EAI Endorsed Transactions
on e-Learning

Research Article **ICST.ORG**

Using Virtual Laboratories as Interactive Textbooks: Studies on Blended Learning in Biotechnology Classrooms

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Abstract

Virtual laboratories, an ICT-based initiative, is a new venture that is becoming more prevalent in universities for improving classroom education. With geographically remote and economically constrained institutes in India as the focus, we developed web-based virtual labs for virtualizing the wet-lab techniques and experiments with the aid of graphics favoured animations, mathematical simulators and remote triggered experimentations. In this paper, we analysed perceived usefulness of Biotechnology virtual labs amongst student groups and its role in improving the student's performance when introduced as a learning tool in a blended classroom scenario. A pedagogical survey, via workshops and online feedback, was carried out among 600 university-level students and 100 remote users of various Indian universities. Comparing learning groups on usage of blended learning approach against a control group (traditional classroom methods) and an experimental group (teacher-mediated virtual labs), our studies indicate augmented academic performance among students in blended environments. Findings also indicated usage of remotely-triggered labs aided enhancing interaction-based lab education enabling anytime-anywhere student participation scenarios.

Keywords: Virtual labs, remote labs, Feedback, student's performance, blended learning

Received on 29 March 2015, accepted on 08 May 2015, published on 14 July 2015

doi: 10.4108/el.2.6.e4

1. Introduction

The current challenging era of technological innovations provided a new pedagogical and economic platform that creates a synergy between teaching and learning in educational system [1]. The style of learning in universities has experienced a paradigm shift from the conventional method of knowledge transfer, where the teachers normally use blackboard - chalk and textbook based teaching process [2]. Education system look to computer instructed modes to promote an active blended learning process, allowing Information and Communication Technology (ICT)-enabled techniques to be integrated into traditional classroom learning [3], [4]. Developing e-learning platforms for visualizing complex biological concepts has thought to be a promising aspect for effective perception of biological processes [5]. Such technologies have become a tool to overcome geographical barriers and thus assisted everybody to learn anytime-anywhere in the absence of an instructor [6], [7]. It had been shown that the performance of students in higher educational institutions who used e-learning tools to aid their education process additionally was better compared to those with face-to-face traditional classroom scenario [8]. Previous studies revealed that E-learning played an important role in diverse regions such as India where the traditional lab facilities at Universities were not very well localized to suit requirements of all sub-regions[6], [9].

ICT-enabled virtual labs, an innovation in technology has proven to be a powerful tool that offers innovations in

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learning through shared interactions to promote learning process [10]. The usage of virtual laboratories in education system has been reported for over 20 years, but its prominent application has grown in the last 5 years to overcome the difficulties faced in a traditional classroom scenario [11], [12]. Several studies on virtual laboratories have been reported recently [13-17]. Governments and educational organizations are now taking up initiatives in setting up virtual laboratories as E-learning repository to augment current learning infrastructure [18]. To students, virtual labs are seen as a personalized learning environment via ICT-mediated visual graphics such as animations and user interactive simulations [19]. From a teacher perspective, the use of advanced computer technologies in a traditional classroom provides a prominent platform for modelling student participation where teachers can monitor the constructivist learning of the students in a better way [20]. It plays a pivotal role in bridging the lack of lab facilities, and devising individual experience at a low cost and thus increases the chances of self organized learning strategies [21]. This ultimately imparts analytical thinking skills amongst the learners [22].

Blended learning, that combines traditional classroom scenario with the usage of computer technologies, is becoming a new approach in the University education [23]. Integration of 'blended learning' approach in the curriculum has shown to extract the advantages from both traditional and e-learning environments. Teachers and researchers of various educational institutions [24] have show. Such learning processes have emerged as a novel trend and is illustrated as a new educational paradigm. It was reported as an alternative solution for overcoming the problems faced in a traditional classroom such as time constrains, distance, sharing of costly equipment, shortage of chemicals and reagents etc. [25]. Students using blended education in universities have been observed to be advantaged in problem-solving skills, time management, and sharing of information that improves the quality of their learning [26]. VL environments also provide an improved individualized learning that helps to meet the needs of both urban areas and economically and geographically challenged rural areas with high level of flexibility and reduced the concerns regarding cost for laboratory set-up [27].

Many universities and research centres included their own virtual laboratories in both science and engineering field to facilitate autonomous learning model [6], [13], [28]. Biotechnology, a growing field in life science is becoming more popular that has led to new advancements in many areas such as medical diagnostic tests, industrial scale testing and other agricultural related researches [29]. Through the virtual learning platform, biologists can tackle the challenges in universities through quantitative experiments and mathematical models [13]. Through the virtual learning platform, biologists can tackle the challenges in universities through quantitative experiments and mathematical models [13]. This cost effective virtual laboratories train the students with sophisticated and complicated instruments routinely employed in modern biological and chemical laboratories. With multi-campus scenarios as in some Universities offering cross-disciplinary courses needs to exploit the use of extensive e-learning facilities [30-31].

Typical methods to predict user acceptance and behaviour in information technology and e-learning are TAM and OER based questions [32]. Such questions include set of constructs to study student behavioural intentions, attitude and other cognitive constructs, namely perceived ease of use and perceived usefulness of the e-learning platform. OER based feedback survey also helped to assess the usage roles in applying virtual labs amongst different users [33].

In this paper, we focus on the role of virtual labs in blended learning and online platform where we access freely available content rich materials including animation, simulation and remote triggered experiments for student groups to analyze their learning behaviour. We also tested including a hybrid approach of using Virtual labs in the curriculum for enhancing the student's academic performance in a blended learning classroom environment.

Virtual and remote triggered laboratories in Biotechnology

Like most science courses, biotechnology courses also require continuous syllabi update and use of complex laboratory techniques, sophisticated instruments and well-standardized protocols [13], [34]. Most common courses that biotechnology programs focus at the University level in India consist of immunology, cell biology, molecular biology, microbiology, immunology, biochemistry, population ecology and biophysics. Significant advances in research have brought laboratory experiences as a key factor of active learning for biotechnology education [35]. However, previous studies [36] reported lots of limitations while performing real labs especially in developing countries. Real lab courses in a curriculum has limited time period of about 2 – 3 hours in a week, which is a major concern for students to get the correct ideas on the experiment [37-38]. Also inadequate power supply, lack of costly reagents and equipment, issues with use of experimental animals and other personnel safety related issues [27] were the most critical problems facing in Universities that were not very well localized. Recent pedagogical surveys have reported that adapting ICT enabled e- learning tools such as virtual labs in education could be a solution to overcome some of the difficulties faced by the traditional labs to a greater extent [13] [32]. The techniques included are in the form of animations, simulations, emulations, haptics, videos and remote triggered experiments [39-40]. Animations are graphics

mediated that helps to make the virtual laboratory with a close semblance to a traditional laboratory setup (Figure 1A and Figure 1B). This realistic representation with the technological advancement has found various applications in modern education system [40-42].

Figure 1A. Graphical illustration of Quadrant streaking

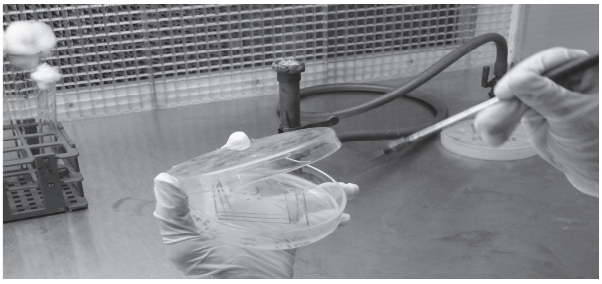

Figure 1B. Quadrant streaking in real lab scenario

Simulation based labs platform needs high degree of interactivity with users and computers. Such labs are thought to be a bio-realistic model that has a synergy between biology and mathematical equations (Figure 2A and Figure 2B).

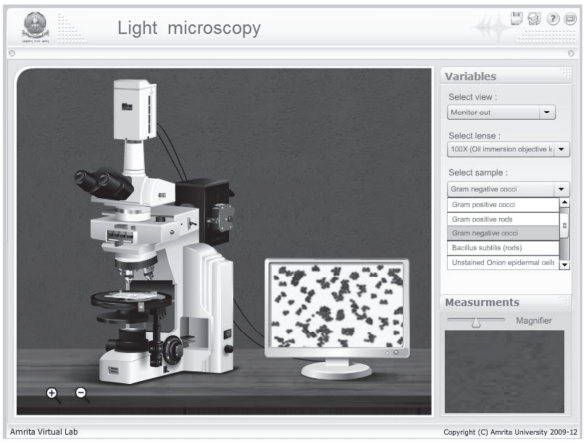

Figure 2A. Simulated light microscope

Figure 2B. Light microscope in a real lab scenario

The remote-triggered laboratories are a new venture to enhance laboratory education. These labs are a hybrid approach that provides real access to costly lab equipment and experiments through the internet. Remote-triggered experiments are designed in such a way that the users can control the remote lab set up with the aid of an interface window which can be viewed through browsers (Figure 3A and Figure 3B).

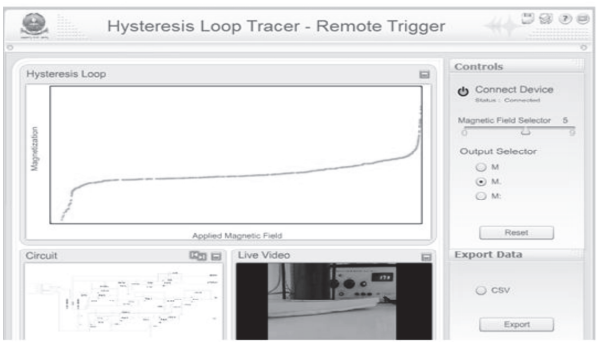

Figure 3A. Hysteresis loop remote live video

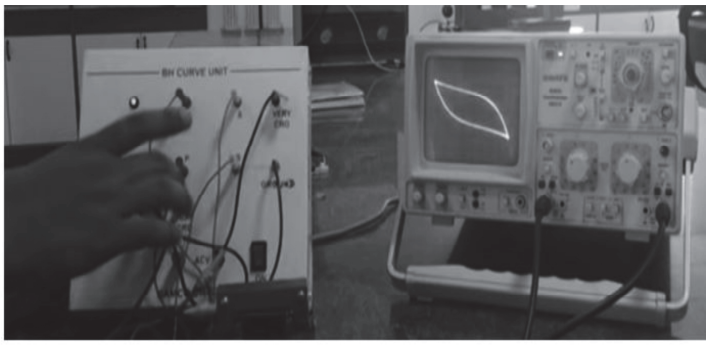

Figure 3B. Performing Hysteresis loop in a real lab

In order to reduce inconsistencies, a slot-booking system was implemented to reserve a particular remotely triggered experiment to a specific user for a time-slot.

2. Methodology

This work was conducted on a group of 600 undergraduate and post graduate students (500 students participated in virtual lab workshops conducted in the year 2014-2015 and 100 online student users) of different Indian universities with Biotechnology course.

2.1. Analysis on impact of virtualization in learning process

In this case study, the data to estimate impact of visualization was collected via a one-day seminar and workshop on "The use of ICT in education", on February 27, 2015. The demonstration and hands on session were followed with a set of questionnaires to evaluate its significant impacts in learning process. Both qualitative and quantitative analysis of content quality, easiness of use of the material, extended use of technologies in education were carried amongst the student groups of a geographically diverse and financially challenged institute in India. The feedback survey included the following statements (Table 1). The participants showed their responses by marking Yes/ No to the respective questions of analysis. The responses from the students were tabulated and recorded for further studies.

2. 2. Analyzing the impact of different learning approaches (Traditional learning, Virtual lab learning and Blended learning) – A case study based on Microbiology virtual labs

The study was performed via organized workshops to analyze impact of different approaches in enhancing student's performance in a classroom.

User Data

We employed pre-test (a test before performing VL) and post-test (a test after performing VL) analysis in this study to evaluate participating groups.

Student Groups

The participants were divided into three groups. Control Group (CG) comprising of 250 students who were subjected to traditional classroom-based learning, Experimental Group (EG) comprising of 250 students who accessed virtual lab platform for their learning process, without the help of an instructor. The third group is the Blended learning group, which comprises of 500 students (including CG and EG), who were subjected to both traditional learning and teacher-mediated virtual lab learning process.

Our preliminary study was to analyze whether the students (Control group) could learn theoretical and experimental concepts in a traditional method of teaching. The overall time period for the learning process was limited to 3 hours. As a part of this study, and as a first step, 30 minutes chalk-and-board lecture series of the experiment, "Carbohydrate Fermentation Test" in Microbiology Lab was provided to the group of students. 30 minutes were provided later to follow a standard laboratory textbook for learning the theoretical and practical background of the experiment. In the next step, they practiced real laboratory techniques where they learnt different fermentation pattern of carbohydrates using different classes of microorganisms such as *Staphylococci*, *E.coli*, *Proteus* etc., within the time limit (2 hours) provided. They were then subjected to a class test (Pre-test), where a set of questions regarding the fermentation media preparation and the fermentation pattern produced by different microorganisms were provided. The individual performance report was noted and tabulated for further analysis. During this study, the difficulties/problems reported by individual student were also recorded. Later the same groups of students (control group) were subjected to learn the same experiment using virtual labs as a learning platform, without the help of an instructor. After the virtual lab experience, a post-test was conducted with the same set of questions as in the pre-test. The performance level of students in each test was noted for further analysis.

In the next step, the experimental group comprising 250 students were allowed to learn the experimental concepts and procedures using Virtual lab learning platform, without the help of an instructor. The study participants were asked to perform the 'Carbohydrate Fermentation Test using the content rich virtual lab material (Figure 4).

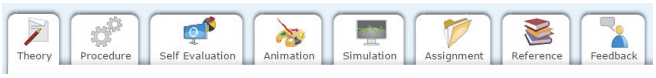

Figure 4. Content rich earning resources available in virtual laboratories

The time for completing the virtual lab exercises was 2 hours (Figure 5). An examination was conducted for participants with the same set of questions as given to the control group. The individual scores were tabulated for further analysis.

In the next step, both CG and EG group were subjected to a blended learning approach. In this scenario, the participants were first subjected to a traditional way of teaching followed by a teacher mediated virtual lab based learning method. An examination was conducted to evaluate the student's performance as in the control group and experimental group.

Table 1. Analysis of virtualization techniques in enhancing education

Analysis factor	Questions for analysis
Content quality	Q1. Do you think VL system help to integrate theory and experiment? Q2. A clear understanding of the experiment and related topics was gained? Q3. Virtual labs provide higher level of engagement in my studies. Q4. Were the results of the experiment easily interpreted?
Easiness of the material	Q1. Did you find all steps easy to repeat? Q2. Would virtual labs help you to do experiments without a teacher's help? Q3. Was the experiment/ process motivating enough? Q4. While doing the virtual labs, did you notice the dangerous parts of the experiments where you could go wrong in a lab?
Extended use of technologies in education	Q1. Was the clicking component (interaction) of the simulator self-indicative? Q2. Was the animation suggests the step by step procedure of the experiment? Q3. Did you make mistakes while doing the simulation? Q4. Did you get the feel of a real lab while performing the experiments virtually?

Figure 5. UG student using virtual labs as a learning platform

The performance level of students in each test was noted for further analysis (See Table 2 for examination questions for control group, experimental group and blended learning group).

2.3. Analyzing the role of Remote labs in supporting science education

As a part of the study, a solar panel experiment was used as a learning exercise to a group of 100 online student users from various regions in India. They were allowed to use the solar panel over the internet. Slot-booking system was enabled to reduce time –management issues related to remotely controlled systems. Questionnaire-based online feedback was collected to analyze the effectiveness of adding remote labs in curriculum and analyzing its significant impact in enhancing students learning process. The questions for analysis were shown in Table 3. The participants marked their choices and individual ratings were recorded.

3. Results

3.1. Visualization techniques using virtual labs improve student attention in a classroom

For analyzing the content quality of virtual labs, a feedback survey was conducted amongst the student participants (Table 1). Analysis of feedback survey showed that 90% of the students indicated that virtual labs (VL) learning platform helped them to integrate both theory and experiment in a better way. Also, 88% of them suggested that they gained a clear understanding of the experiment and related topics with the usage of VL

system in their learning process. Moreover, 85% of the participants supported that VL provided higher level of engagement in their studies making it as a complementary tool for making education more interesting and easier. Nearly 95% of them reported that they could easily interpret the results of the experiment with user-interaction and reduced their problems in laboratory education (Figure.6). But, 10-15% of the participants reported they were facing difficulties in using virtual labs, due to the lack of computer literacy (comments from the feedback).

Table 2. Examination questions for control group, experimental group and blended learning group

Sl No.	Questions for analyzing students performance in different learning process
1	The indicator used in the Phenol red carbohydrate fermentation test
2	The importance of indicator in the Phenol red carbohydrate fermentation broth
3	The ability of microorganism to ferment carbohydrate mainly depends on
4	End-products of fermentation
5	The reason for remaining the color of the phenol red broth unchanged after the incubation of the culture.
6	The color of the phenol red in its acidic form
7	Acid and gas production during fermentation
8	Phenol red carbohydrate fermentation broth is
10	The result of application of high temperature for sugar sterilization

Table 3. Analyzing role of remote labs in education platform

Sl.No	Questions for analysis
1	How well could you control the remote equipment?
2	How would you compare a remote experiment to a real lab experiment?
3	How do you rate the experiment?
4	Did you feel the absence of an instructor?
5	Would you like to include remote labs in your regular traditional classroom scenario?

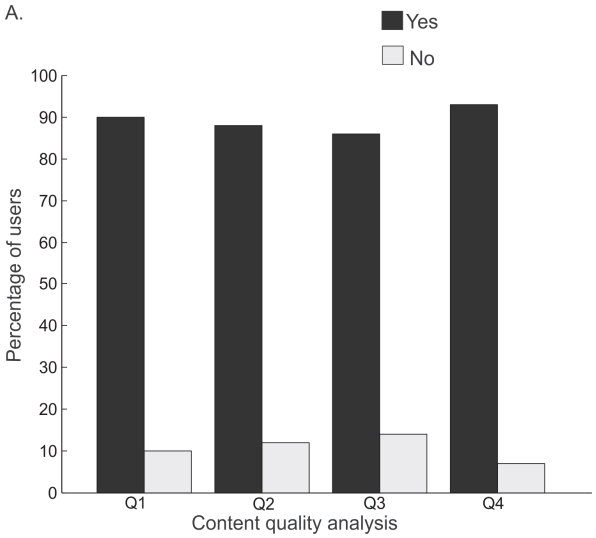

Figure 6. Analysis of content quality of virtual labs (See Table 1 for the analysis questions)

Feedback data was also collected from the participants for analyzing the easiness of use of the learning material provided by the virtual lab education platform (See Table 1 for analysis questions). Among the student participants, 95% of them suggested that they could easily repeat all the steps in the animation and simulation techniques. 90% of them indicated they were able to follow the virtual lab experiments even without the help of a teacher or lab instructor. Nearly 87% of the students indicated that the virtualization of the experimental procedure was motivating enough to engage them in their laboratory education. Also 90% indicated that they noticed/made mistakes while performing the virtual experiment and hence suggested that it could reduce the typical mistakes that could go wrong in a real lab scenario (Figure 7).

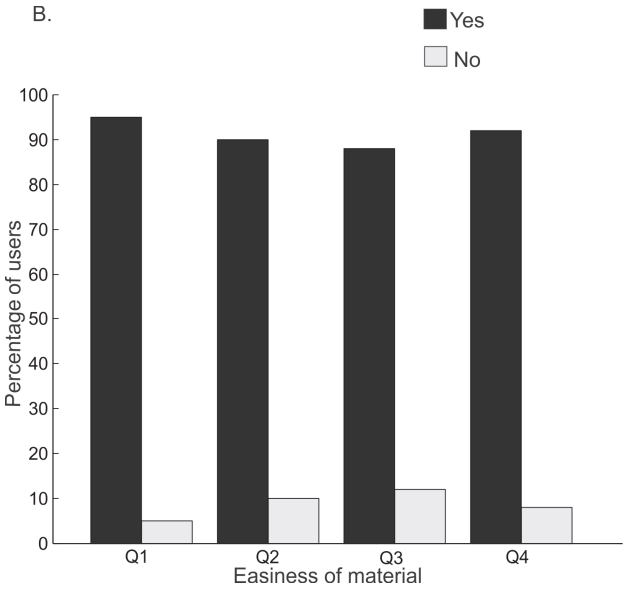

Figure 7. Analysis of easiness of virtual lab material

In addition to this, the feedback reports also suggested that the extended use of ICT enabled technologies have a significant role in enhancing the education process. Feedback report from the surveys amongst the students showed that the clicking component (interactive sessions) of the simulator was self-indicative that helped them to improve their laboratory skills. Also 100% of them supported the animated experiments provided the details of the experiment in a step-by-step approach that helped them to understand the experimental setup in a better way. This indicated that most of the students preferred both animations and simulations in their learning process. 95% of them completed the simulation based experiments with mistakes and thus they could repeat the experiment several times without the loss of chemicals, equipment damage etc. Moreover, 90% of them indicated animations and simulations provided them an actual feel of a real lab, thus facilitating the laboratory experiences at anytime-anywhere (Figure 8).

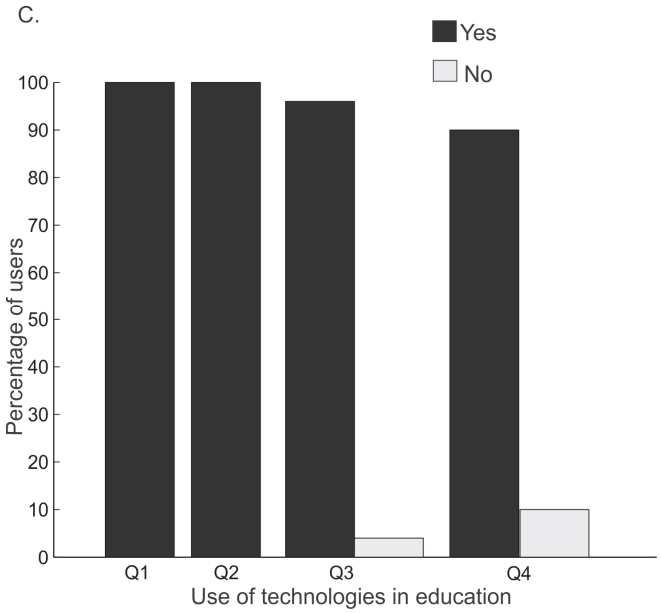

Figure 8. ICT enabled technologies (animation and simulation) in laboratory education

3.2. Blended learning with ICT enabled virtual labs – role of explicit interactions in enhancing student's academic performances

Blended learning with ICT enabled virtual labs improved student's performance level. The statistics showed that there was a significant difference between the pre-test and post-test score of the control groups. 4% (n=10) of the control groups were able to score marks in the range of 90-99% in the post-test, whereas the same group of users did not score as much in their pre-test evaluations. Most of the control groups (n=225) scored more than 60%

of marks in the post test evaluations, thus improving the class average from the pre-test scenario (Table 4). The study suggested the role of virtual labs as an augmented laboratory education tool for making education more effective.

The study was extended to analyze significant impact of including virtual labs in the university curriculum. A comparative analysis of percentage of marks scored by the students in the experimental group and blended learning group were also tabulated (Table 5). The study was extended to analyze significant impact of including virtual labs in the university curriculum. A comparative analysis of percentage of marks scored by the students in the experimental group and blended learning group were also tabulated (Table 5).

The statistics showed that the students performed better in a blended learning approach compared to teacher assisted virtual lab learning platform. This suggested that they could use virtual labs as an interactive textbook in addition to the traditional classroom learning that helped them to improve their average performance level in the examinations.

3.3. Remote labs as better online interactive textbooks

Questionnaire based feedback data were collected after deploying the remote solar panel experiment. The survey (see Table 3 for analysis questions) amongst the students showed that 75% of them were able to operate the remote equipment easily without the help of an instructor, while 15% of them indicated that they faced difficulties while performing the experiment. Moreover, 10% of the participants suggested that they need further improvements in the remote experimentation for making it more functional for their learning process (Figure 9).

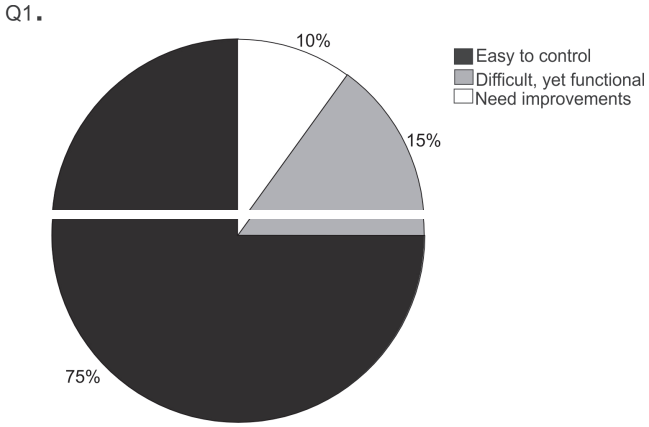

Figure 9. Analysis of remote equipment control

Also, 35% of the participants rated that the remote experiments are more similar to the real lab scenario that could help them in their learning process remotely. 30% of them indicated remote labs provide an alternative working environment with controls over the internet. While 25% of the students suggested that they need more improvements to make the experiment to a close proximity to the real lab setup. 10% of them indicated that remote labs never replace the real labs, due to the difficulty in operating the remote experiments and equipment due to the server issues (Figure 10).

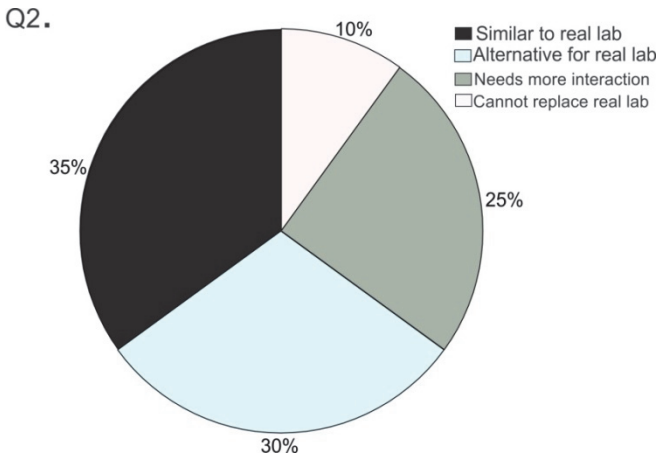

Figure 10. Student's responses on comparing the remote labs to a real lab scenario

Also, the feedback analysis indicated student's choices of using remote triggered labs in their learning process. From the participant feedback, 87% of them suggested that remote triggered labs are useful as a pre-lab material for making the laboratory education more effective while 13% of them suggested that they could use it as a post-lab material after completing the real lab experiments (Figure 11). This would be helpful for them to repeatedly use the remote laboratory equipment without any damage or cost related issues. Moreover, 72% of the participants supported that they were able to operate the remote experiments without the physical presence of instructors, where as 28% reported that they need an instructor for operating the equipment (Figure 12), since they experienced several issues during the experimental process (Kumar et.al, manuscript submitted).

Table 4. Control group user's performance rate in pre-test and post-test examination.

Study group	Percentage of marks	Pre- test evaluation (Percentage of users) (Tradition method of learning)	Post- test evaluation (Percentage of users) (Virtual labs as learning material without the help of an instructor)
Control group (n=250)	100	0	0
	90-99	0	4
	80-89	0	10
	70-79	16	32
	60-69	20	44
	50-59	40	10
	<50	24	0

Table 5. Experimental group and blended group user's performance rate in the examination

Study group	Percentage of marks	Percentage of users
Experimental group (n=250) [Virtual labs as learning material without the help of an instructor]	100	2
	90-99	26
	80-89	36
	70-79	20
	60-69	16
	50-59	0
	<50	0
Blended learning group (n=500) (Both CG and EG) [Traditional method of learning and Virtual lab learning with instructor]	100	10
	90-99	44
	80-89	30
	70-79	16
	60-69	0
	50-59	0
	<50	0

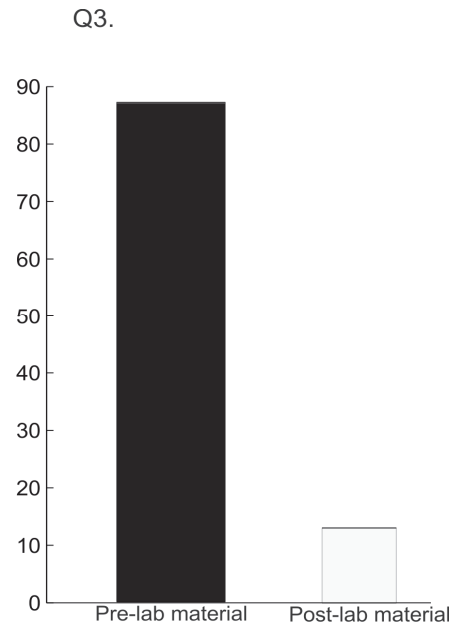

Figure 11. Student's responses of using remote labs in learning process

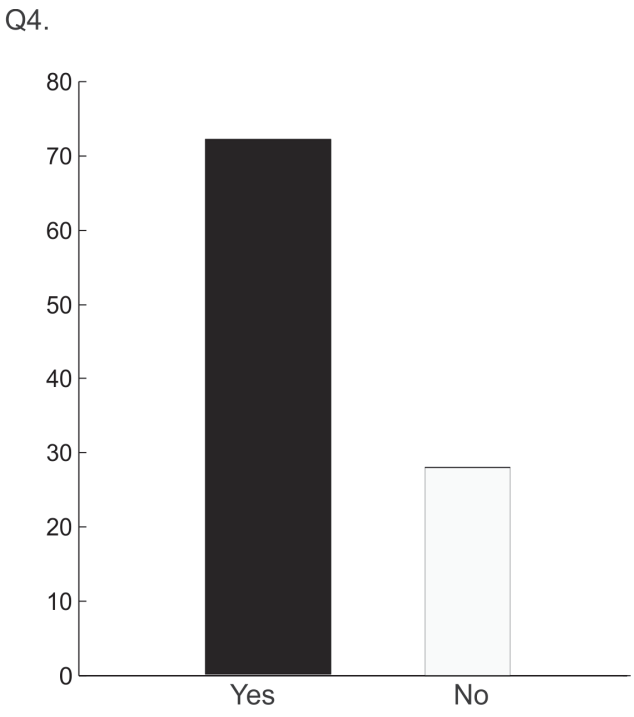

Figure 12. Remote labs as self learning material

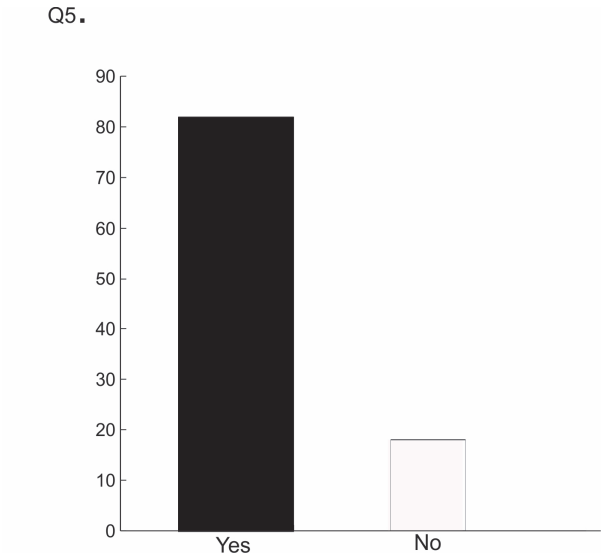

Figure 13. Remote labs in a blended classroom education

3.4. Remote labs as a blended learning tool

Among the students who participated in the online remote triggered lab workshop, 82% of them suggested that technologies like remote triggering of lab equipment were helpful in their classroom education scenario, whereas 18% did not favour use of such tools in blended learning due to the lack of internet access at the remote places (Figure 13).

4. Discussion

In this diffusion-based case study, we analyzed the impact of virtualization techniques such as animation and simulation in enhancing the learning process of the student groups, specifically among various Indian Universities. Overall studies indicated that the virtual lab demonstrations were a new venture in the in the field of education, as they make a new dimension in visual learning. Also, we have used a pre-test and post-test examination pattern for analyzing whether the virtual lab platform has a significant role in increasing the student's performance level in a classroom education. The results suggested that the content-rich learning materials provided by the virtual labs helped the students to understand the basic concepts of the experiments in a better way. Blended learning approach was tested because of the direct correlation between teachers and students in a classroom. The evaluation scores of the experimental group and blended learning group showed the use of virtual labs as a supplementary learning material and its subsequent usage in the curriculum ensured a better performance during evaluations. The results suggested

that the students, who used virtual labs as an addition to traditional laboratory studies performed better in the examination compared to those who went through the typical classroom approach alone. The incorporation of hybrid approaches of using virtual labs along with classroom laboratory education allowed making significant improvements in student academic performances. During the workshops, some of the students indicated their comments as: "The opportunity for manipulating or changing the parameters of the experiment according to our wish is something that I found very interesting in virtual labs". "Virtual labs provided a wide range of possible results, as in the experiment Selective and Differential media of microorganism, which gave a feeling of trying out different possible reactions of microorganism. Such possibilities would be less in a wet lab, augmenting virtual labs as a supplementary education tool". "Vivid presentation in an interactive way itself is interesting. Curiosity helps to complete the experiment in an easy way". Also, a professor who participated in the teacher workshop indicated that "The workshop was very useful and I am sure it will attract students also. Less time, No chemicals, no pollution involved. Hence Green approach, well organized platform for learning. The system is highly benefited for improving the quality of education in rural areas."

User interaction and learner satisfaction were the primary challenges for constructing successful remote triggered laboratories. We also evaluated the role of remotely triggered labs in a blended learning system. Most users suggested that the use of advanced technologies like remote triggering were helpful in classroom education scenario, making it as pre-lab material for enhancing laboratory education. Most students were able to control the remote experiments without any difficulties, thus providing a user-friendly outlook to the modern laboratory education. The repeated usage of the lab equipment has a potential role in adaptive learning to improve the level of performance in the classroom. This suggested the implementation of remote labs in a blended learning approach to reduce most of the economical and financial issues faced by many universities in India. Several internet related issues were also a major concern for the successful deliverability of such ICT-enabled techniques, especially in the remote location. Although these initial results suggested virtual labs to be effective, the study is being extended to understand the interaction of social, cognitive and teaching presences in a virtual scene and within traditional blended learning environments.

4. Conclusion

Virtual labs are becoming a predominant classroom component for experimental studies in many universities including those in India and other developing nations. The emerging achievements of virtual labs in creating online Biotechnology courses need further research. We foresee this virtual lab system as a version of an interactive textbook. Interactive mechanisms in such environments seems to aid student usage and enhance student participation in blended and remote learning scenarios. The virtual lab project is freely already online for public use via http://amrita.vlab.co.in/ and can be accessed after signing up with a google or open id.

Acknowledgements.

This project derives direction and ideas from the Chancellor of Amrita University, Sri Mata Amritanandamayi Devi. This work is funded under the Sakshat project of National Mission on Education through ICT (Phase I and Phase II), Department of Higher Education, MHRD, Government of India. The authors would like to acknowledge the contributions of Sanjay Pal, Nandita Mishra, Sobha V. Nair, Vidhya Prakash, Ajith Madhavan and Swarna Iyer of Amrita School of Biotechnology.

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