper reports that applying virtualization techniques, biotechnology education could be intensified in terms of student attention and virtual lab can serve as an effective teaching pedagogy. The paper shows how virtual labs in biotechnology can be exploited to improve teaching and student performance. This study analyzes the trends of user behavior towards virtual laboratories and the usability of these laboratories as a learning and curriculum material. Findings from indicated biotechnology virtual laboratories encompass all the core subjects of their curriculum materials in an easy and understandable way with user-interaction and serve to reduce the problems of laboratory education especially in economically challenged and geographically remote areas. Virtual laboratories target a user-friendly outlook to modern laboratory education, aiding as an optional evaluation component for University teachers.

KEYWORDS: *Biotechnology, Learning pedagogy, Simulation, Virtual labs, Visual learning*

Introduction

Most universities in developing countries are struggling with economical stress in attaining all the laboratory resources required for cost-effective laboratory education (Ma, Nickerson, 2006). Majority of schools in remote areas lack good teachers, good laboratories and other facilities for teaching (Mitra et al., 2005). Overcrowded classrooms are also a big problem for both teachers and students. In this condition, the teachers are forced to teach students in a "show and tell" manner in front of the whole classroom because of which the students face difficulties in paying attention towards the class (Zumbach et al., 2006). Laboratories have been shown to play a pivotal role in student's constructivist education (D'Souza et al., 2001). Major problems associated with a typical biology laboratory course are extended time requirements to train a student and the cost related to it. Some other issues which affect the current laboratory education includes the lack of sufficient reagents and equipments, limitations on the use of hazardous materials, ethical considerations and lack of practical skills (Bell, 1999; Tuysuz, 2010; Kisnieriene et al., 2008). Several research studies have suggested that continuous development in information technology has changed the laboratory education platform (Scanlon et al., 2002). In this scenario, online tools have been developed to overcome these constraints and supplement classroom teaching by developing artificial educational environments (Sapula, Haule, 2011). Web-based technology has provided new inventions towards effective educational tools for imparting exciting opportunities to improve the quality of teaching and science literacy. Virtual laboratory is one of such artificial educational environment developed to complement the current educational issues. Virtual laboratories were developed as effective computerized learning tools which substitute real laboratory resources with virtually defined techniques including hands-on experiments and demonstrations. Virtual laboratories are supported with a variety of instructional technologies including simulations, animations, videos, remote triggered experiments which facilitates user interactions. Virtually developed simulations can resolve difficulties due to inadequate lab requirements by allowing users to experience the experiment safely and repeatedly even at home (Muhamad et al., 2010). One of the most important characteristics of virtual lab is its high degree

of flexibility which facilitates students self learning at anytime and anywhere (Budhu, 2002; Koretsky et al., 2011). A widely accepted example of such a web based interactive teaching tool is HHMI virtual labs developed by Howard Hughes Medical Institute which implement mathematical models in biological phenomenon[1]. Biotechnology, a rapidly growing field of interdisciplinary science, plays an indispensable role in framing the career of science graduates. It is a combination of various sophisticated technologies which focus on many fields of science such as cell biology, molecular biology, microbiology, biochemistry, immunology, ecology, statistics and engineering sciences. The arrival of biotechnology has opened a new world to the field of science research. The recombinant DNA technology, one of the applications of biotechnology, is widely used to exploit the features of biological systems for industrial purpose such as the production of effective therapeutic drugs which has a massive impact on health care. Using genetically modified organisms, biotechnologists produce large amount of biopharmaceuticals and biological products. Biotechnology is widely used in forensic sciences especially in criminal investigations and paternity testing. Gene therapy is one of the most encouraging fields of biotechnology which helps to treat diseases by altering the DNA. As an overall, the field of Biotechnology acquired an important role in every step of human life such as, health care, production of transgenic plants and animals with improved qualities, development of valuable products and in avoiding environmental problems. To make biotechnology education pervasive, laboratory facilities need more attention.

1.http://www.hhmi.org/biointeractive/vlabs

Biotechnology virtual laboratories

As most science courses, biotechnology courses also require continuous syllabi update and use of sophisticated laboratory techniques and protocols. It was necessary to develop an online tool that supplements the classroom learning with main focus on biotechnology laboratory sessions. Another feature that supports the use of virtual laboratories at universities was the increasing interest among user groups when considering ethical consideration in animal and human research. It has been indicated that visual learning play a major role in enhancing students understanding ability through visually explained concepts (Rajendran et al., 2010).

As part of a National mission on education, developing nations like India have started investing in virtual laboratories. VALUE (Virtual Amrita Laboratories Universalizing Education) is one such National mission project looking at setting up a new pedagogy of virtual laboratories (Diwakar et al., 2012).

Biotechnology virtual laboratories use technologies like animation, simulation and remote triggered experiments. Virtual simulations which are developed on the basis of mathematical equations provide a safe user-interactive platform to practice the real works (Al-Safadi, Al-Safadi, 2009). The use of interactive animation and simulation show an increasingly important role on current teaching scenario (Chu,1999; Yarden et al., 2011). VALUE biotechnology virtual labs use 2D flash based animations with visually explained hands-on labs with step-by-step protocol carried out in the laboratory, which gives a laboratory-feel to the users (Diwakar et al., 2012). Technologies like remote triggered laboratories were designed to reduce the distance between the user and the experiment (Casini et al., 2001, 2003). Remote-triggered experiments were mainly focused on engineering subjects which are equipment-dependent, whereas biology "experiments" rely on human interaction. Therefore it has been difficult to include many remote-triggered 'experiments' in biotechnology.

The content in biotechnology virtual labs included virtualized techniques in cell and molecular biology, immunology, microbiology, neuroscience and population ecology and has been discussed elsewhere. (Diwakar et al., 2012). In our project[2], we have also included bio-inspired robotics lab and biophysics lab, which deal with biorobotics, neuronal robotics and biophysical techniques respectively through remote-triggered approach. Advanced techniques like modeling of Bioreactor and cultivation methods[3], mass spectrometry methods like MALDI-TOF MS, gel based proteomics, PMF[4] etc. are also included in biotechnology virtual labs. To perform all these experiments in real lab requires costly reagents, prolonged time period, well-designed equipment and skilled personnel. Some of these experiments necessitate the use of hazardous chemicals such as Ethidium bromide, Acrylamide etc.; improper handling of these chemicals may cause health hazards. Taking all these difficulties into consideration, biotechnology virtual labs have been developed as a supplement to overcome these issues to a greater extent.

2. http://amrita.edu/virtuallabs

3. www.iitd.vlab.co.in

4. www.iitb.vlab.co.in

Educators have suggested that virtual laboratories were multi-performers as teaching tools and as curriculum material, by including ICT technologies. Different case study analysis and workshops conducted in Biotechnology virtual labs support the immense use of virtual labs for supplementing educational purpose. Advanced technology helps teachers in reducing the work load by delivering their instructions to students through virtual laboratory based learning (Buntat et al., 2010; Diwakar et al, 2011). In this paper, we have analyzed the impact of biotechnology virtual laboratories on user behavior and their role as a teaching and curriculum tool through feedback, surveys and workshops.

Table 1. Different components of Biotechnology Virtual laboratories

Animation only experiments	Interactive animation	Simulation	Video
Technique for visualization	Interactivity with users	High degree of interactivity (emulation)	Precisely reproduce an experiment in real lab environment
Supplement traditional class room learning	Provide guidance for learning	Can be manipulated by users to adjust real-world parameters	Step by step protocol is discussed
Easily accessible at any time - anywhere	Feel of real laboratory environment	Variables realistic to traditional system	High quality results are displayed
Increased curiosity of learners	Random results are displayed for different users	User can work individually	Simple way of learning
Graphics oriented method of learning	All the possible outcomes are displayed effectively	Hands on experience on sophisticated instruments	Induce a better way of understanding
Easy to understand	Easily interpretable	Experiments are dynamic in nature	Freely available online

Methods and approach

Virtual biotechnology laboratory experiments (VALUE)[5] were modeled based on the syllabi of many Indian universities. Experiments from various subjects like Biochemistry, Microbiology, Population Ecology, Cell Biology, Molecular Biology, Immunology, Bioreactor design and modeling, techniques in proteomics such as

5. see http://amrita.edu/virtuallabs

MALDI -TOF MS analysis are animated using 2D Adobe Flash (AS3) based animations. This aids in illustrating detailed procedures such as wet lab protocols and heavy engineering techniques that are out of scope for simulation due to complicated equations, numerical issues in simulation, lack of modeling data etc. Besides animation, another common technique in our virtual labs includes engineering-based approaches such as remote-triggered experiments or remote-controlled experiments. Adobe flash was chosen for developing simulators for its commonness as a browser plug-in and offers features including 3D effects. Incompatibility issues were reduced using flash as the medium (Diwakar et al., 2011).

A. VL User Interface

Selected biotechnology experiments from undergraduate (UG) and postgraduate (PG) curriculum of various universities were standardized by referring text books, lab manuals and journal articles. The experiment was then performed in a real laboratory to obtain data needed for the virtual demonstration of the experiment. After validation, video of the experiment was recorded. The experiment was virtualized using this data. The different methods, used to virtualize the experiments and its significance in learning process, are listed in Table 1.

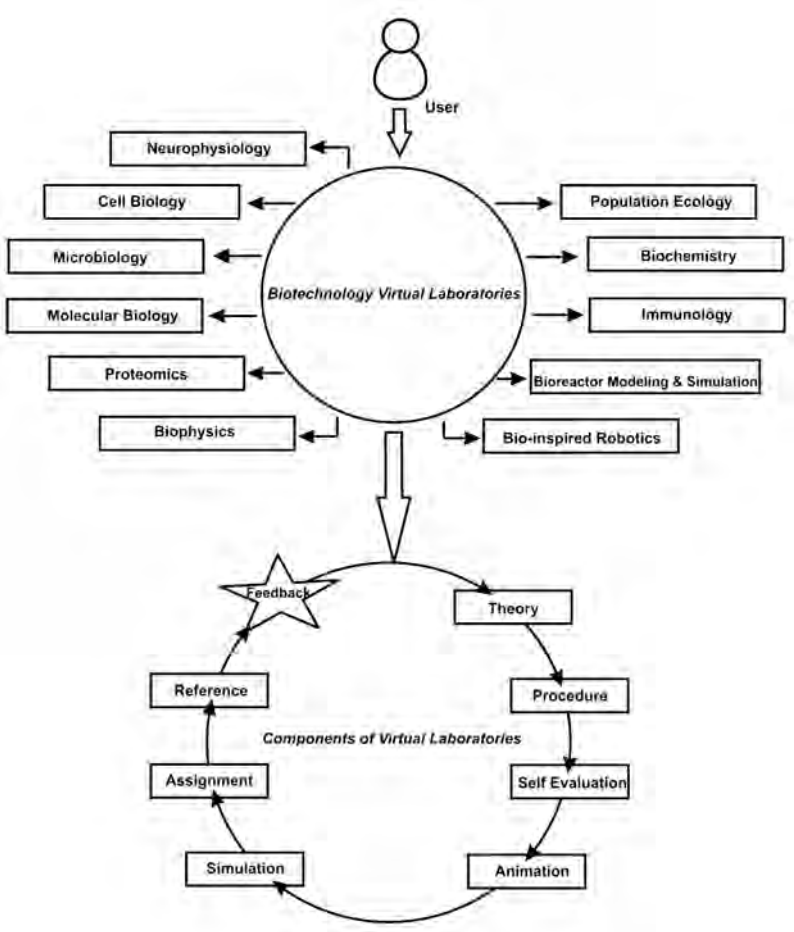
In our virtual biotechnology laboratories, these components were found to be very useful for educating the user groups. In a broader sense, simulations play a vital role in gaining knowledge on sophisticated instruments, which are of prime importance in learning Biotechnology courses. Similarly the animated experiments in all the core subjects provide a better understanding of the concepts in an easier way. The interactive animations in experiments such as Triple Sugar Iron (TSI) test needs the user interaction for moving on to further steps. The experiment was also conducted in a real-world environment and was recorded as "lab video" to help a user understand laboratory scenarios.

In addition to these components, the virtual laboratories also provide a detailed theory and step-by-step procedure of the experiment. Each experiment in the biotechnology virtual laboratories includes several components from theory, procedure, assignments etc. (see Figure 1).

Apart from theory and procedure, another important feature of virtual laboratories was a "self-evaluation" quiz which helps

the users to analyze their knowledge on a particular area. The "Assignment" section includes a set of questions regarding the experiment that one would answer as part of a "Lab examination" Additional information about the experiments was linked in the "Reference" section.

Figure 1. A model of virtual Biotechnology laboratory



Feedback was a critical element in virtual laboratories that will help in further improvement and/development of the quality of the experiment with regard to the suggestions from the users. Since it is an assessment tool for estimating user quality, the user participation and their opinions about particular experiment were recorded and analyzed.

B. Protocol virtualization steps

Virtualization of the experimental protocol depends on a series of steps (Figure 2). Based on the experiment performed in a real laboratory, a story-board was sketched. After verification of the story-board, the experimental steps were categorized into significant and semi-significant steps. The significant steps included the most critical parts of the experiment including the step-by-step procedure and result-related portions. To cut costs and keep focus on the experiment, the non-critical steps (such as pipette tip discarding, gloves removal, washing the glass wares etc.) were not animated. User-interaction and mathematical modeling were added to provide "real-world" feel.

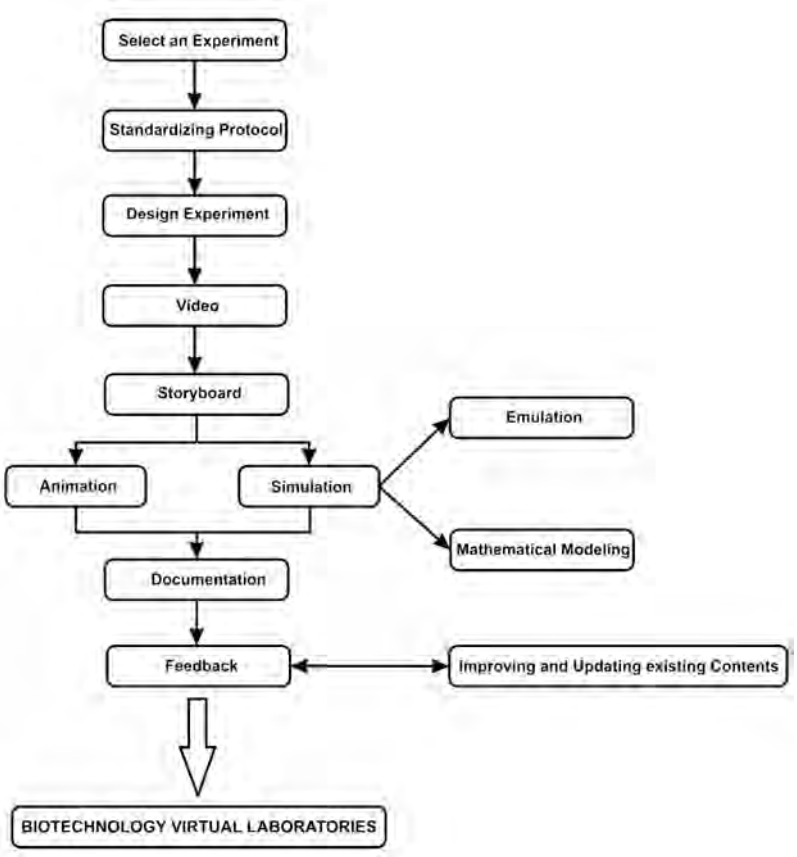


Figure 2. Virtualization steps in developing Biotechnology virtual laboratories

In addition to this, remote-triggered experiments are designed in such a way that the user groups controls the experiment with the help of an interface window which can be viewed through browsers. As the user operates the controls, the request will be send to the server in remote place, where the overall set up of the experiment is connected. This request is then passed on to the hardware, and the response is acquired using DAQ device (Data Acquisition). This will send an output to the server, which is then transferred to the clients.

C. Accessing the role of virtual labs - Methods

The effect of virtual laboratories in three different scenarios (see Figure 3) was analyzed using the following criteria:

I. User behavior and Biotechnology virtual laboratories

User behavior in terms of preference and usage were studied based on online feedback collected. The data observed were then tabulated and the impact of virtual laboratories towards increasing user's attention to a particular concept was analyzed. The feedback collected on each core subjects also were studied for assessing the number of users, their suggestions for improving the quality of the virtual laboratory experiments.

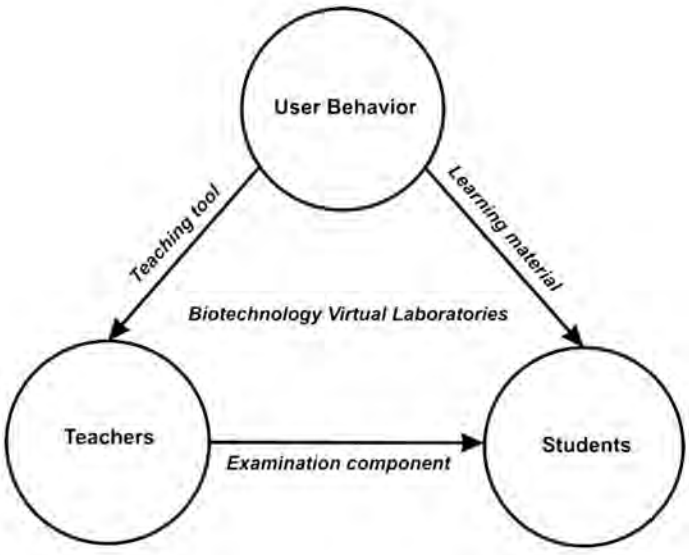


Figure 3. Impact of virtual laboratories in education

II. Virtual laboratories as an effective teaching tool

In order to study the role of virtual laboratories as a teaching tool, a general survey was conducted among the teachers of different universities. The main objective of the survey was to analyze whether the virtual laboratories assist teachers in conducting examinations, thereby reducing their overwhelming work pressure and time.
The teachers answered a set of Likert-scale questions including the following:

1. Virtual labs provides basic information in a variety of ways (Text, graphics, animation, video, simulation etc.).
2. I find virtual labs to be more useful compared to traditional methods used in instructional process.
3. I can include virtual labs in my teaching; so that it will reduce my time spend in preparing the materials for students.
4. I will encourage my students to use virtual labs so that they can improve their understanding and thereby reduce my effort in teaching.
5. The technical support from virtual labs is satisfactory in improving education.
6. Virtual labs helps to understand common mistakes one will make while performing an experiment in a real lab.
7. I like the way of teaching and assessing student's knowledge using virtual labs.
8. I can find time to include virtual labs in my classroom teaching.
9. I will encourage my colleagues to use virtual labs to support their teaching.
10. Did you get the quality of a "real lab" in virtual lab experiments?

The individual points given for each question by the teachers were calculated and the impacts of virtual laboratories in the teaching process were analyzed.

III. Virtual laboratories as a curriculum material

Different surveys were collected during virtual lab workshops that were conducted among the teachers and students of various universities to analyze the impact of virtual laboratories for

implementing it as a curriculum material. The workshops given to teachers focused on providing the general information on virtual laboratories followed by a hands-on session where they can clarify their issues regarding the usability and adaptability of Virtual laboratories. The further survey questions provided to them includes their opinion to implement Virtual laboratories core subjects in their curriculum material for improving the students' knowledge level.

Results

Virtual laboratories in educational system

I. Trends in usage of Biotechnology virtual laboratories

Statistical studies related to the usage of virtual laboratories indicated that the number of users is increasing day by day. The data shows that, nearly 45.084 users visited the biotechnology virtual laboratories at a time period of February to March, 2012, with an increase of 78% new users (Figure 4).

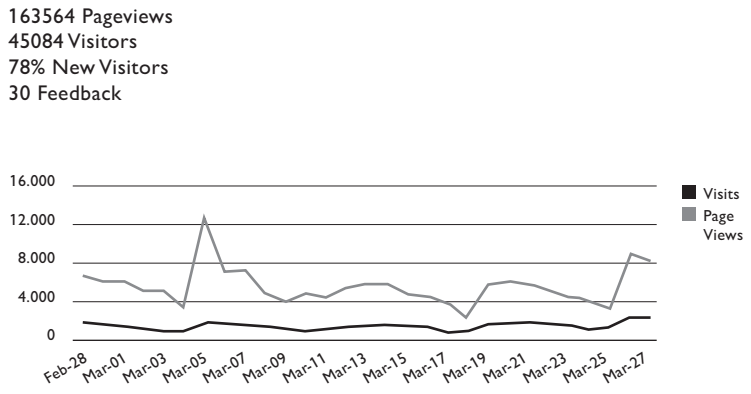


Figure 4. Trends in usage of Biotechnology virtual laboratories. Official release of virtual labs was on Feb, 21, 2012. User statistics in terms of page views and number of visitors were essential for estimating the nature of surveys.

The feedback data collected from various users were used to rate the online performance of the experiments of all the disciplines of Biotechnology virtual laboratories. Among the different users (see Figure 5), 19.87% of them support Biotechnology virtual laboratories as an excellent online tool for their learning purpose, 35% rated as very good, 29.12% of the users consider virtual laboratories as good, while 14.35% of them rated virtual laboratories as an average

tool for understanding the concepts. 1.66% users rated virtual laboratories as a poor online tool.

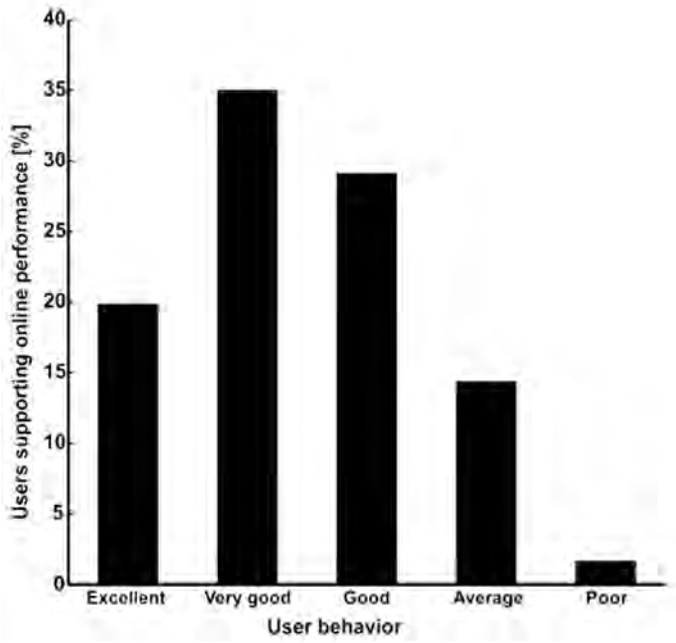


Figure 5. Virtual laboratories as an online performance tool. Percentage of users supporting virtual laboratories as an online performance tool is shown on Y-axis and Likert scale of user behavior on X-axis

II. Influence of Biotechnology Virtual laboratories in teaching process
A user survey amongst participating teachers on their opinions on virtual laboratories was collected (see Table 2).

Percentage of marks	No. of teachers	Percentage of teachers	Likert scale
>90	10	33.33	Excellent
80-89	14	46.66	Very good
70-79	4	13.33	Good
60-69	1	3.33	Satisfactory
<60	1	3.33	Below average

Table 2. Percentage wise analysis of teacher-survey

The analysis of the data from the survey among teachers indicated that 46.66% of them were interested to include virtual labs in their instructional process. However 3.33% of the University teachers

feel that it is difficult to implement virtual laboratories as a classroom material (Figure 6). However participating teachers suggested that they could use virtual laboratories as an examination component, thereby assess the performance of students in a better way.

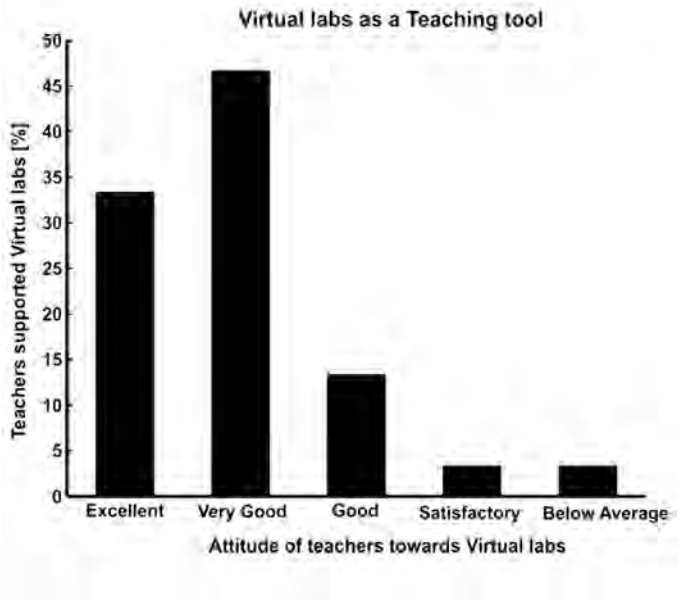


Figure 6. Percentage of university teachers supporting virtual labs as a teaching tool is analyzed by plotting percentage of teachers is on Y axis and attitude of teachers on X axis.

III. Biotechnology virtual laboratories in Curriculum of different Universities

From the workshop conducted among university teachers, 90% of them felt that most of the experiments included in their curriculum were virtualized in the Biotechnology virtual laboratories. Similarly, 75% of the students who attended the survey and hands-on session strongly agreed that they can use virtual laboratories in their learning process even without the help of an instructor. Data indicated that 60% students were able to completely understand the concepts of the experiment by viewing animation alone, whereas, those referred only the documentation part of the experiment (without going through other portions of the lab), found it difficult to gain collective information of the related topic. In our survey, student users agreed that they could use the video component as a supplement to the animation for their active learning process.

Discussion

In this study, the effective role of virtual laboratories as a teaching and curriculum tool in helping both students and teachers was analyzed along with trends in virtual laboratories. The data analyzed from the overall studies indicated that the virtual lab was useful as a teaching and curriculum tool. Virtual labs enhanced professional development of students by providing instruction (Huang, 2003) with new web technologies. As teaching material, Biotechnology virtual laboratories were effective as they allow the repeatability of a laboratory experiment by allowing the students to access it repeatedly without any time and distance limitations. Content-rich virtual lab with theory and procedure, animated demonstrations, interactive simulations, videos, self-evaluation augment the classroom lectures. Preliminary case studies suggest that virtual laboratories can be critical for student's learning process. Survey data also support that teachers show interest to include virtual labs as a teaching tool with their classroom lectures as they reduce their workload to a significant extent (Diwakar et al., 2011). Most teachers have indicated that virtual laboratories can be used effectively to provide lab demonstrations to an overcrowded classroom (Diwakar et al., 2010). Study also promoted the use of Biotechnology virtual laboratories as an examination component to assess student's performance in a better way with materials like self evaluation and students assignments.

Incorporation of virtual labs in curriculum may hold a higher impact on education due to its complementary contents. The Biotechnology virtual labs were mainly developed as an assisting tool for laboratory education in order to help under and postgraduates in University-level science courses. The study also showed that the students, who used virtual labs as an addition to traditional laboratory study, understood concepts of experiments and were enthusiastic in clearing their doubts in comparison to those who went through the typical classroom approach alone. The surveys also supported the use of videos provided with Biotechnology virtual laboratories as a supplement to the animation. Content-rich virtual lab served as motivational medium towards problem-solving skills amongst students and generated interest towards the subject (data not shown).

Statistical studies on feedback results related to the usage of

virtual laboratories indicate that the number of virtual lab users is increasing constantly. The user- friendly virtual lab allows the users to study the experiments which are normally difficult to conduct in real labs.

Conclusion

Web-mediated technologies are becoming common in the field of education as they make a new dimension in visual learning. Results obtained from this study imply that Biotechnology virtual laboratories may play a pivotal role in educational system as an effective curriculum and teaching tool. By using virtual labs, teachers may spend lesser time and much lesser effort in their classroom lectures. In some surveys, we found virtual labs as a better supplement to reduce teaching workload. As most of the educational institutions face difficulties in conducting traditional laboratories especially in science subjects, Biotechnology virtual labs provides a better real lab scenario with virtually explained concepts. The present study implicates the significance of biotechnology virtual labs in making users proactive in their studies by providing any-time support. It was noted that most of the teachers showed interest towards incorporation of a hybrid approach of using virtual labs along with laboratory education in undergraduate and postgraduate curriculum suggesting the use of virtual labs as a visual learning tool. We find the role of virtual laboratories as an effective teaching tool and as a curriculum gizmo. However, more elaborate use cases and feedback-oriented surveys on geographically remote and financially-challenged scenarios may be needed to understand the adaptability and usability of such online labs.

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Sintesi

Il Governo indiano, nel quadro della "National Mission on Education through Information and Communication Technologies" (NME-ICT), sta promuovendo la realizzazione di alcuni progetti a diffusione nazionale per potenziare l'applicazione delle ICT in campo educativo. L'università indiana Amrita, in partnership con l'Indian Institute of Technology (IIT) con diverse sedi distribuite in nove regioni indiane (Dehli, Kanpur, Bombay, Madras, Kharagpur, Guwahati, Roorkee, Hyderabad e Dayalbagh), ha partecipato alla ricerca con uno studio sul ruolo dei virtual laboratory nella Biotecnologia.

Il subcontinente indiano, con i suoi milioni di studenti universitari, non è attualmente in grado di sostenere i costi necessari per provvedere a realizzare un numero adeguato di laboratori tecnologicamente avanzati ed equipaggiati per la ricerca biotecnologica. Per risolvere questo problema, ad un tempo educativo ed economico, il governo ha promosso l'applicazione dei virtual lab, iniziativa in cui si sono impegnati il professor Bipin Nair, coordinatore nazionale per le Biotecnologie e l'ingegneria biomedica, e il prof. Achutan coordinatore del progetto VALUE condotto all'Amrita University. I laboratori che sono stati implementati nell'ambito del progetto sono disponibili online sul sito dell'Amrita (http://amrita.edu/virtuallabs/) e sul sito nazionale dell'iniziativa (http://vlab.co.in).

I primi risultati della sperimentazione sono stati pubblicati in occasione della conferenza IEEE Global Humanitarian Challenge 2011 che si è tenuta a Seattle il 30 ottobre scorso e alcuni contributi sono apparsi su riviste internazionali. In questa prima fase del lavoro, un risultato fondamentale è stato la realizzazione della piattaforma CAP-VL (Collaboration and Accessibility Platform for Virtual Labs) che ospita i laboratori. Nella fase attuale di implementazione e sperimentazione progettuale, il team di ricercatori coinvolti nel progetto sono giunti alla sedimentazione dei seguenti risultati:

1. *I laboratori virtuali hanno confermato l'efficacia come complementi per la ricerca laboratoriale.*
2. *Gli studenti hanno appreso i parametri da applicare in un laboratorio reale attraverso la sperimentazione e l'esercitazione in laboratori virtuali.*
3. *I risultati e le attività che si svolgono nei virtual lab sono applicabili anche come contenuti di lezioni frontali in classe.*
4. *I virtual lab permettono di integrare nel percorso universitario e formativo studenti svantaggiati per ragioni economiche o perché residenti in zone geograficamente isolate.*
5. *L'attuale obiettivo, per continuare ed ampliare la sperimentazione, consiste nell'aumentare il numero di enti, studenti e docenti coinvolti, al fine di migliorare,*

rivedere ed ampliare tanto i contenuti veicolati nei laboratori virtuali, quanto l'approccio didattico.

6. *Gli strumenti didattici introdotti nel laboratorio devono essere sempre testati attraverso l'uso e la successiva valutazione.*