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Received September 25, 2013, accepted October 6, 2013, date of publication October 18, 2013, date of current version October 25, 2013.

Digital Object Identifier 10.1109/ACCESS.2013.2286202

Virtual Labs Project: A Paradigm Shift in Internet-Based Remote Experimentation

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ABSTRACT The lack of good and up-to-date lab experiments form a major impediment in the domain of engineering education. Often, the lab experiments are outdated. The Virtual Labs project addresses the issue of lack of good lab facilities, as well as trained teachers, by making remote experimentation possible. The pedagogy is student-centric. The Virtual Labs project has also developed a novel methodology for field trials, outreach, and quality control. Virtual Labs also provide tremendous cost advantage. The Virtual Labs project is a wonderful example of an open educational resource developed by a multiinstitution multidiscipline project team. Over 100 000 students are currently using the online labs under the Virtual Labs project. Many of these labs are being accessed outside the regular lab hours.

INDEX TERMS Open educational resources (OERs), remote experimentation, information and communications technology (ICT), internet-based experimentation.

I. INTRODUCTION

Good lab facilities and updated lab experiments are critical for any engineering college. Physical distances and the lack of resources often make it difficult to perform experiments, especially when they involve sophisticated instruments. Also, good teachers are always a scarce resource. The Virtual Labs project is an Open Educational Resource (OER) that addresses this issue of lack of good lab facilities, as well as trained teachers, by making remote experimentation possible. With the present day internet and computer technologies, these limitations no longer hamper students and researchers in enhancing their skills and knowledge. Yet another objective is to arouse the curiosity of the students and permit them to learn at their own pace. This facilitates the absorption of basic and advanced concepts through remote experimentation. Internet based experimentation further permits use of resources – knowledge, software, and data available on the web, apart from encouraging skilful experiments being simultaneously performed at points separated in space. In the Virtual Labs project, web-enabled experiments have been designed for remote operation and viewing. Specifically, the Virtual Labs project provides the following:

(a) Access to quality labs to those engineering colleges that lack these lab facilities.
(b) Access to quality labs as a complementary facility to those colleges that already have labs
(c) A complete Learning Management System around these labs
(d) Teacher-training and skill-set augmentation through workshops and on-site training.

The Pilot Phase of the Virtual Labs project started in April 2009. During this phase, approximately twenty labs were developed as proof of concept. The Main Phase started in April 2010. The participating institutes in this project are: IIT Delhi, IIT Kanpur, IIT Bombay, IIT Madras, IIT Kharagpur, IIT Guwahati, IIT Roorkee, IIIT Hyderabad, Amrita University and Dayalbagh University. IIT Delhi is coordinating this project under the National Mission on Education through Information and Communications Technology (NMEICT) [1], sponsored by the Ministry of Human Resource Development (MHRD).

There have been earlier attempts at providing remote access to labs [2]–[6]. The first paper reporting the use of remote labs in an undergraduate course, applied to control engineering laboratories, appeared in 1996 [2]. Several authors also reported remote labs, as an aid to teaching [7]–[9]. However, most of these labs were developed as standalone initiatives [10]–[15]. Several collaborative initiatives have been also taken by the teaching fraternity for developing online labs, such as iLabCentral, LiLa, Labshare, Go-labs, ISES, National Collaboratories etc. [19]–[24]. The REXNET project is an example in which human resources and the available equipments are shared between different teaching institutions [25]. However, Virtual Labs project is a paradigm shift in the area of ICT-based education. For the first time, such an initiative has been taken up in India in the area of remote-experimentation on such a large scale. It covers all important areas of engineering and sciences. Over one hundred labs comprising of more than a thousand experiments have been developed. We describe in this paper how Virtual

Labs project is much more than simply providing access to lab experiments. Virtual Labs project is a step towards 'student-centric' pedagogy, where the student decides the pace of learning. In addition to providing access to lab experiments, Virtual Labs project has created an ecosystem around these labs. This ecosystem is crucial for the continued sustenance of these labs. We have also evolved new processes that ensure high quality of labs, as well as, transparency and openness. The rest of the paper is organized as follows. In Section II we provide the background behind the Virtual Labs project and discuss the salient features. The overall organization of this project is described in Section III. The various steps involved in the development of the Virtual Labs project are described in Section IV. Virtual Labs also provide tremendous cost advantage. This cost advantage is highlighted in Section V. An important feature of Virtual Labs is the mechanism for quality checks and the provision for mid-term corrections. Section VI describes the novel processes and guidelines for quality checks evolved specifically for this project. The Virtual Labs project has been developed keeping the end user in mind. The methodology for field trials and outreach is outlined in Section VII. In order to maintain transparency and openness, several processes have been built into the project, which are briefly discussed in Section VIII. The impact of the Virtual Labs project is discussed in Section IX. Finally, the paper concludes in Section X.

II. BACKGROUND

A. TERMINOLOGY

Presently, the community working on remote experimentation uses the following terms/expressions [26]–[28]:

Online Lab: This is used for a laboratory accessible through the internet, which can either be a remote triggered, a virtual one (simulated) or measurement based. The basic concept of online labs is shown in Fig. 1.

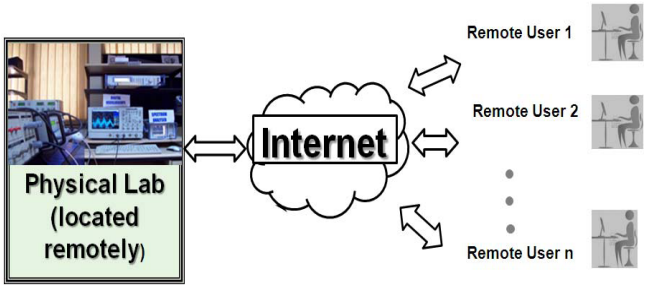

FIGURE 1. The basic concept of online labs.

Virtual Lab: Refers to a simulated lab. This is sometimes called ''Simulation-based Virtual Lab''. In these types of labs, there is no real hardware or equipment at the back end. Instead, there is a simulation engine that provides output based on mathematical equations that model the real-world. This can, at-best, provide an approximate version of the 'real-world' experiment. The simulations are carried out remotely at a high-end server, and the results are communicated to the student over the Internet. Such labs are scalable and can cater to a large number of simultaneous users.

Remote Lab or a Remote-triggered Lab: Refers to a remotely accessible real lab. In these labs, the user is able to trigger a real-experiment on a real piece of equipment or hardware. The output of the experiment (being conducted remotely) is communicated back to the student over the Internet. This class of Virtual Labs gives the student the output of real-time experiments. Typically, time-slots are booked before conducting such experiments. Many such labs provide additional inputs to the students like accompanying audio and video streaming of an actual lab experiment and equipment.

Measurement based Labs: These labs provide the corresponding measurement data for the experiment previously carried out on an actual system. These labs are closer to the 'real-world' experiment than the simulation based labs, because they deliver to the students measurement data from real equipment.

The online labs reported in this paper are primarily simulation based labs. All labs under the Virtual Labs project can be accessed through a common website: www.vlab.co.in. At the user end, a PC and broadband connectivity enables the user to access these online labs.

B. OBJECTIVES

The Virtual Labs project was initiated to address the basic problem of lack of good lab facilities in many engineering colleges. The main objectives of the Virtual Labs project are as follows:

- To provide remote-access to labs in various disciplines of science and engineering.
- To cater to students at the Under-graduate (UG) level, Post-graduate (PG) level as well as to research scholars.
- To enable the students to learn at their own pace, and to arouse their curiosity.
- To provide a complete Learning Management System (LMS) that includes online lab-manuals, web-resources, video-lectures, animated demonstrations, step-by-step procedures, sample output, self evaluation and a question bank.

C. INTENDED BENEFICIARIES

The intended beneficiaries of the Virtual Labs project are:

- All students and faculty members of science and engineering colleges, who do not have access to good lab-facilities.
- High-school students, whose inquisitiveness will be triggered, possibly motivating them to take up higher-studies.
- Researchers in different institutes who can collaborate/share equipment and resources.
- Different engineering colleges, who can benefit from the content and related teaching resources.

D. BROAD AREAS OF VIRTUAL LABS

Virtual Labs project span almost all areas of science and engineering. The broad areas (disciplines) of Virtual Labs are:

- Electronics and Communication Engineering
- Computer Science and Engineering
- Electrical Engineering
- Mechanical Engineering
- Civil Engineering
- Chemical Engineering
- Biomedical and Biotechnology Engineering
- Chemical Sciences
- Physical Sciences

Over one hundred Virtual Labs are currently being used by students and teachers in various disciplines.

E. ACCESS POLICY FOR VIRTUAL LABS PROJECT

The online labs developed under the Virtual Labs project are free for the student community. In some labs, a login is required for monitoring purpose. In the next version, it is planned to have a barrier-free entry to all labs under the Virtual Labs project.

III. OVERALL ORGANIZATION OF THE PROJECT

The Virtual Labs project is an excellent example of Multi-Institution Multi-Discipline (MIMD) project, sponsored by Ministry of Human Resource Development (MHRD), India. Over one hundred Virtual Labs have been developed in 9 disciplines by 12 participating institutes. We have evolved a novel process for coordinating the activities across different institutes and various disciplines. The overall structure of the Virtual Labs project organization is given in Fig. 2. Each participating institute has a Participating Institute Coordinator (PIC) who is in charge of the financial transactions and policy decisions. Virtual Lab Project covers all the major disciplines of Engineering and Sciences. Therefore, the Virtual Labs project has Discipline-wise National Coordinators (DNCs) who have the ownership of a particular engineering discipline (e.g. Electrical engineering, Mechanical engineering etc.). There are total of 9 DNC's in the Project. It is very important for this project to have a seamless information flow, to and from, over 150 faculty members who are involved in the development of the Virtual Labs. They are the lab-developers (LD), and are responsible for the technical development of the Virtual Labs. The overall structure of the Virtual Labs from the perspective of engineering disciplines is shown in Fig. 3. The novel processes developed for the functioning of this MIMD project is discussed in the following section.

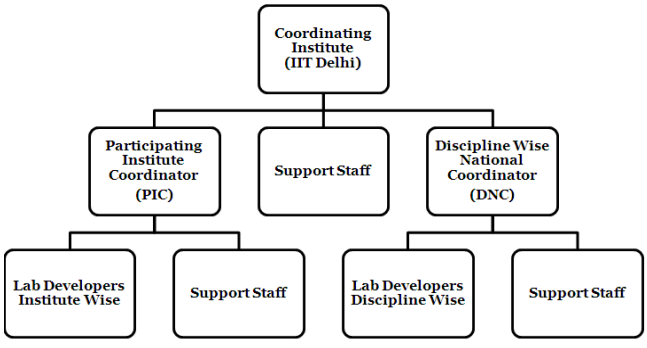

FIGURE 2. Overall structure of Virtual Lab project.

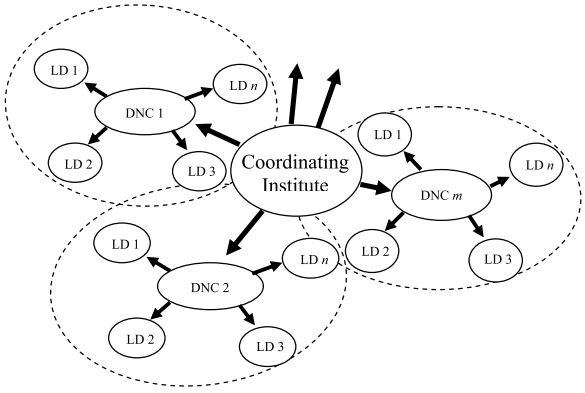

FIGURE 3. Virtual Lab project from the perspective of engineering disciplines.

IV. DEVELOPMENT OF VIRTUAL LAB

In order to manage this large MIMD project, several novel processes and guidelines have been evolved so as to standardize the labs, and ensure the quality of the content, as well as, user experience. Some of these are described below:

1) *Developing the experiments:* All labs in the Virtual Labs project have been developed in a distributed fashion by the twelve participating institutes. The basic guiding philosophy is to ensure that there is minimum hardware and bandwidth requirements at the user end. The lab developers are free to use any software that best suits the development of the lab experiments. For example, the lab developer can use any web-based client technology that can interact with JavaScript in the client side. That can possibly include both Adobe Flash and Java Applets. The user front end is standardized, where the inputs to the experiments are fed by the user. These inputs are processed at the back-end by a simulation engine. The result of the simulation is then sent back to the user in a form that is useful, and can be visualized. There has been a general policy to use openware (e.g. Scilab) as opposed to licensed software (e.g. Matlab). However, many labs do use licensed software at the backend (e.g. Labview).
2) *Common website for all Virtual Labs:* All Virtual Labs can be accessed through a common website: www.vlab.co.in. At the user end, a PC and broadband connectivity enables the user to access Virtual labs. Even though the labs have been developed by different institutes, and are housed in different locations, the students see one common website for accessing these Virtual Labs.
3) *Common front-end:* All users see a common web-based front-end which has been designed for ease of use. The Virtual Labs have standardized look and feel. All web pages are icon based. The virtual labs have clearly-

defined objectives of the lab, methodology, online lab manual, pre- and post-experiment quizzes, animations and web-resources.

4) *Methodology for mid-term evaluations:* All the labs under development undergo rigorous examination by subject experts. Periodic mid-term evaluations are carried out by the DNCs. Over 50 subject experts, mainly from the different Indian Institute of Technology (IIT), have been involved at various stages for the technical evaluation of Virtual Labs project. The evaluation process has been standardized in order to ensure basic quality levels. There is a standard evaluation form and the evaluations are demo-based. The evaluation fields include the clarity of the objectives of the experiment, quality of the lab manual, step-by-step procedures, pre-experiment and post-experiment quizzes, animation and video-tutorials, learning component offered by the experiment, ability to complement a theory course and the feel for doing the experiment remotely. Cross-pollination of ideas and sharing of best practices occur during the mid-term evaluations where all lab-developers of a certain disciplines meet and present their labs.
5) *Back-end:* The back-end is completely computer-driven. Virtual Labs project provides to the students the result of an experiment by one of the following methods (or possibly a combination): (a) Modeling the physical phenomenon by a set of equations and carrying out simulations to yield the result of the particular experiment, (b) providing a corresponding measurement data for the Virtual Lab experiment based on previously carried out measurements on an actual system, or (c) remotely triggering an experiment in an actual lab and providing the student the result of the experiment through the computer interface.
6) *Learning Management System (LMS):* The Virtual Lab project provides a complete Learning Management System. For most users, the Virtual Lab project provides all the relevant material at one place including the Objectives of the Experiment, Lab Procedure, Lab manual, Pre and Post-experiment quizzes, additional Lab resources, in addition to the Virtual Lab experiment. Most labs also have an associated question bank. We are also planning to add project ideas that students can undertake.
7) *Open Source Software:* Emphasis is given on the use of open source software's at the backend.
8) *Integration:* The integration of all the virtual labs is an important step towards standardization and scalability. The simulation-based labs are more amenable to integration and scaling. Integration enables the following:
   a) Cloud-based/central-server based content management of the labs
   b) Protection of the source code
   c) Version control and reporting/tracking of bugs
   d) Centralized feedback collection

V. COST EFFECTIVENESS OF VIRTUAL LABS

Apart from benefits like proliferation of quality labs, central up-gradation of new experiments, training of faculty members of various engineering colleges, collation of lab related information at one place, the Virtual Labs project also provides tremendous cost advantage. Virtual Labs have the potential to cater to many more students as opposed to a physical lab, besides being more cost effective. Virtual Labs provide the cost advantage due to the following reasons:

- Virtual Labs can be used outside the regular lab hours.
- Virtual Labs can be used every day, including the weekend.

Table 1 gives the Student Gain Factor (SGF) and the Economic Gain Factor (EGF). The average SGF greater than unity implies that the same equipment in a Virtual Lab can support more number of students per year. Our approximate calculation suggests that the average SGF equals 80. The number of students using a physical lab is based on typical usage at undergraduate level. The number of students using online lab is far greater because of the availability of these labs outside regular lab hours. The estimate for remote triggered labs assumes about 200 working days in a year, with the possibility of conducting 10 experiments (in slots) in a 5 hour cycle. The estimate for simulation based labs assumes about 300 working days in a year, with the possibility of conducting 20 experiments in a 24 hour cycle. Thus Virtual Labs can support almost eighty times the number of students, on an average.

TABLE 1. Cost Benefit Analysis.

Per Year	Physical Lab		Online Lab		Remarks
	EB	SB	RT	SB	
No. of students who use this setup	50	50	2000	6000	Average Student Gain Factor = 80
Cost per student (in Indian Rupees)	6000	1000	225	42	Average Economic Gain Factor = 25

EB= Equipment based, RT= Remote Triggered,
SB = Simulation based

In order to calculate the Economic Gain Factor for the online labs, the cost of internet access has been added to the cost of the equipment. Initial calculations suggest the average EGF for online labs is close to 25. This implies that the average cost per student is almost 25 times cheaper in the case of online labs. These numbers are purely indicative, and have been arrived at based on the assumptions for a typical lab. Clearly, every lab will have a different SGF and EGF, depending on the time a student has to spend in the lab and the cost of the equipment.

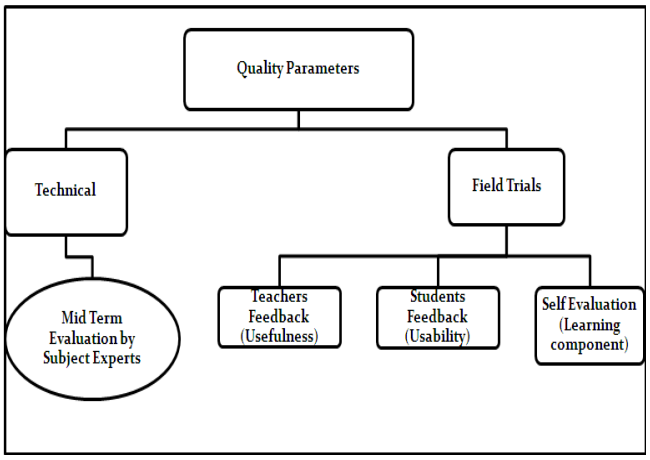

FIGURE 4. Process of quality control.

Other benefits of online labs that cannot be measured in Rupee terms are:

- Many colleges, who may be able to afford some of the equipment, probably do not know how to design experiments around them or even to run an experimental lab. Virtual Labs will be an asset in such cases.
- New experiments can be added at the central location, and all users of the Virtual Labs project can benefit from the up-gradation. Similarly, removal of obsolete experiments can be done centrally.
- Using this remote infrastructure, several colleges can try out the experiments and decide whether or not to include it in their curriculum. If found suitable, the colleges can replicate them in large numbers, say thousands, thereby promoting actual, hands-on experimentation, as well.
- Apart from sharing of equipment, Virtual Labs provide additional resources, laboratory manuals, pre- and post experiment quizzes for self-evaluation.
- Virtual labs provides an opportunity for people in non-formal sectors, including, industry.

VI. QUALITY PARAMETERS

An important feature of the Virtual Labs project is the mechanism for quality checks and the provision for mid-term corrections. A set of quality parameters has been defined centrally, and form the basic standard for all the Virtual Labs. These quality parameters pertain to the front end user interface, the software used at the back end, the basic features required to be built in all labs, ease of use (good user experience), scalability, learning component etc. The feedback regarding the technical aspects of the Virtual Labs are sought from the subject experts, while the feedback regarding the user experience is obtained during field trials. The user experience involves the usefulness, usability and the learning component of the Virtual Labs. The process of quality control is shown in Fig. 4. Every lab undergoes a technical evaluation by a team of subject expert. For this, mid-term evaluations are organized periodically. Field trials are conducted to measure the usefulness of these labs (from teachers' feedback forms), usability (from students' feedback forms) and the actual learning component (from the self evaluation of students).

As seen from Fig. 4 a lot of feedback is collected regarding the labs. A team goes through the feedback received, filters them and passes the actionable points to the lab developers for the improvement of the labs. The detail of the feedback mechanism is given in Fig. 5. Over 100,000 feedback forms have been collected and processed till date. The pie-chart for the student and faculty feedback is shown in Fig. 6 (a) and 6 (b). Feedback is sought on the (i) efficacy of the virtual lab experiment, (ii) online manual, (iii) ease of performing the experiment, (iv) the web-interface and (v) the overall usefulness of the virtual lab.

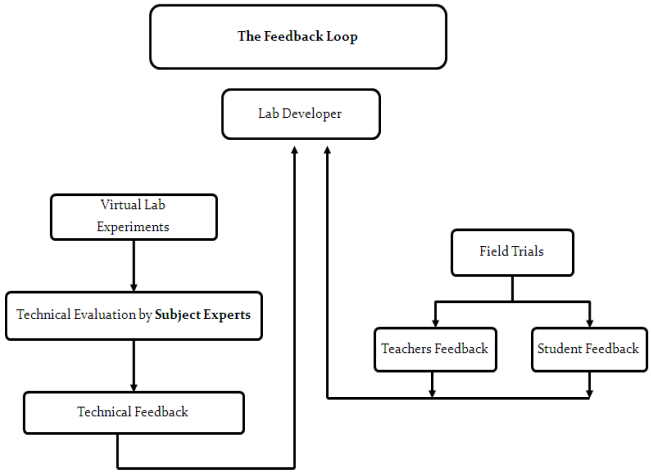

FIGURE 5. The feedback mechanism.

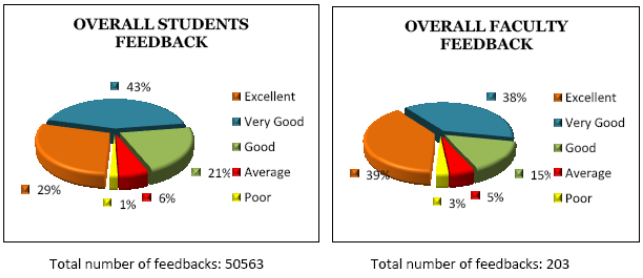

FIGURE 6. (a) Student feedback, (b) Faculty feedback.

A. METHODOLOGY FOR FIELD TRIALS

One of the important aspects of this project has been exhaustive field trials before the completion of the project. The end users have been closely involved in the development of Virtual Labs. Typically, a virtual lab, with eight experiments, takes about 2 years to develop. This development cycle includes mid-term evaluations by subject experts. As soon as a lab is close to 80% completion, it is given to the user community for usage and feedback. The user community is made to feel a part of the development process, as their feedback is used to improve and augment the labs under development. The process of field trials has been standard-

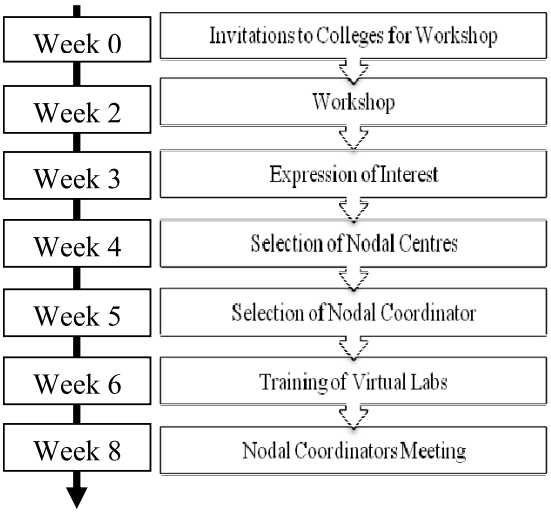

FIGURE 7. The Flowchart for the selection of Nodal Centers.

ized, and is depicted in Fig. 7. The process starts with a workshop, which explains the concept of the Virtual Labs project and provides an overview. Demonstrations are invariably given to showcase the power of Virtual Labs. After the workshop, an expression of interest is sought. This is done to ensure a basic level of commitment. Those who qualify are declared Nodal Centers (NC), and two Nodal Center Coordinators (NCC) are selected as liaison persons. This is followed by extensive on-site training and on-site workshops. The exchange of ideas and discussions take place during the NCC meetings, which are held regularly. The NCCs discuss their experience and provide constructive suggestions. The field engineers visit the NC regularly and assist the students with Virtual Labs experiments. A timetable for the entire semester is chalked out in advance for field visits. At the end of each session, the students fill out a feedback form, which is shared with the lab developers. In addition to this, there is a technical team in the back office that answers queries from the students and teachers.

B. GEOGRAPHICAL COVERAGE

The Virtual Labs project is being developed at twelve participating institutes, the locations of which are shown in Fig. 8. Each participating institute is catering to the engineering colleges located in the catchment area, located around that participating institute. Various models for outreach are being tried. Nodal centers have been created, where experiments under the Virtual Labs project are being conducted in a regular manner. In some institutes, the labs developed under the Virtual Labs project have been linked to the Quality Improvement Program (QIP) for teachers, where the teachers of engineering colleges are being exposed to these online labs. Currently over 100 engineering colleges in India are using the online labs under the Virtual Labs project on a regular basis. Based on the web-analytics, users from different part of the world are also using these online labs.

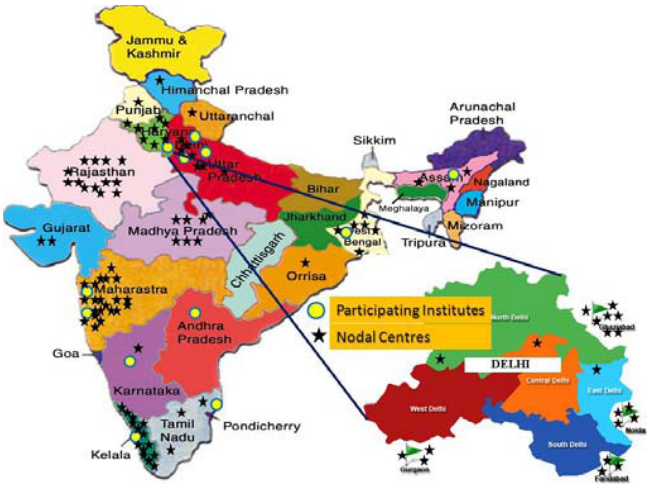

FIGURE 8. Location of the participating institutes and nodal centers.

C. THE ECOSYSTEM

Fig. 9 describes the overall ecosystem of Virtual Lab project. All the entities of the Virtual Lab project, from the developer to users are closely interlinked and related. One of the challenges for wide-scale adoption of the online labs under the Virtual Labs project is the non-uniformity of syllabi in different engineering colleges. An important outcome of this Virtual Labs project is that a lot of content related to engineering labs has become collated at one place. In a way, we have created a super-set of the syllabi of several technical universities, the IITs and the National Institutes of Technology (NITs). Eventually, we envisage the Virtual Lab ecosystem to sustain this project. It is anticipated that other contributors will join in and develop online labs in the 'gap-areas'.

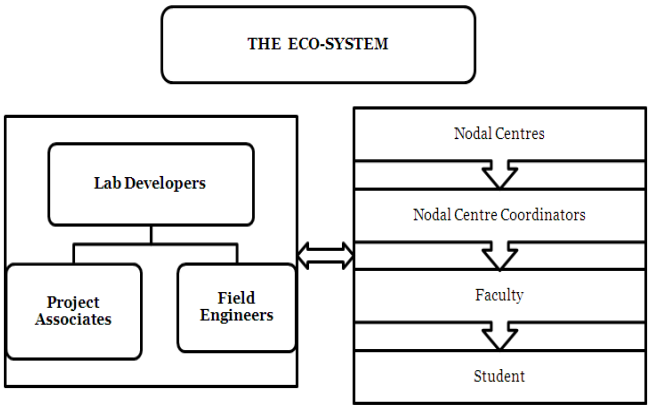

FIGURE 9. The ecosystem for the Virtual Labs project.

VII. TRANSPARENCY AND OPENNESS

As described earlier, the Virtual Labs project is being carried forward by the Virtual Labs consortium, consisting of twelve participating institutes. In order to maintain transparency and openness, several processes have been built into the project. These processes also help in cross pollination of ideas and promulgation of the best practices. The important points are:

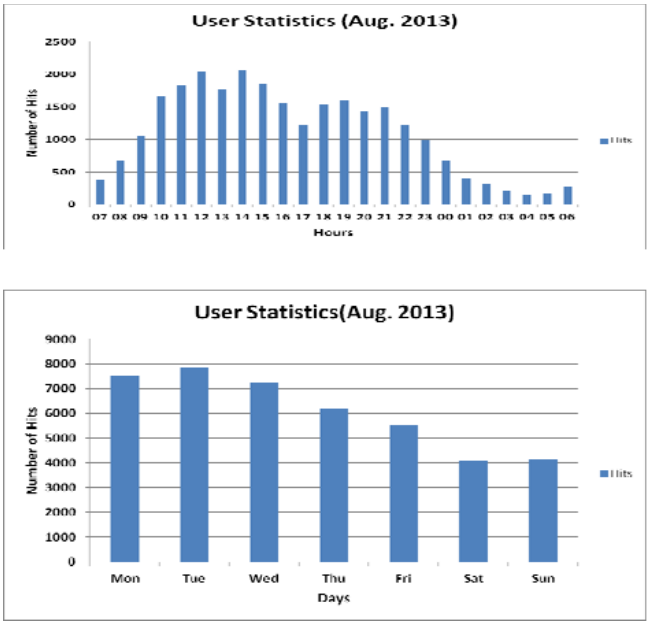

FIGURE 10. **Typical daily and weekly usage. Virtual Labs are widely used (a) outside the regular lab hours and (b) on the weekends.**

1) *Administrative website:* All expenses above a certain amount as well as the list of equipment purchased are posted on a common website.
2) *Common repository:* All documents, presentations, whitepapers related to the project are kept in a common repository that is accessible to all participating institutes.
3) *Wiki:* A wiki has been created for the developer community, as well as, the user community where information related to the labs is documented.
4) *Developers' Forum:* A discussion forum has been created for the developer community where the best practices are discussed. Periodically, developers' meet is organized so that the lab developers and project associates from various participating institutes can interact.
5) *Newsletter:* A newsletter goes out to nodal centers informing them of the latest developments related to the Virtual Labs project.

VIII. IMPACT OF VIRTUAL LABS

Based on the feedback from the user community, we can highlight the true impact of the Virtual Labs project as follows:

1. It provides remote access to quality labs
2. It provides a complete learning management system at one place
3. It allows the students to learn at their own pace, at a place and time of their choice

The feedback from both teachers and students suggest that the above-mentioned value-additions are all equally important to them. Virtual labs are now been regularly used by students in over one hundred engineering colleges across India. Over 100,000 students have used the experiments provided by Virtual labs project and have provided their feedback on the experiments. One of the interesting observations is that these labs are being commonly used outside the regular lab hours, often late in the night and over the weekend (see Fig. 10). This is one of the key advantages of Virtual labs over the hands-on labs. The online labs under the Virtual Labs project are being used in several ways, including (a) stand-alone labs, (b) complementary to existing labs, (c) for demonstrations to large classes and (d) accompaniment to theory classes. Ultimately, the students will be able to access these online labs from a variety of access devices, including their PCs, laptops, PDAs and smart-phones.

IX. CONCLUSION

The Virtual Labs project is a paradigm shift in the area of internet-based remote experimentation. For the first time, such a large Multi Institution Multi Discipline project has been carried out in India. Over 100,000 students are already using these labs. The Virtual Labs project has standardized the technology developed for this project. This is ideal for scaling up and horizontal transfer of technology. Some of the important contributions of this project are the development of (a) a standard website for hosting all Virtual Labs, (b) a standard process for quality control, (c) a standard process for field trials, (d) a complete Learning Management System, (e) the Wiki and Developer forum, (f) standard administrative website for all labs, (g) repository of all project related documents and (h) special features for security of information. Virtual Labs project has also evolved a novel methodology for field trials, outreach and quality control. These online labs also provide tremendous advantage both in terms of the number of students who can access these labs and the costs. Initial calculations show a 'student gain factor' of 80 and 'economic gain factor' of 25. The online labs under the Virtual Labs project not only arouse curiosity in students but also permit them to learn at their own pace. The pedagogy is student-centric. The effectiveness of these labs is evident from their use outside the lab hours, even late in the night. Virtual Labs are truly 'any-place, any-pace, any-time, any-type' Labs!'

ACKNOWLEDGMENT

The Virtual Labs project reflects the consolidated effort of all the participating institutes, the institute coordinators, the discipline-wise national coordinators, all the lab developers and the subject experts. The author specifically wishes to acknowledge the efforts of all the participating institute coordinators: Dr. S. Khandekar (IIT Kanpur), Dr. S. Noronha (IIT Bombay), Dr. P. Sriram (IIT Madras), Dr. C. S. Kumar (IIT Kharagpur), Dr. R. Bhattacharjee (IIT Guwahati), Dr. V. Kumar (IIT Roorkee), Dr. J. Sivaswamy (IIIT Hyderabad), Dr. K. Achuthan (Amrita University), Dr. Satsangee (Dayalbagh University), Dr. K. V. Gangadharan (NITK Surathkal) and Dr. S. Agashe (COE Pune). The Virtual Labs project has also benefitted immensely from the feedback of N. K. Sinha, Dr. R. K. Shevgaonkar, Dr. S. Prasad, Dr. K. Moudgalya, Dr. M. Sundar and Dr. V. Choppella.

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