

Role of ICT-enabled Virtual Laboratories in Biotechnology Education: Case studies on blended and remote learning

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Abstract— Virtual labs are popularized as a visual education tool that offers diverse analysis of experiments through different components like graphics mediated animations, mathematically modeled simulations, user-interactive emulations, remote-triggered experiments and the use of augmented perception haptic devices. With the advances in ICT-based education, virtual labs have become a novel platform that helps users to engage in their proactive learning process. Our goal was to analyze the effective role of biotechnology virtual labs in improving academic performance of students and complementing classroom education. We tested the adaptability, perceived usefulness and ease of use of biotechnology virtual labs on different user groups in sciences and engineering. This study focuses mainly on the student and teacher groups from different universities across India. Feedback data was collected via a direct approach using organized workshops conducted in the year 2014 - 2015. 85% of participants suggested perceived usefulness of biotechnology virtual labs helped them to improve their academic performance compared to a traditional classroom scenario. Most users indicated the learning materials provided by virtual lab system were easy to understand, thus suggesting the better adaptability of ICT-enabled techniques amongst different users. This augments the role of virtual labs for remote learners all over the world. For India, such learning methods have helped overcome limitations seen in classroom-based education such as equipment accessibility, location and other economic issues. Through these studies, we construe the usage of virtual labs as a next-gen interactive textbook and as a media-rich learning source of distance and blended education.

Keywords—virtual labs; biotechnology education; TAM; OER; blended learning; remote learning.

I. INTRODUCTION

Information and Communication Technologies have brought opportunities and challenges for university students and teachers in developing countries [1], [2]. Many educational institutes have been introducing blended learning approaches in their curriculum, combining both face-to-face and online instructional methods [3]. Recent research indicated advantages of blended learning for students including increased flexibility, student engagement and motivation [4]. Also, online education has an important role in training students to generate new knowledge and motivate them to deliver novel ideas, which was thought to be elementary for education in 21st century [5]. Educational practices such as those not only involved in delivering content through web, but included learner participation in accessing learning materials via internet, interaction with instructors and other learners [6]. Virtual laboratories are online education tools that bring a new dimension in learning science using visualization techniques such as animation, interactive platforms like simulations, remotely controlled equipment and recorded video components [7] (see Fig. 1).

Virtual and online labs are deployed via animations, simulations and remotely triggered online experiments.

Animations are visualization techniques mainly used to attract user's attention, engage learner, and sustain motivation [8]. Studies also reported that using virtual techniques, students were able to develop skill competencies in visual communication, observation, concentration and cognition [9]. Previous studies have shown that use of visualization technologies in education have shown progressive effects in students understanding of scientific concepts [10], [11]. Animations delivered a high degree of reality to virtual labs through their similarity to appearance and feel of a real lab [12]. This allows teachers to use animation as an instructional material and allow ease of teaching experiments by limiting preparation time and expense [13]. Disciplines like biotechnology and biology rely intensively on visual details and detailed step-by-step protocols, which necessitate that virtual labs in biotechnology are animation and media rich [14].

Simulations include mathematical models and calculate effects of certain inputs and decide results accordingly [15]. It provides quantitative and hands-on experience to each experiment that supplements real laboratory practices and skills [16]. It have been noticed that simulation motivate and engage students in their learning by providing high interaction, active engagement and participation, immediate feedback, repeated practice challenge [17]. Simulation-based teaching involve different activities like providing interesting step-by-step procedures for each concepts, interactive assignments for students to incorporate different ideas and also to notice dangerous parts of experiments where they could go wrong in a lab [18], [19]. On the other hand, simulation-based learning enhance students creative thinking and self-organization abilities [20].

Remotely-triggered (RT) laboratories connect users through public and private networks [21], providing a distant learning platform for laboratory experiments via hands-on sessions that helps learners to operate equipment over the internet [22]. RT laboratories implemented in various institutes allow sharing light to complex and expensive instruments between institutes across the world. Such labs are accessible anytime via the internet and port lab activity to distant learning environments [23].

A. Blended Learning in Education

Blended learning refers to a combination of virtual and physical environments, i.e. mixing of different learning environments. Student's face-to-face interaction in traditional classroom with internet and computer-mediated technologies is a feature in blended learning. Garrison and Vaughan define blended learning as the thoughtful fusion of face-to-face and online learning experiences emphasizing the need for reflection on traditional approaches and for redesigning learning and teaching in this new terrain [24]. Previous studies have shown that teachers support blended learning method since it improved teaching and class management practices [25].

Virtual labs have been presented as effective blended learning tools implemented across several institutions in India [14]. Role of such virtual labs in learning process, when used as a pre-lab material, was modeled towards

effective time management and as a self -assessment tool. Previous studies on calculation of economic gain factor for online labs have been shown that the average cost per student to access internet is 25 times cheaper than cost of lab equipment used [26]. This hints that virtual labs provide advantage in number of students who can access these labs and the costs.

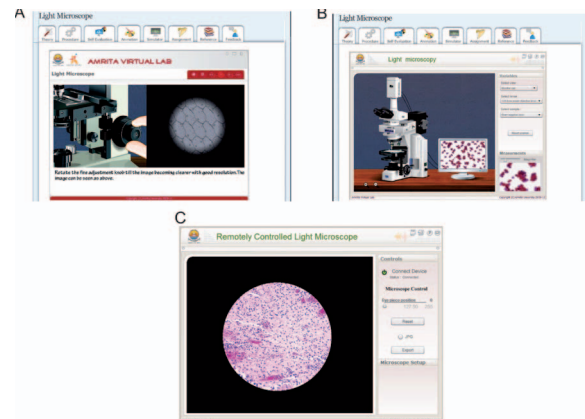


Fig. 1. Different modes in Virtual lab experiments. A. Animation based light microscope experiment B. Simulation based light microscope experiment C. Remote Triggered light microscope (See <http://vlab.amrita.edu/>)

In this paper, our goal was to analyze the effective roles of virtual labs in improving academic performance of biotechnology students and in complementing classroom education. We tested adaptability, perceived usefulness and ease of use of Biotechnology virtual labs by different users, from science and engineering background. Though virtual labs are content rich, in order to make it beneficial, usage needs to be adapted in different ways.

In our case, virtual labs were developed as an interactive self-learning material using visualization techniques namely, animation, simulations, emulations and via remotely triggered experiments. Users could effectively use the techniques to gain their individual preferences and needs. To analyze the adaptability to virtual labs, some user characteristics like transformation, augmentation and substitution need to be identified when they are changing from traditional way of learning to a newly introduced system [27]. Transformation is defined as the change in users when the user migrates from a text-based learning to a visual-based interactive learning. Augmentation is known to happen when students adapt using virtual labs along with their traditional learning, for example using VL as a pre-lab material to improve their skills and performance in a real lab [25]. Substitution may occur when a user prefers virtual labs as a supplementary tool in their education, for example, they can access and perform an experiment even beyond the class hours. Perceived usefulness (PU) is the degree to which the users believe that usage of virtual labs in their curriculum would enhance their learning process [28], [29]. Perceived usefulness was measured from user performance, speed, efficiency and productivity while doing an experiment [30]. Ease of use (EU) of an online lab was to measure the degree

to which the user believes that using virtual labs makes them free of physical and cognitive effort while learning. Ease of use was significantly influenced by user's perceived usefulness of particular system [28], [29]. It was estimated from performance, positive attitude and greater intention of user towards the system.

Our focus was to estimate the time taken by study participants to understand an experimental concept using biotechnology virtual labs as an educational platform, without the help of a lab instructor and compare the same within a classroom experience. The study also focused on advantages of including virtual labs in curriculum of Indian universities for providing a better education beyond the limits of a traditional classroom scenario. We also focused on usage of virtual labs as a new pedagogy for distance education courses to enable students to access equipment and laboratory resources free of cost, thus experiencing a real lab environment additionally post-scheduled lab hours.

II. METHODS

As a part of our study, we conducted several workshops in different Universities all over India in the year 2014 – 2015. Though virtual labs include an online feedback facility, this study was based on a direct written feedback collected from the workshop participants. A total of 400 students and 100 teachers participated in various workshops. During the workshops, apart from introducing biotechnology virtual labs, *in silico* experimentation (computer-based hands-on session) was also carried out in order to give an experience of an online laboratory practice. After providing basic instructions on how to use virtual lab tools, time was allocated to participants to complete virtual lab experiments. Time taken by study participants to understand an experimental concept without the help of a lab instructor was noted. To analyze adaptability, perceived usefulness and ease of use of virtual labs, we collected questionnaire-based feedbacks based on the Technology Acceptance Model (TAM) and IEEE Open Education Resources (OER) surveys.

A. Analysis of User Adaptability to Virtual Labs

Adaptability to blended learning system in classroom education was evaluated from feedback analysis among students, teachers based on content quality, use of computer based tools, and user interaction with virtual labs. Following statements and user's responses (yes/no) were used for assessment.

- Virtual lab techniques are easy to use for my studies.
- Virtual lab techniques helped me in better understanding of basic concepts necessary for performing a real experiment.
- Virtual lab techniques like animation and simulation enhanced and motivated my attention towards learning.
- I could 'feel' a real lab environment while performing virtual lab experiment.

B. Analyzing Perceived Usefulness among users

We analyzed the perceived usefulness of virtual labs among participants to know whether they believe that they can enhance their learning process by including virtual lab in curriculum. To assess PU, we selected a classroom of 50 students among all workshop participants and asked them to perform the blood grouping experiment (<http://goo.gl/X7LMEe>) in virtual labs. A questionnaire-based feedback was collected after they completed experiment. The feedback included the following questions:

- Did you get the "feel" of a real lab while performing the experiments virtually?
- Did you get a good understanding of the experiment after completing the experiment?
- After practicing the virtual lab experiment, do you "feel" you can perform the same experiment in a real lab without the help of an instructor?

Students were then asked to perform the same experiment in a real lab. We observed the performance of each student in the lab while doing the experiment. After completion, another questionnaire was given to students that included the following questions:

- Using virtual lab in my studies improves my learning quality
- Virtual lab is an effective tool to learn how to use costly equipment and reagents that are commonly used in a real laboratory.
- If I use virtual lab as a pre-lab material, it improves my performance in real laboratory session
- Virtual lab helps to learn step-by-step procedure of an experiment without the help of an instructor.
- Virtual lab helps to make experimental calculations easier and to analyze and interpret results without the help of an instructor

C. Analyzing the ease of use of Virtual Labs

The role of cognitive effort on learning process of user was analyzed using feedback based on the following questionnaire.

- Do you agree that virtual labs are easy learning tools?
- With virtual labs, could you learn an experiment without the help of an instructor?
- Does remote lab give you a "feel" of handling real equipment?
- Were you able to repeat all steps in the real lab after training with virtual labs?

D. Analyzing acceptance of Virtual labs amongst teachers

We analyzed teacher's role in introducing blended learning in classroom teaching and their usage of virtual labs as a teaching material. A survey was conducted among 100 University professors who participated in workshops conducted at various South Indian universities. A questionnaire-based feedback was collected from teachers. Some of the questions asked to teachers are listed:

- Would you support blended learning in classroom education?
- Would you suggest virtual Lab as a reference material for laboratory education?
- Do you agree that remote lab helps teaching students on how to operate lab equipment properly before entering to real lab?
- When comparing with traditional classroom teaching, do you feel that blended learning approach would help reduce your effort in teaching?

To assess how many teachers were willing to include virtual labs in their syllabus, we asked them an additional question to know if they were interested to coordinate a nodal center at their school/campus. A nodal center [31] is an institute directly advised by the project and used virtual labs as a part of their regular curriculum. By becoming a nodal center, the teachers and students also gained additional teaching and learning material and lab support. Feedback data was then evaluated and correlated for various assessments.

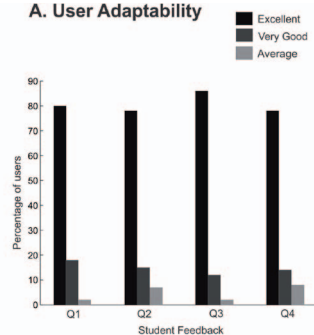
III. RESULTS

From individual responses collected as feedback, both positive and negative responses were used to evaluate the role of blended learning in augmenting biotechnology education (see Fig. 2).

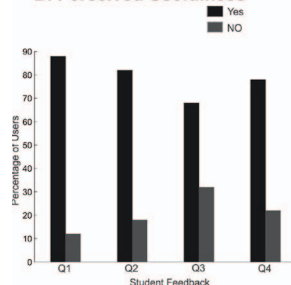
A. Significant percentage of students adapted to blended learning environment

Student's feedback on four different questions was analyzed in order to study their adaptability to virtual labs. In the first question, students were asked to rate the easiness of use of virtual lab techniques in their studies. Among 400 students, 320 of them rated it as 'excellent' tool that made their education more interesting and easier, while 72 rated it as 'very good' and 8 of them rated it as an 'average' tool and attributed the difficulty in handling computer-based environments due to lack of computer training or access. The second question was to rate virtual lab for better understanding of 'basic' concepts needed for performing a real experiment. 312 students rated it as 'excellent' complementary online tool for effective understanding of concepts, while 60 of them opted 'very good' and 28 students rated as 'average' tool. Third question was to rate animation and simulation technique that enhance and motivate them towards learning. For this, 344 students supported as 'excellent' tool that motivated them to use ICT-enabled tools in their education while 48 selected 'very good' and 8 students opted as 'average' tool. Last question was to rate virtual lab techniques as a real lab environment while performing virtual lab experiment. 312 students suggest it as 'excellent' tool for giving a real lab environment feeling while 56 of them suggested as 'very good' and 32 as an 'average' tool for this (see Fig. 2A). Overall feedback results indicated more than 80% of the student users adapted to blended learning environment.

A. User Adaptability



B. Perceived Usefulness



C. Ease of Use

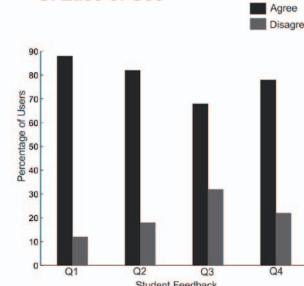


Fig. 2. Feedback analysis of user adaptability, perceived usefulness and ease of use on virtual labs

B. Virtual labs improved student learning and increased perceived usefulness

Perceived usefulness of virtual labs was evaluated from feedback collected from a classroom of 50 students (see Fig. 2B). 78% of students indicated virtual lab improves their learning quality and helps to understand experiments in a better way. 84% of students mentioned that virtual lab was an effective tool to learn the usage of costly equipment and reagents that are commonly used in real laboratories. 80% of them indicated it as a pre-lab material that helps to improve performance in a real laboratory session. 92% of student users reported that they could learn step-by-step procedure of an experiment without the help of an instructor. 78% responses indicated that virtual labs helped to make experimental calculations easier and to analyze and interpret results without the help of an instructor. The response suggested the perception of virtual labs as "interactive textbooks", thanks to the role of content and assessment possibilities within the VL platform [32].

C. Virtual lab techniques are understandable and easy to use

Feedback collected from students after practicing the virtual labs indicated that virtual lab techniques were easy to use and concepts were 'learnt' by the users through the process. 88% students mentioned virtual lab tools as an easy learning tool. 82% of students reported that they were able to learn an experiment without the help of an instructor. 78% of students indicated that after experiencing virtual experiment, all steps were easy to repeat in real lab. 68% responses showed that remote lab gave them a "feel" of handling real equipment while 32% of them were not able to handle these

online experiments properly due to some network issues (see Fig. 2C).

D. Implementing virtual labs in teaching process

Usage of biotechnology virtual labs as a teaching material was analyzed by a feedback-based survey conducted among 100 teachers from different Indian universities who participated in VL workshops. Feedback indicated that 23% of teachers used virtual labs in a blended learning model in classroom education to aid their teaching responsibilities. 24% of teachers indicated virtual lab served as a reference material for laboratory education. 18% of responses implicated that remote lab helps them in preparing students for operating an equipment correctly before entering a real laboratory. 23% of teachers used blended learning approach in their teaching due to reduced teaching effort (see Fig. 3). We estimated 95% of teachers who participated in the workshop implemented virtual lab-based blended learning for their students and expressed their willingness to establish a nodal center in their institute.

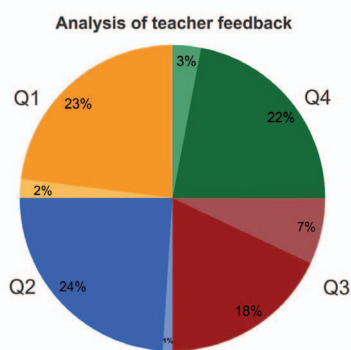


Fig. 3. Analysis of teacher feedback on biotechnology virtual labs

IV. DISCUSSION

In this survey-based study, we analyzed the role of virtual labs as a blended learning tool in supporting both biotechnology teachers and students. With a significant response relating the ability to learn experimental process without a tutor, virtual labs may be an autonomous learning tool for distance and mobile education. We tested perceived usefulness, adaptability and ease of use of virtual labs amongst students via a questionnaire-based feedback. Feedback from student users indicated that they were able to use the virtual labs as autonomous learning tools and were motivated to study laboratory techniques effectively. Most students reported that they could adapt to using and including biotechnology virtual labs within their curriculum. Additionally, an increase in perceived usefulness and ease of use of virtual labs was noted among student groups. With remotely triggered labs, students indicated higher perceived usefulness as they provided a direct access to the real equipment augmenting their practical skills. Most student users finished more than one experiment using virtual labs within one hour, which was not possible in real lab. The

study also explored how teachers supported virtual labs in blended learning mode. A university teacher commented, "the approach is an innovative teaching method and instead of teaching in a traditional way-using blackboard and lecture notes, virtual labs are very interesting with animations, simulations and remote equipment". More than eighty percent of teachers who attended workshops promoted the use of virtual labs to evaluate student's performance with self-evaluation questions and assignments provided in virtual lab. Teachers from rural areas in India mentioned that many students in their institution are unable to do all experiments properly due to lack of equipment or other facilities. Therefore, they found virtual lab as a useful material for them to overcome these problems. 95% of teachers participated in the workshop showed their interest to initiate nodal center in their institute to support blended learning and remote learning in university education. The teachers from nodal centers commented that apart from advantages like providing online quality labs, training for teachers and students, upgradation of new labs and existing content, virtual labs have known cost benefits also. Many educational institutes in India are not be able to afford the cost of some of the equipment, such as Patch Clamp equipment and some teachers probably do not know the experimental designs to run a real lab. In such cases, the free online virtual labs are known to be better teaching and practicing aid tools in gaining the knowledge of lab set-up and experimental procedures. Also, these labs are student-centric, since it is easily accessible to them outside regular lab hours. Students also reported that they could create different conditions by changing the variables in simulation-based experiments in disciplines such as population ecology, neurophysiology and biochemistry, thus provided them extra freedom to explore the labs and helped to understand underlying principles. Thus, simulations aid in their learning, without wasting time or costly reagents in the real lab. In case of microbiology, cell biology and molecular biology experiments, users could learn experimental scenario using virtual lab techniques, without ruining expensive bacterial cultures. Virtual lab usage that is currently at greater than 100000 registered users on the CAPVL platform [32] for all virtual labs, indicates a constant increase in the number of users from all over the world. However, in this study to avoid assessment errors, we only used direct feedback data but online feedback have detailed similar results on usage and are being reported in another study (manuscript in preparation).

With the student's use of such resources, student users, with and without instructor presence, are perceiving these labs as learning tools and interactive textbooks. The potential role of such tools may also need further analysis using evaluation methods and surveys on individual and clustered classroom groups.

V. CONCLUSION

This ongoing study indicates both students and teachers were ready to use virtual labs as a supplementary educational tool and support blended/distance learning for biotechnology education, although replacing real labs in biological sciences will not be possible within the context of being "low-cost". Virtual labs may be very effective for complementing

education methods and teaching material for teachers and students who have limited access to laboratory facilities in their institutes. Further behavioral studies on user groups will be needed to distinguish cognitive learning modes on distance learners and to identify the impact of tutors in biotechnology laboratory education.

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