



Virtualisation of engineering discipline experiments for an Internet-based remote laboratory

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A comprehensive survey on the Internet based virtualisation of experiments is presented, covering several individual as well as collaborative efforts in various engineering disciplines. From this survey it could be concluded that there is a pressing need to develop full-fledged remote laboratory experiments for integrated directly into engineering curricula. The paper subsequently summarises the experiences of authors during the design, evolution and implementation of virtualisation for a number of engineering experiments, enabling these to be accessed through the Internet as virtual experiments. It also covers the features required to give the 'feel' of performing experiments, inclusion of learning components, incorporation of easy navigation, testing of effectiveness of learning, and development of useful feedback mechanisms. A detailed feedback analysis from prospective learners is presented on the effectiveness of the virtual laboratory.

Introduction

For last two decades, computing, information and communication, electronics, instrumentation, mechatronics, and electrical technology have been among the fastest growing areas in the engineering field. We have witnessed a major paradigm shift in the technology, starting from analog to digital, macro to micro, from fixed (or wired) communication to mobile (or wireless) communication, etc. Due to this, there is a lag for traditional laboratories in keeping up with some of modern industry's requirements, not only in these fields but also in other, traditional engineering fields like mechanical, materials and metallurgy, chemical, civil, textile, etc. New equipment which can be operated remotely has come into being, new interdisciplinary products have appeared in the market, and new theories have been applied to existing devices, for example mechatronics, biotechnology, nanotechnology, etc. All of these circumstances give new expectations to current engineers and technologists, and at the same time, they challenge our practices in education for modern engineering and technology.

The concept of traditional real laboratories in technical institutions has many limitations. The availability of resources may be too limited to provide basic as well as advanced laboratory equipments, and there may be a paucity of qualified faculty members. Even if the facilities are there, in many cases a student may end up as a spectator in the conduct of experiments, due to being in a large group. Students are not free to do experiments according to their own schedules, as the time slot for an experiment may be limited to the usual working hours. The new era of education demands a revolution and modernisation in techniques for engineering education. One

gap in engineering education is the lack of complete set of e-experiments, that is a full scale virtual laboratory, instead of few virtual experiments in a particular engineering discipline.

The virtualisation of experiments is one of the most efficient ways for the modernisation of traditional engineering laboratories. Virtualisation is basically the conversion of real experiments into virtual experiments with the help of information and communication technologies (ICT), which provide a real laboratory environment and 'feel' to perform the experiment. The basic goal for virtualisation is to provide a facility to perform the experiment by using the Internet. This can provide a highly interactive and powerful learning environment for the engineering disciplines and enables a learner to select and control all the related parameters of the experiments. A complete graphical interface with the adequate learning components and a scientific approach can provide the 'feel' of performing experiment efficiently. The virtualisation of an experiment and its application by Internet based remote techniques can provide a relevant and meaningful practical learning experience. This relatively new concept of virtualisation is cost effective and there is no time bound for the users as experiments could be accessed "24-7". Virtual experiments can be used extensively for teaching, e-learning, and other computer-based education.

Literature review

In the past decade or so, experimental simulations have appeared with discipline specific texts, such as Jones and Childers (2001), and Christian and Belloni (2001), or on the world wide web at sites such as the *Physical Sciences Resource Center* [<http://www.psrc-online.org/>]. Many of these simulations are implemented using Java applets, and are well designed and executed. Other online experimentation includes the Stevens Institute of Technology in their *Remote Dynamical Systems Laboratory* [<http://www.stevens.edu/remotelabs/>], which incorporated several online experiments but is subject to limited use and limited data. Mercer University has implemented the *Online Interactive Chaotic Pendulum* [<http://physics.mercer.edu/pendulum>]. The site has an exemplary interface and data presentation, but doesn't provide easy access to data. Several mechanical engineering courses have online experimentation, including Curtin University [<http://www.cage.curtin.edu.au/mechanical/info/vibrations>]. These sites tend to be highly technical and their online availability appears to be limited. Other organisations that have executed online experimentation include the *Advanced Liquid Crystalline Optical Materials (ALCOM) Science and Technology Center* [<http://www.lci.kent.edu/ALCOM/alcom.html>] of the Kent State University. Tan, Tang and Paterson at Queensland University of Technology had a project on developing a web based remotely controlled mechanical vibrations laboratory via the Internet. The system allowed flexibility for students to access a range of laboratory experiments at any time and any place where there is an Internet connection.

Coito et al. (2007), Bauer and Fedák (2007) and Bachnak et al. (2003) discussed the ability to control and monitor processes from remote locations through a PC-based data acquisition for online and off line analyses. Advances in networking technologies and development of measurement hardware and software has turned PCs into platforms capable of continuous remote monitoring using the Internet (Fountain & Wright, 2000). Software programs that facilitate the developments of such applications are available (Bishop, 2001; Egarievwe et al., 2000). A user can publish data on the web with little or no programming experience. The software creates user interfaces on a

web page to give the user access to the system (Travis, 2000). Antunes, Paulino & Piteau (1998) developed predictive methods to remotely analyse heat exchanger tube responses and wear for realistic multi-supported tubes and flow configurations. Buckman (2000) presented an introduction to the virtual instrumentation to increase the ease of use for students, and the capability to add new measurements that were otherwise unaffordable.

Overstreet and Tzes (1998) described the design and development of generic virtual instrument used for real time experimentation at the control engineering laboratory of their institute in a remote-access environment. Salzmann (1999) proposed the steps of remote, real time control over the Internet, and demonstrated the feasibility of using a distributed online laboratory to complement and enhance the traditional laboratory. Ertugrul (2000) reported such software tool applications, and his paper aimed to provide some background knowledge about the tools and to address common problems encountered by users. Resendez and Bachnak (2003) and Bachnak et al. (2003) showed that such software tools could be used to perform data acquisition and remotely control hardware devices through the Internet.

Trevelyan (2002) aimed to provide a cost effective online laboratory to staff and students. Their first project was a tele-robot, which was written in special purpose software written in C, C++ and Java. Trevelyan (2004) reviewed all the principal lessons their group learned since 1994 and briefly described Telelabs, a cost-effective framework to provide an extendable series of online labs that could be sustained from normal operating budgets. Hofmann and Bubb (2003) explained about the virtual environment for the typical industrial application. Almgren and Cahow (2005) explained the way to make engineering education more innovative by using the Internet. Pheatt and Ballester (2003) discussed the design and implementation of web courses and remote experiments, and the incorporation of these techniques into the curriculum without acquiring equipment, setting up equipment or creating a laboratory environment. Che (2005) presented the development of biology engineering education along with a discussion on the development of e-learning with a time sharing mainframe model and providing a centralised, remotely controllable biology lab.

Feisel and Rosa (2005) explored the major factors influencing conventional laboratories. They described the various limitations which affect the effectiveness of laboratory work and also its importance in science and engineering education. Ozeki et al. (2006) produced remote experiments with a digital certificate and encryption of communication data to protect a supervisory control system against illegal access. They did the development of the remote experiment system with testing and demonstration. Jeschke et al. (2008) discussed the integration of experimental setups into a virtual cooperative knowledge space, so that availability and accessibility can be enhanced for a wide range of users. They worked out the architecture and implementation of the remote experiment. Gröber, Vetter, Eckert & Jodl (2007) described a remote laboratory and its helpfulness to provide a tool to sustain this shift towards a student-centred engineering teaching approach.

In papers by Bauer and Fedák (2007) and Bauer et al. (2008) a distance measurement application for educational purposes was described, and the monitoring of industrial applications was studied through web based applications. Macías and Méndez (2008) described the automation of their laboratory and rapid integration of automation systems into most of the engineering processes. Cui, Wang, Zhang and Akujuobi

(2008) focused on the reasons for traditional laboratories lagging behind and emphasised the basic demands behind the modern trend to increased virtualisation. Koliás et al. (2007) provided a categorisation of remote experimentation in education according to the platform used for conducting the experiments and the scientific field represented. Gadzhanov and Nafalski (2010) reviewed the pedagogical effectiveness of distance education, with a special focus on remote laboratories for measurement and control. Machotka et al. (2010) developed the remote laboratory *NetLab* at the University of South Australia. *NetLab* was developed from the beginning as a collaborative learning environment that enables students to cooperate while conducting remote experiments via the Internet on both the domestic and international levels. Herrera and Fuller (2011) proposed a model for the implementation of remote experimentation laboratories in a distributed collaborative scenario, focusing on two crucial key elements, namely the shared knowledge and the interaction for the collaboration. They contributed towards the implementation of remote experimentation using collaborative scenarios.

The present work summarises the challenges faced in developing virtual experiments for a typical engineering laboratory. It presents the process of developing online virtual experiments in a step by step approach with access solely via the Internet, for a typical engineering lab, a mechanical vibration laboratory. It presents a discussion on the design and implementation of a virtual laboratory through the use of web-based deployment. The goal of this project is to develop reliable, understandable, repeatable and low maintenance virtual experiments. This paper also describes various classes of virtualisation of laboratories, requirements and challenges in virtualisation of experiments, software selection, benefits of the software tool chosen for the present case, and steps in the virtualisation of one experiment as an illustrative example.

Themes in virtualisation of laboratory experiments

The basic concept of virtualisation of an experiment is to provide a virtual platform for learners to perform the experiment with their own selection of parameters. The effort is towards mimicking the working procedure in a real laboratory, and its environment in the virtual workbench. Virtual experiments are designed and sequenced in such a manner as to give a real feel of performing the experiment. During the experiment, the learner can save and edit the desired data for his/her analysis. Apart from these the focus is also aims to embed a maximum number of learning components in virtual experiments. Virtualisations of experiments could be broadly classified, based on the form data used for performing the experiment, as follows

- i. *Numerical simulation based*: It is completely based on theoretical calculations and is nothing to do with the real experiments. The design of the virtual lab has no practical limitations; however, it requires careful thinking to incorporate them to have a feel of actual experiments. It provides very little feel of experiment, and it is just like a numerical simulation; however, it has advantage that a large number of users can use it at any time.
- ii. *Measurement data based*: It is based on the actual measured data. It utilises a large database which contains carefully preplanned measurement data. It shows the actual behaviour of the system in the virtual experiment, but the user is restricted to choosing parameters which are provided in the virtual program. To provide a real feel of experiment a large data set based on various combinations of input

parameters is essential to cover various options of the actual experiment during virtualisation, including some not so carefully performed experimental data. With careful design and selection of parameters this could provide the feel of performing experiment and it has potential for scalability to accommodate large number of users at a time.

- iii. *Real time data based*: It utilises the real experiment in real time, and measurement data is acquired online. A learner will not have any control in the experiment, except in acquiring real time data. In this case the experimental set up will be in working condition all the time (or predefined timings). It may require human interference (or help) and a learner could acquire real time data through the Internet from a remote location. For this case, the feel of laboratory is marginal; however, the feel of performing experiment is not there since there is no control of performing experiments with the learner.
- iv. *Remote trigger based*: It utilises a real experiment in real time, and experimental data is acquired by a learner online. The learner gives an online trigger to start the experiment, however, he/she will have hardly any control in performing the experiment until it finishes itself, except in acquiring online data whenever it is found to be suitable. An advantage for this kind of experiment is that instruments and test rigs need not run all the time, a remote user can trigger it to run, and has some feel of actuating the experiment remotely.
- v. *Remote control based*: It is very similar to remote triggering, however, the user has more freedom in performing the experimentation. The remote control based virtual experiment gives more options to a learner to control online the parameters of an experiment, thereby having a better feel for performing the experiment remotely. This particular theme is the most challenging, especially for conventional engineering disciplines (like mechanical, aerospace, chemical, material and metallurgy, etc.) where fully remote control could be a very costly development due to physical movement and manipulation of a test specimen and other test rig objects. The main difficulty with this theme is scalability, as a single user must have control at a given period of time while performing virtual experiments, whilst other users or prospective users would be spectators.
- vi. *Hybrid based*: As remote control based virtualisation is the most difficult to deploy, a hybrid virtualisation theme of virtual experiments may be based on a combination all the themes described above. Depending upon the need to enhance the feel of laboratory and feel of performing experiments, with some compromise on the fully control based theme, a suitable combination of themes may be most appropriate.

The above themes have their advantages and limitations. The aim of the present work is enable virtual experiments with an effective learning component. The term *effective learning component* signifies core contents of the experimentation, its representation in terms of graphs, video, animation, provision for real data downloading, and editing and interpreting as per the user requirement and the feel of performing the experiment. The virtual experiment provides pertinent information related to the particular experiment, including the experiment manual, video and sound clips, and interpretation and comparison of the theoretical and experimental results. These things help for better understanding of the basics and core content of the experiment. For this purpose the *measurement based* virtual experiment is best suited. It gives the feel of

performing the experiment, real measurement data and simulates the actual laboratory environment in terms of input selection and performance of an experiment. At the same time, virtual experiments also enable theoretical calculations for comparison with actual experimental results, based on the chosen input configurations made by a learner, and other standard parameters. Moreover, a greater number of learners could utilise the same virtual workbench concurrently and take data from the same database (i.e., it is scalable during the deployment).

The measurement based virtual laboratory includes the following components (i) experimental setup, (ii) measurement system, (iii) data base of measurements, (iv) virtual bench with Internet publishing tools, and (v) user computers. Once the virtual test bench is published on the Internet, the user can access the virtual laboratory from a remote location.

Requirements in a measurement based virtual laboratory

To create a measurement based virtual laboratory, there are number of requirements and challenges which leads to the creation of the building blocks and their connections to deploy a virtual laboratory. These requirements include:

1. *A real laboratory*: To create a virtual laboratory we need a real laboratory with adequate experimental setups, different sets of test configurations, a variety of measuring, data-acquisition and analysis instruments, and analysis software.
2. *Software*: Programming software is required which must be powerful and versatile enough to make a virtual test bench with the help of a good GUI (graphical user interface). The software selection for virtualisation is very crucial and the software must have adequate function to fulfill the purpose of imparting feel of laboratory and feel of performing experiments during the virtualisation.
3. *Experimentation and data collection*: This is the core part of the creation of a virtual laboratory. Different experiments are required to be performed with all possible sets of reasonable input configurations and it is required to perform experiment many times with the same input configuration to check the consistency of the result. The experiment must be carried out with extreme care and accuracy, and should follow a standard procedure.
4. *Data storage*: In the collection of experimental data, the number of data sets may become large, which requires a large capacity for data storage and management. These data should contain both good quality data and not so good quality data, so that a learner is attentive about the quality of the data being obtained during virtual experiments.
5. *Virtualisation programming and personnel requirements*: The programming of the virtual experiments requires personnel those who have strong skills in a range of programming software as well as high expertise in measurement and signal processing, and familiarity with the experimental procedure.
6. *Internet publishing*: Publishing of a virtual engine software on the Internet and its testing also involves much technical expertise and patience; especially requiring learner feedback and appropriate revision processes.

7. *Feel of performing an experiment*: This is a major challenge for a virtual lab developer and it requires careful planning to impart the feel of a lab and the satisfaction of performing a virtual experiment.
8. *Learning components*: This is the main objective for a developer: to impart learning and testing components while a user is performing the virtual experiment. In a virtual lab no real instructor is available and the developer has to create a virtual instructor for the user. The virtual programs are designed with an assumption that users are first time users of a virtual experiment. Every step needs to be very clearly explained with respect to fundamental concepts, procedure and what user needs to do in order to progress the experiment. For this purpose, video and audio clips may be provided. The learning components which indicate the basic as well as in-depth knowledge may not be appreciated by the user during first few *real experiments* but in virtual experiments it is very clearly mentioned and demonstrated for better understanding by the user. It may include also examples from daily life and other related facts which will help the user to understand the experiment clearly.

Selection of the software for the virtualisation

The selection of basic platform software is crucial for virtualisation. The software should have enough features to meet the requirements of virtual programming. Some of the required key features of the software are as follows:

- a. *Graphical user interface (GUI)*: Excellent GUI helps the user to understand the experiment better. It provides icons, figures, indications, etc. It makes the programs more user-friendly with the help of graphics;
- b. *Multi-platform portability*: Makes it possible to run the program under different operating systems;
- c. *Modularity*: Allows developing applications in number of parts. The combination of all parts gives the complete program. It reduces complexities in programming and undertaking modifications and editing;
- d. *Compatibility with hardware*: It enables the acquisition of data from different interface hardware. It enables valid connections with hardware equipment for the purpose of data exchange;
- e. *Compatibility with existing code*: It allows running and incorporating programs previously developed for older versions. Because of rapid research and development, software developers may launch updated versions frequently.
- f. *Advanced debugging*: It facilitates the detection of mistakes in the existing code. Advance debugging features helps programmers to quickly check defects and obtain the possible solutions;
- g. *Help options*: This is very helpful for designer during learning to use the software and also to explore the programs. It should provide quick help for the different functions and also should provide the basic programs related to every function;
- h. *Extendable program libraries*: It provides ready made basic programs that can be directly used in any other program. It also enables designer to make programs and save them into the library, for potential use as functions in other programs in the future;
- i. *Multimedia capabilities*: Multimedia tools and objects are essential to play audio and video clips during the program, to help give a real feel of a lab environment. The software should support the multimedia function and connectivity;

- j. *User friendly*: It is a most important factor for software selection. Software must be user friendly and provide easy ways to proceed in program development. The graphical user interface, multimedia application, etc., contribute towards making the program more user friendly.

There are numerous interactive computer-delivered simulations, control, and scientific visualisation solutions software packages that are available for the programming and virtualisation, e.g. *Hypertext*, *Authorware*, *Director*, *Labtech*, *Visual C*, *C++*, *Visual Basic*, *Matlab/Simulink*, *LabVIEW*, etc. *LabVIEW* is a powerful industrial standard graphical development software. For the present virtualisation of a vibration laboratory, this software is found to be suitable because of its following properties and benefits:

- *Easy to learn and use*: The innovative graphical interface makes it efficient learning software and helps the programmer to attain faster development.
- *Complete functionality*: Thousands of built-in analysis functions are available (including in some specialised topics), which makes the programming much easier and compact by using these functions.
- *Integrated I/O capabilities*: The software provides for direct connectivity with the hardware component; it becomes very convenient for data collection. The acquired data can be analysed in different forms as per the requirement.
- *Exploration of concepts*: It provides features by which a user can interactively explore design parameters, investigate solutions, and instrument any algorithm and theory-based relationships to effectively tie theory to practice.
- *Improved learning experience*: The software block diagram looks similar to flow diagrams that are used to teach engineering concepts to students, which leads to a more intuitive transition from these concepts to programming.
- *Integration with hardware to design experiments*: To completely understand the concepts, users need to build systems that interact with real world signals. This provides flexible and robust hardware that students can use in conjunction with the software tool to design and test simple experiments.
- *Accelerated learning*: One can access the tools and functions through interactive palettes, dialogs, menus, and hundreds of function blocks, known as virtual instruments (VIs). One can drag and drop these VIs onto a diagram to define the behaviour of any applications. This 'point and click' approach shortens the time it takes to get from initial setup to a final solution.

The above mentioned properties and functions benefit both programmer and student. *LabVIEW* provides all required tools and functions which can enable the experiments to be virtual and efficient for distance learning. Figure 1 shows a typical GUI capability of this software.

Learning modules in a virtual experiments

Addition of information and learning modules into virtual experiments is one of the challenging tasks for the virtual laboratory developer. Effective learning components should be embedded by various means, not only about the experiment but also related theory. Some of the means by which this may be done include:

- i. Photographs and figures of machines and different instruments are provided in the virtual experiment program, so that users will know the experimental setup, measuring instruments, and the basic information about the overall experimental system.

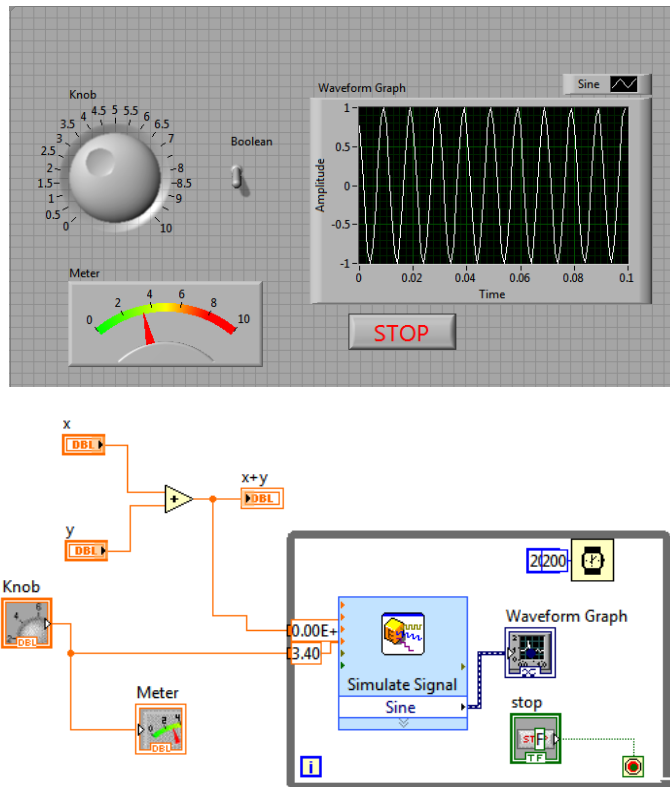


Figure 1: Graphics and I/O control display (upper), and a model of the data flow and its graphical programming (lower)

- ii. Audio and video are also added in the virtual experiment programs. These demonstrate the experiment setup, experimental procedure, instructions, precautions, and all other related information about the experiment.
- iii. Detailed laboratory manuals are provided before starting the experiment. These laboratory manuals are designed to give maximum learning content which include the basic theory behind the experiment, all theoretical and experimental calculations, and step by step procedures for virtual experimentation.
- iv. Learners have to go through the laboratory manual before proceeding to conduct the virtual experiment. At the beginning of the experiment, an evaluation test is required. After successful completion of the experiment, the program again provides an evaluation test. At the end, the program summarises the details of the experiment, including personal information, input parameters, results and marks obtained by the user, and stores it as a report sheet for the user.
- v. Web cameras are provided near the experimental setup to capture and provide online a video record. This help to the user to know more exactly about the setup preparation and also receive a close up view of each component.
- vi. A 'help page' is provided to assist the learner at any step in the program. The learner can navigate to the 'help page' in case of any confusion or if more information is sought.

- vii. For the better visualisation of graphs, a graph palette is provided with a number of ancillary functions. Users can edit the graph, zoom in, and save the graphs and all other data to a local hard disk.
- viii. If the virtual experiment is too easy to perform, then users may complete it very quickly; however, by doing so they may overlook basic concepts and key points in the experiment. To overcome this problem, intermediate evaluation is included to make the learning more interactive and effective.

In virtualisation, one of the most important aims is to give users a feel of performing the experiment. To fulfill this requirement, with the help of the audio and video, a demonstration of the complete experiment is provided. Virtual reality is provided to give control of camera to the user for exploring the laboratory and experimental setup, including 360 degree movement, zooming, and jumping from one designated position to another.

A step by step procedure for virtual experiments

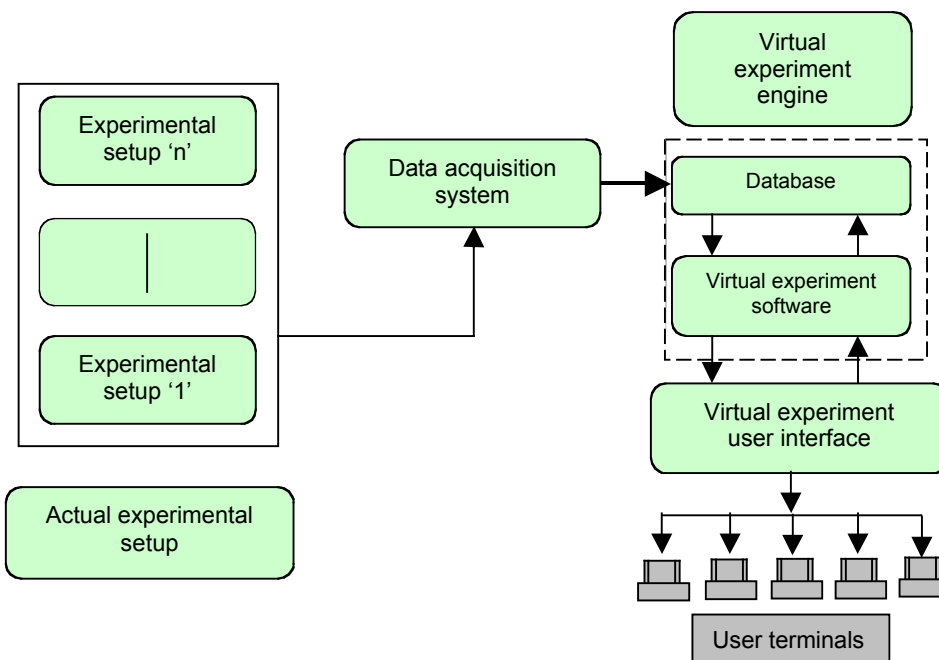


Figure 2: Basic block diagram of virtual experiment development and application

The virtualisation of experiments needs a step by step procedure to be followed as in the case of actual laboratory (Figure 2):

- i. *Arrangement of experimental setup*: The experimental setup is arranged as per the required configuration.
- ii. *Experiments and data collection*: The experiment is performed and data collected by using the measurement hardware and software.
- iii. *Repetition of experiments*: The repetition of experiment is done for the same configuration, and by using all possible combinations of input configurations.

- iv. *Preparation of database:* All the data are collected and processed for preparation of the database.
- v. *Computer programming for virtualisation:* This is the most taxing and carefully planned part of the virtualisation. The programming is done in a sequence which follows the same sequence as in the case of an actual experiment. This virtual engine with data base is published by using the Internet publishing tools of the virtualisation software.

Upon publication the experiment is made ready for access by remote users. The details and outcomes are described below.

1. *Title page:* Figure 3 shows a typical first page for a virtual experiment. It includes the title of experiment, and a photograph of an experimental setup. After starting the program the user has to follow instructions given on each page to complete the virtual experiment successfully.



Figure 3: Title page of a typical virtual test bench

2. *Introduction:* This section contains the aim of experiment, some important definitions related to experiments, and general instructions for the proceeding pages of the virtual program.
3. *Pre-test:* Before starting the virtual experiment, the virtual program offers a test based on the basic information about the experiment. If users qualify, then they may proceed, otherwise they are required to revisit the user manual.
4. *Input section:* This section contains various input options (Figure 4). Some personal information about the user and input parameter options for the experiment are asked at this stage. Users can choose the input configuration, that is the test specimen material, its dimensions, the transducer for the measurement, etc. Users have to select proper inputs to proceed with the virtual experiment. When users enters an input configuration, each parameter generates a specific number and thus forms a set of numbers. Based on the input configuration, the virtual program obtains particular stored measurements of vibration data from the database, related

to that particular configuration. For each experiment's configurations the database contains ten sets of data, which are chosen randomly by the program by. This is to give the users a feeling that even when choosing the same configuration at a subsequent time, they get different sets of data, which would be the case with an actual experiment.

Figure 4: User input section in the virtual test bench

5. *Performing Experiment:* After the proper selection of the input parameters, users perform the experiment. During the experiment the program takes data from the database files. The data is taken as an array and is plotted in the loop one by one by using a script (computer code) inside the loop. These files are read and are plotted in a particular sequence with animation to give the impression of an actual data display on a virtual instrument (Figure 5).

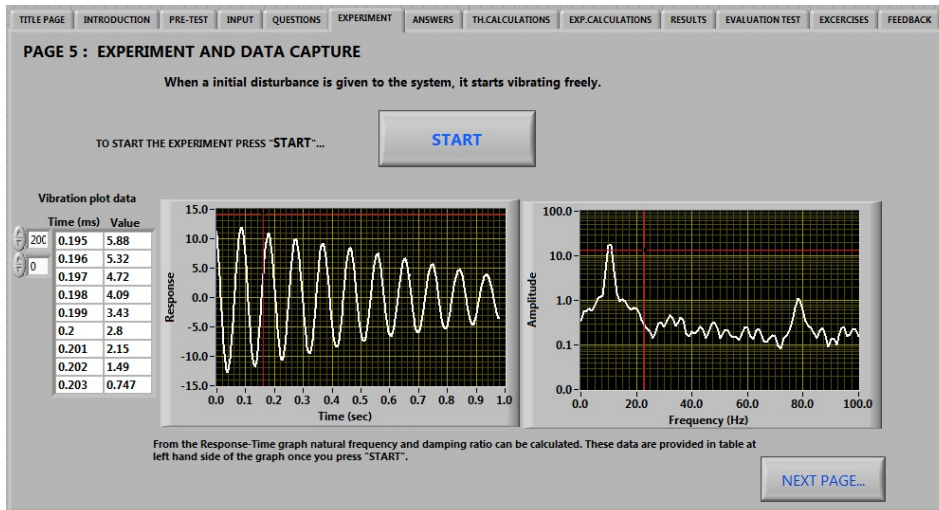


Figure 5: Experiment data presentation in the virtual test bench

6. *Theoretical calculations:* Theoretical calculations are done based on the input configuration chosen by the user. The program decodes the input and generates related physical parameters, for example the Young’s modulus, the density and dimensions of the test specimen. By using these values the theoretical calculations are done with the help of formula provided in detailed manuals.
7. *Experimental calculations:* The experimental data calculations are done by using the data taken by the program randomly from already stored measurements in the database (Figure 6).

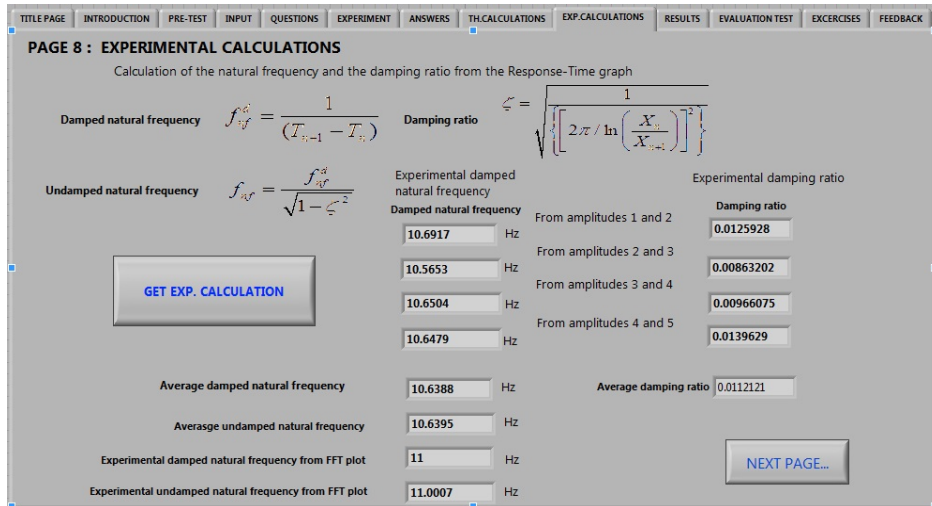


Figure 6: Experimental calculations in the virtual test bench

8. *Results:* The result is basically a comparison of theoretical and experimental results. The comparison is done and the percentage error is calculated. Results are interpreted at this stage as a learning component.

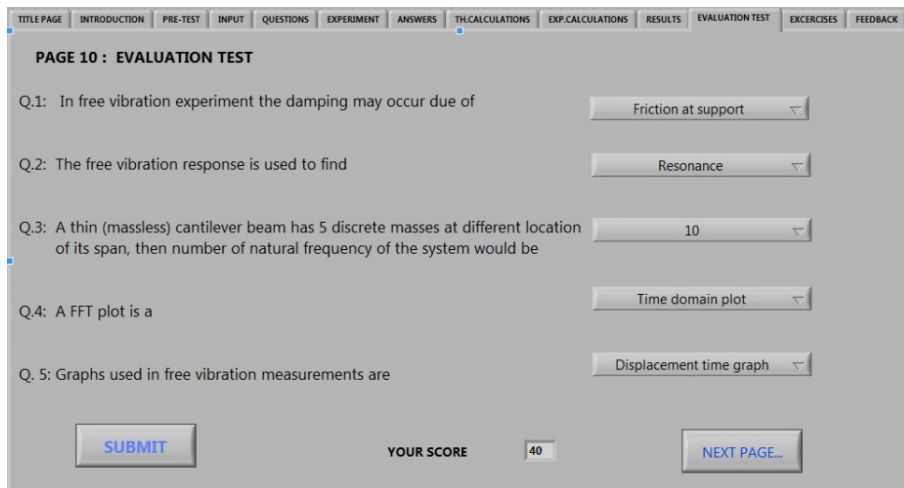


Figure 7: A typical evaluation test to judge the student performance

9. *Evaluation test:* After successful completion of the experiment, the virtual program offers an evaluation test for the user (Figure 7). It gives optional question based on the experiment. It is to check the performance and knowledge gain by the user while performing the virtual experiment.
10. *Exercise:* After evaluation test the program includes some exercise questions related to the experiment. This helps to explore the basic concepts explored by the experiment. The programs also provides answers to the user.
11. *Feedback:* At the end of the experiment, the program asks for the feedback on the experiment (Figure 8). This feedback is quite helpful for the programmer, to enhance the content and gain information about any shortcomings and ideas about improvements.

The screenshot shows a web interface for a virtual test bench. At the top, there is a navigation menu with tabs: TITLE PAGE, INTRODUCTION, PRE-TEST, INPUT, QUESTIONS, EXPERIMENT, ANSWERS, TH.CALCULATIONS, EXP.CALCULATIONS, RESULTS, EVALUATION TEST, EXERCISES, and FEEDBACK. The current page is 'PAGE 12 : FEEDBACK'. It contains six numbered questions, each followed by a dropdown menu with 'EXCELLENT' selected. The questions are:

- How do you rate the online performance?
- To what extent did you have control over the interaction?
- To what degree was the actual lab environment simulated?
- The manuals are found to be helpful
- The result of the experiment were easily interpretable
- The E-experiment is quite helpful for learning

 Below the questions is a section titled 'FEED BACK AND SUGGESTION FOR IMPROVEMENT :' with a large empty text box. To the right of this box is a 'SUBMIT' button. At the bottom of the page, there is a red text message: 'Refresh the page to perform the experiment with a new set of configurations ...'.

Figure 8: Feedback from user in the virtual test bench

12. *Feedback enhancement:* Feedback from users and enhancements to improve the virtual program are continuous processes to make the program more user-friendly, convenient, and illustrative for the maximum benefit to the user.

The pre-test and the evaluation test are included to have a self test of student performance. It gives indirectly some information about the effectiveness of the user manual and the virtual experiment. Also this ensures that students learnt effectively during the experiment. These test questions are selected randomly from a question bank, so that every time a student performs an experiment he or she encounters with questions and may learns more from re-testing.

Feedback sessions and its analysis

For the initial versions of the online virtual laboratory, virtual experimentation and feedback sessions were organised for two different batches of students, one comprising students who had never performed this experiment in a real laboratory class (Batch-I) and the other class students who had experienced this experiment previously in a real laboratory class (Batch-II). However, all of these students had some theoretical

background in the subject. A terminal was provided to a group of two students, with a copy of the feedback form for each student and there were total twelve such groups. The aim in using the two batches was to enable a comparison of the responses to the remote experiment from beginners and more experienced users.

The feedback was obtained from questions related to various aspects of the virtual programs. It included questions regarding online performance of experiments, control over experiment, simulated laboratory environment, effectiveness of the user manual, ease of interpretation of the results, understanding of experiments and related topics, the feel of performing experiments, availability of related extra information, and any major problems encountered. Questions were asked also about the feel of an actual lab, feel of absence of instructor, user friendliness and navigational aspect, effectiveness of content, sequence of the performing steps, and challenges faced in the virtual lab compared with a real lab. This comprehensive feedback is summarised in a Table 1 for the quantitative feedback and analysed below for the qualitative feedback.

From Table 1 and Figure 9, it can be observed that the average rating from Batch-I students was better than from Batch-II. The Batch-I rating was narrow from 'Good' to 'Excellent'; however, Batch-II rating was wider from 'Average' to 'Excellent'. It is due probably to Batch-II having an earlier, real experiment available for comparison. Apart from this qualitative feedback, comments were gathered from the students and were used to improve the technical quality, navigation, and aesthetics aspects. Most of the users who performed real experiments commented that it is effective utilisation of time with the same level of learning attained. Most users agreed to that and were enthusiastic to work further on virtual experiments.

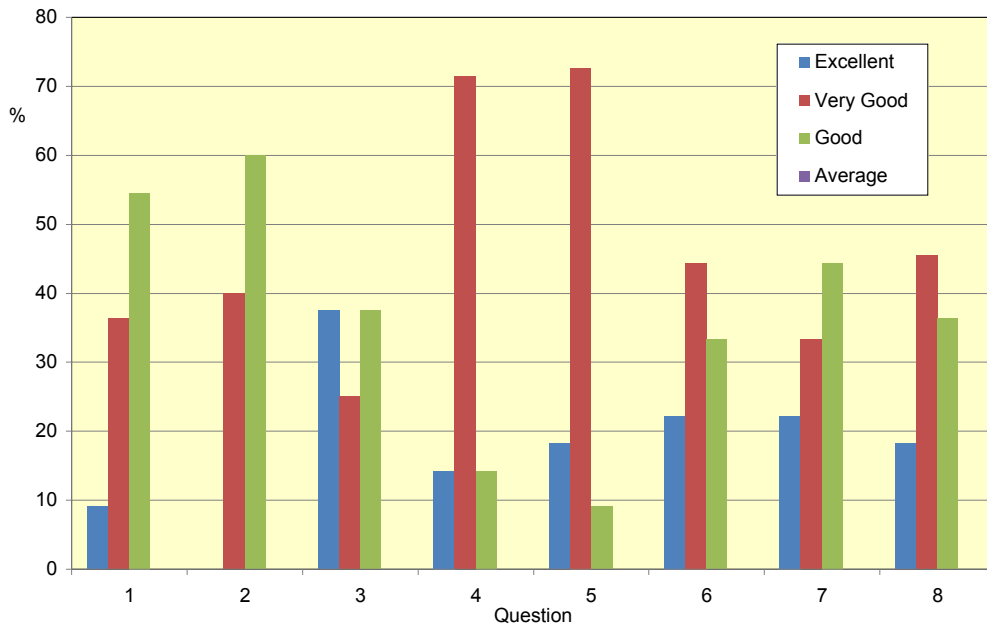
Table 1: Summary of feedback in percentage on effectiveness of the virtual laboratory (first version)

Question		Excellent		Very good		Good		Average	
		NU	EU	NU	EU	NU	EU	NU	EU
1.	Rate the online performance of the experiment	9.1	16.6	36.4	5.5	54.5	61.1	0	16.6
2.	User control	0	5.55	40	27.7	60	55.5	0	11.1
3.	Actual lab environment simulated	37.5	17.6	25	41.1	37.5	29.4	0	11.7
4.	User friendliness and ease in acquiring data	14.3	16.6	71.4	50	14.3	27.7	0	5.5
5.	Quality of lab manuals	18.2	36.8	72.7	15.7	9.1	42.1	0	5.2
6.	Information related with the objective of the experiments	22.2	16.6	44.4	33.3	33.3	38.8	0	11.1
7.	Interpretability of results	22.2	16.6	33.3	38.8	44.4	38.8	0	5.5
8.	A substantial gain in understanding of experiments and related topics	18.2	16.6	45.5	50	36.4	27.7	0	5.5

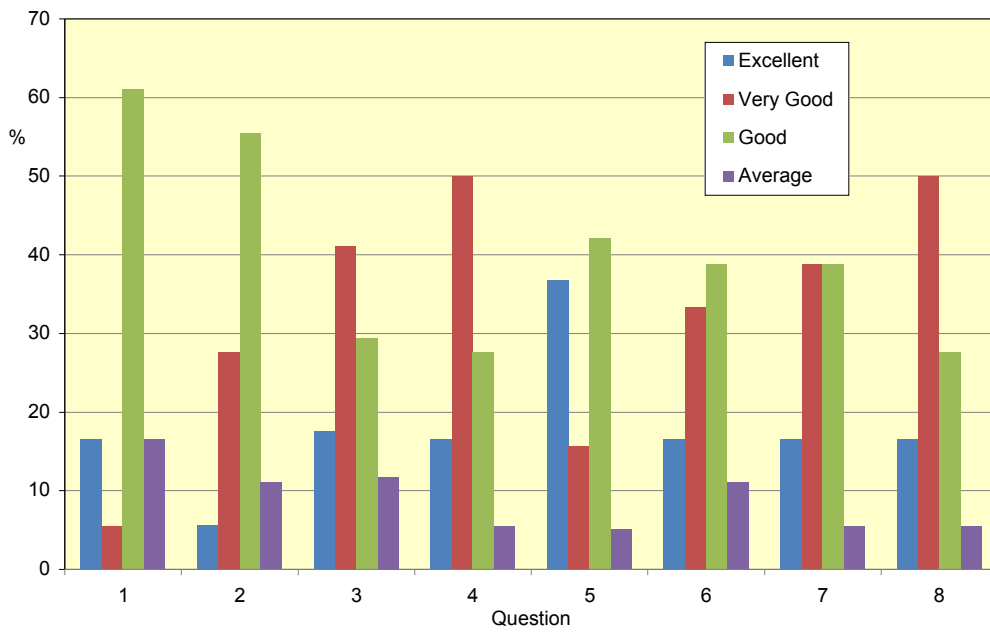
NU: New user Batch I (never did real experiments on vibration lab; n=11);

EU: Experienced user Batch II (already done vibration lab; n=18)

Based on the first round of feedback, the virtual lab site and virtual experiments were improved. The second version of the online virtual laboratory was provided to two new batches of students (Batch III and IV). The feedback is summarised in Table 2 and Figure 10. There is good improvement in the feedback ratings from both batches, namely no previous experience (Batch I versus Batch III) and previous exposure to real experiments prior to performing the virtual experiments (Batch II versus Batch IV). From the statistics is clear that students accepted the concept of virtualisation and also they appreciated the usefulness of it for remote learners.



a. New user (Batch I; n=11)



(b) Experienced user (Batch II; n=18)

Figure 9: Summary of feedback from learners for the first version of virtual lab (Parameters 1 to 8 are corresponding to Table 1)

Table 2: Summary of feedback in percentage on effectiveness of the virtual laboratory (second version)

Question	Excellent		Very good		Good		Average	
	NU	EU	NU	EU	NU	EU	NU	EU
1. Rate the online performance of the experiment	42.9	54.5	28.6	45.5	28.6	0	0	0
2. User control	14.3	36.3	35.7	36.3	42.9	27.3	7.1	0
3. Actual lab environment simulated	14.3	27.3	50.0	45.5	28.6	18.2	7.1	9.1
4. User friendliness and ease in acquiring data	57.1	63.6	35.7	27.3	7.1	9.1	0	0
5. Quality of lab manuals	42.9	36.3	21.4	36.3	35.7	18.2	0	9.1
6. Information related with the objective of the experiments	42.9	45.5	42.9	18.2	14.3	18.2	0	18.2
7. Interpretability of results	57.1	36.3	7.1	54.5	28.6	9.1	7.1	0
8. A gain in understanding of experiments and related topics	71.4	45.5	14.3	27.3	14.3	27.2	0	0

NU: New user Batch III (never did real experiments on vibration lab; n=14);

EU: Experienced user batch IV (already did vibration lab; n=11)

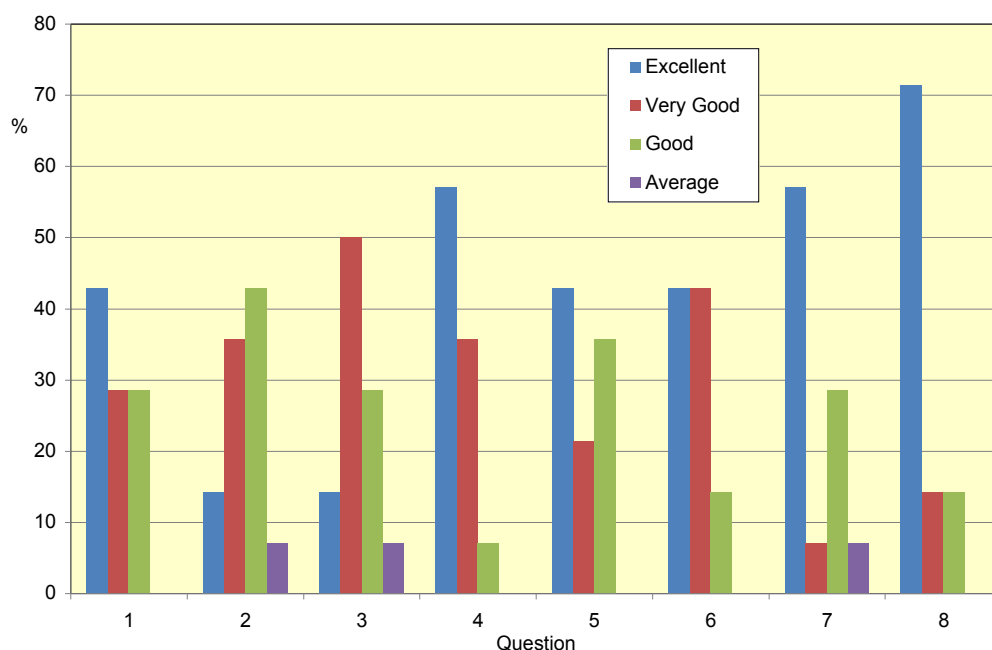


Figure 10a. New user (Batch III; n=14)
(Parameters 1 to 8 are corresponding to Table 2)

The feedback also included responses to several descriptive questions related to helpfulness, difficulties, personal experiences and suggestions. These descriptive answers or suggestions were analysed to help with enhancing the effectiveness of learning. Expressions of appreciation were common, but there were also many suggestions for improvement. Most of the suggestions concerned the addition of animation, and obtaining clearer views and explanations of experiments, plots and results.

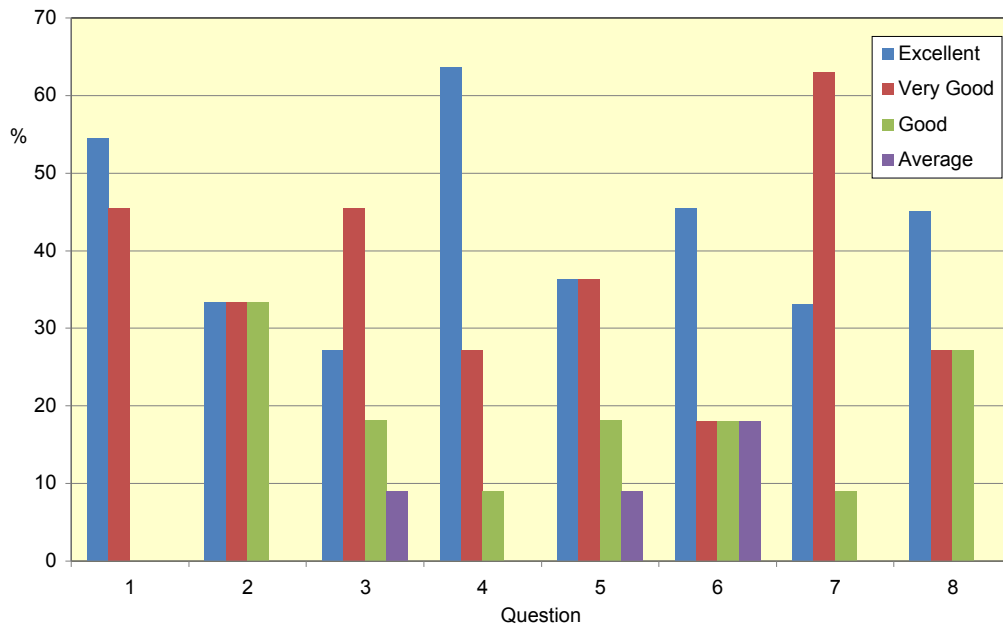


Figure 10b. Experienced user (Batch IV; n=11)

Figure 10: Summary of feedback from learners for the second version of the virtual lab (Parameters 1 to 8 are corresponding to Table 2)

Enhancing the effectiveness of the virtual programs

The analysis of feedback is taken into consideration to enhance the effectiveness of the virtual programs. From the user feedback, needs were identified for a more user friendly approach, additional graphical interfaces, and improvements in the sequencing and format of representation in various sections. The pages are updated and the complete virtual programs are improved according to the requirement. Now the experiment ready for demonstration and testing in a larger domain. The online feedback at the end of experiment and through the website are very important for further enhancement of the virtual programs. These could be improved enough to provide quality education at minimum cost and with high effectiveness of learning and knowledge transfer.

Conclusions

The present paper recommends measurement based virtualisation as the most effective way to deploy the virtual experiments. The present paper focuses on the requirement of modernisation of the laboratory in terms of the state of the art educational technology and providing the most effective practical experience of the theoretical concepts. In the present work, the several engineering experiments of a typical engineering lab have been virtualised. This includes detailed documentation of the experiment, student's performance evaluation, and feedback from the target users. The developed programs have been published into the Internet [<http://www.vlab.co.in/>] by using a software tool for web publishing. This tool provides a facility to publish the

programs into the Internet, which are now accessible from anywhere by using any Internet connection. Since the present virtual experiments are for a single user with no interactions with multiple users; the future research could involve virtual experiments with collaborative and distributed scenarios, especially development of tools for interactions and collaborations. The challenges in virtual laboratories are enormous and in future it will grow further with potential development into mobile technology based experiments.

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References

- Agelidis, V. G. (2005). A laboratory-supported power electronics and related technologies undergraduate curriculum for aerospace engineering students. *International Journal of Engineering Education*, 21(6), 1177-1188. [abstract only]
<http://www.ijee.ie/covers/covandabs21-6.pdf>
- ALCOM Education Project (2002). *Online Experiments*. <http://olbers.kent.edu/alcomed>
- Almgren, R. C. & Cahow, J. A. (2005). Evolving technologies and trends for innovative online delivery of engineering curriculum. *International Journal of Online Engineering*, 1(1).
<http://online-journals.org/index.php/i-joe/article/view/292>
- De Araujo, M., Antunes, J. & Piteau, P. (1998). Remote identification of impact forces on loosely supported tubes: Part 1 - basic theory and experiments. *Journal of Sound and Vibration*, 215(5), 1015-1041. <http://dx.doi.org/10.1006/jsvi.1998.1618>
- Antunes, J., Paulino, M. & Piteau, P. (1998). Remote identification of impact forces on loosely supported tubes: Part 2 - complex vibro-impact motions. *Journal of Sound and Vibration*, 215(5), 1043-1064. <http://dx.doi.org/10.1006/jsvi.1998.1619>
- Bachnak, R., Steidley, C. & Resendez, K. (2003). Virtual experiment in data acquisition, display, and monitoring. *Proceedings of the 2003 ASEE Gulf-Southwest Annual Conference*. The University of Texas at Arlington, American Society for Engineering Education.
- Bauer, P., Dudak, J. & Maga, D. (2006). Distance practical education with DelftWebLab. *12th International Power Electronics and Motion Control Conference, EPE-PEMC 2006*, Portoroz. pp.2111-2117. <http://dx.doi.org/10.1109/EPEPEMC.2006.4778719>
- Bauer, P. & Fedák, V. (2007). Implementation of e-learning platform for distance practical education in electrical engineering. *5th International Conference on Emerging e-learning Technologies and Applications*. The High Tatras, Slovakia, 6-8 September.
<http://repository.tudelft.nl/assets/uuid:ab5558ce-9efd-4ed0-8391-f0507de904fc/211538.pdf>
- Bauer, P., Fedák, V., Hajek, V. & Lampropoulos, I. (2008). Survey of distance laboratories in power electronics. *IEEE 39th Annual Power Electronics Specialists Conference*. Rhodes, 15-19 June. <http://dx.doi.org/10.1109/PESC.2008.4591967>
- Bauer, P., Fedák, V. & Rompelman, O. (2008). PEMCWebLab: Distance and virtual laboratories in electrical engineering: development and trends. *13th International Power Electronics and Motion Control Conference*. Poznan, 30 September.
<http://dx.doi.org/10.1109/EPEPEMC.2008.4635615>

- Bishop, R. (2001). *LabVIEW Student Edition 6I*. New York: Prentice Hall.
- Buckman, A. B. (2000). VI-based introductory electrical engineering laboratory course. *International Journal of Engineering Education*, 16(3), 212-217. <http://www.ijee.ie/articles/Vol16-3/ijee1125.pdf>
- Che, A. J. (2005). Remote biology labs. *International Journal of Engineering Education*, 16, 181-192. [verified 27 Jul 2011] <http://austinche.name/docs/remotebioblab.pdf>
- Christian, W. & Belloni, M. (2001). *Physlets: Teaching physics with interactive curricular material*. Upper Saddle River, NY: Prentice Hall.
- Coito, F, Gomes, L. & Costa, A. (2007). Simulation, emulation and remote experiments. *Proceedings of the Workshop on using VR in Education*. Lisboa, pp. 99-110. [verified 27 Jul 2011; 4.8 MB] <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.112.509&rep=rep1&type=pdf#page=99>
- Cui, S., Wang, Y., Zhang, Y. & Akujuobi, C. (2008). Laboratories enhancement with LabView-based graphical development tools. In *American Society for Engineering Education Annual Conference*. <http://soa.asee.org/paper/conference/paper-view.cfm?id=7830>
- de Castro, L. N. & Rosatelli, M. C. (2008). Virtual laboratories as tools for supporting teaching and learning activities, Guest Editor Preface. *International Journal of Distance Education Technologies*, 6(2), i. [verified 28 Jul 2011] [http://www.igi-global.com/Files/Ancillary/JDET%20preface%206\(2\).pdf](http://www.igi-global.com/Files/Ancillary/JDET%20preface%206(2).pdf)
- E-learning Distance Interactive Practical Education – EDIPE* (undated). Project of the European Community Leonardo da Vinci Vocational Training Programme. <http://www.powerweblab.com/>
- Egarievwe, S., Okobiah, O., Ajiboye, O., Fowler, L., Thorne, S. & Collins, W. (2000). Internet application of LabVIEW in computer based learning. *European Journal of Open and Distance Learning* 2000. <http://www.eurodl.org/materials/contrib/2000/icl2000/egarievwe/internet.html>
- Ertugrul, N. (1998). New era in engineering experiments: An integrated and interactive teaching/learning approach and real-time visualizations. *International Journal of Engineering Education*, 14(5), 344-355. <http://www.ijee.ie/articles/Vol14-5/ijee1027.pdf>
- Ertugrul, N. (2000). Towards virtual laboratories: A survey of LabVIEW-based teaching/learning tools and future trends. *International Journal of Engineering Education*, 16(3), 171-180. <http://www.ijee.ie/articles/Vol16-3/ijee1116.pdf>
- Ertugrul, N. & Henry, J. (2000). Special issue: LabVIEW applications in engineering education. *International Journal of Engineering Education*, 16(3). <http://www.ijee.ie/contents/c160300.html>
- Fernandez, C., Vicente, M. A. & Jimenez, L. M. (2005). Virtual laboratories for control education: a combined methodology. *International Journal of Engineering Education*, 21(6), 1059-1067. http://www.ijee.ie/latestissues/Vol21-6/07_ijee1706.pdf
- Feisel, L. & Rosa, A. (2005). The role of the laboratory in undergraduate engineering education. *International Journal of Engineering Education*, 94(1), 121-130. [verified 27 Jul 2011] <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.134.3555&rep=rep1&type=pdf>
- Fountain, T. & Wright, R. (2000). Internet enabled measurements. *Dedicated Systems Magazine*, 2000 Q4. http://www.omimo.be/magazine/00q4/2000q4_p072.pdf
- Gadzhanov, S. & Nafalski, A. (2010). Pedagogical effectiveness of remote laboratories for measurement and control. *World Transactions on Engineering and Technology Education*, 8(2), 162-167. [http://www.wiete.com.au/journals/WTE&TE/Pages/Vol.8,%20No.2%20\(2010\)/6-15-GADZHANOV.pdf](http://www.wiete.com.au/journals/WTE&TE/Pages/Vol.8,%20No.2%20(2010)/6-15-GADZHANOV.pdf)

- Gergic, B. & Hercog, D. (2006). Virtual instruments for remote experiments visualization. *International Symposium Remote Engineering Virtual Instrumentation*. Maribor, Slovenia, 29-30 June. [verified 27 Jun 2011] <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.1985&rep=rep1&type=pdf>
- Gillet, D., Nguyen Ngoc, A. V. & Rekik, Y. (2005). Collaborative web-based experimentation in flexible engineering education. *IEEE Transactions on Education*, 48(4), 696-704. <http://dx.doi.org/10.1109/TE.2005.852592>
- Glava, A. E. & Glava, C. C. (2009). Best practices in design and delivery of school learning situations based on virtual instrumentation experiments in science education. *Proceedings of the Fifth International Conference on Multimedia & ICTs in Education*. Lisbon, Portugal, 22-24 April 2009. <http://www.formatex.org/micte2009/book/699-704.pdf>
- Gomes, L. & Garcia-Zubia, J. (Eds) (2007). *Advances on remote laboratories and e-learning experiences*. Bilbao: University of Deusto. [verified 28 Jul 2011; 3.4 MB] https://www.weblab.deusto.es/Advances_on_remote_labs.pdf
- Gröber, S., Vetter, M., Eckert, B. & Jodl, H.-J. (2007). Experimenting from a distance — remotely controlled laboratory (RCL). *European Journal of Physics*, 28(3), S127-S141. <http://dx.doi.org/10.1088/0143-0807/28/3/S12>
- Herrera, O. & Fuller, D. A. (2011). Collaborative model for remote experimentation laboratories used by non-hierarchical distributed groups of engineering students. *Australasian Journal of Educational Technology*, 27(3), 428-445. <http://www.ascilite.org.au/ajet/ajet27/herrera.html>
- Hofmann, J. & Bubb, H. (2003). Presence in industrial virtual environment applications - susceptibility and measurement reliability. *Journal of the 3D-Forum Society*, 16(4), 117-122. [verified 28 Jul 2011] http://www.vepsy.com/communication/book4/4_16HOFMAN.PDF
- Intel (2006). Intel virtualization technology. *Intel Technology Journal*, 10(3). <http://www.intel.com/technology/itj/2006/v10i3/index.htm>
- Jeschke, S., Richter, T. & Sinha, U. (2008). Embedding virtual and remote experiments into a cooperative knowledge space. *38th Annual ASEE/IEEE Frontiers in Education Conference*. Saratoga Springs, NY. <http://dx.doi.org/10.1109/FIE.2008.4720356>
- Kolias, V., Anagnostopoulos, I. & Kayafas, E. (2007). Remote experiments in education: A survey over different platforms and application fields. *11th International Conference on Optimization of Electrical and Electronic Equipment*. 22-24 May 2008, Brasov, Romania. pp. 181-188. Digital <http://dx.doi.org/10.1109/OPTIM.2008.4602519>
- Lerro, F. G. & Protano, M. D. (2007). Web-based remote semiconductors devices testing laboratory. *International Journal of Online Engineering*, 3(3), 161-164. <http://online-journals.org/index.php/i-joe/article/view/432>
- Machotka, J., Nedic, Z., Nafalski A. & Göl, Ö. (2010). Collaboration in the remote laboratory NetLab. In *1st WIETE Annual Conference on Engineering and Technology Education*. Pattaya, Thailand, 22-25 February. http://www.wiete.com.au/conferences/1st_wiete/6-20-Machotka.pdf
- Macías, M. E. & Méndez, I. (2008). TeleLab - Remote automations lab in real time. *38th ASEE/IEEE Frontiers in Education Conference*. Saratoga Springs, NY. <http://fie-conference.org/fie2008/papers/1360.pdf>
- National Instruments (undated). Taking your measurements to the web with LabView. <http://www.ni.com/labview/>
- Overstreet, J. & Tzes A. (1998). Internet-based client/server virtual instrument designs for real-time remote-access control engineering laboratory. *American Control Conference*, Philadelphia. [verified 27 Jul 2011] <http://discoverlab.com/References/ot98csm.pdf>

- Pheatt, C. B. & Balleste, J. L. (2003). Developing web-based experiments. *Journal of Computing Sciences in Colleges*, 18(4), 238-245.
<http://portal.acm.org/citation.cfm?id=767638&CFID=32599583&CFTOKEN=97979995>
- Resendez, K. & Bachnak, R. (2003). LabVIEW programming for Internet-based measurements. *Journal of Computing Sciences in Colleges*, 18(4), 79-85.
<http://portal.acm.org/citation.cfm?id=767613>
- Sakata, S., Totsuka, T., Kiyono, K., Oshima, T., Sato, M. & Ozeki, T. (2008). Progress of data processing system in JT-60: Development of remote experiment system. *Fusion Engineering and Design*, 81(15-17), 1775-1778. <http://dx.doi.org/10.1016/j.fusengdes.2006.04.006>
- Salzmann C., Gillet, D., Latchman, H. & Crisalle, O. (1999). Online engineering laboratories: Real time control over the Internet. *Proceedings of the ASEE Annual Conference & Exposition*, Session 2532.
- Tan, A. C. C., Tang, T. & Paterson, G. (2008). Web-based remote vibration experimental laboratory. In G. Varady (Ed.), *Proceedings of the International Conference on Engineering Education (ICEE2008)*, 27-31 July 2008, Hungary, Pecs-Budapest.
http://www.iceehungary.net/download/fullp/full_papers/full_paper11.pdf
- Trevelyan, J. (2002). Towards cost effective on-line laboratories. *Proceedings of 2002 Network Learning Conference (NL2002)*, Berlin, May 2002. [verified 28 Jul 2011]
<http://telerobot.mech.uwa.edu.au/Information/Trevelyan-NL2002.pdf>
- Trevelyan, J. (2004). Lessons learned from 10 years experience with remote laboratories. *International Conference on Engineering Education and Research "Progress through Partnership" VSB-TUO, Ostrava*. [verified 28 Jul 2011; 1.6 MB]
<http://www.ineer.org/Events/ICEER2004/Proceedings/papers/0687.pdf>
- Travis, F. (2000). *Internet applications in LabView*. Upper Saddle River, NJ: Prentice Hall.
- Virtual Labs (undated). An Initiative of Ministry of Human Resource Development, Government of India. Under the National Mission on Education through ICT. <http://www.vlab.co.in/>
- Yeung, K. & Huan, J. (2003). Development of a remote-access laboratory: A DC motor control experiment. *Computers in Industry*, 52(3), 305-311. [http://dx.doi.org/10.1016/S0166-3615\(03\)00133-7](http://dx.doi.org/10.1016/S0166-3615(03)00133-7)

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