DEVELOPMENT AND EVALUATION OF PERSONALISED REMOTE EXPERIMENTS IN AN ENGINEERING DEGREE

M. C. Levesley, P. Culmer, K. Page, J. Gallagher, A. P. H. Weightman, B. B. Bhakta, A. Tennant
University of Leeds, Leeds, LS2 9JT, UK

P. Cripton
Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada

Keywords: e-Learning, Remotely Operated Experiments, Web-based Learning and Teaching Technologies.

Abstract: A system to allow remote access to experimental equipment via the internet has been developed at the University of Leeds in the UK. This system, called *ReLOAD* (Real Labs Operated At a Distance), has been used to deliver laboratory sessions to over 200 undergraduate engineering students at the University of British Columbia, using laboratory equipment located at Leeds. The laboratory sessions were developed from well established *face-to-face* sessions used at the University of Leeds for many years. New equipment was built and a personalised experiment for each student was generated to ensure student's learning objective remained the same but the data used to present the experimental problem varied. As part of the experiment, students were asked to determine the length of a vibrating beam from their experimental data. Using prizes for the closest answer to the measured length as an incentive, students were asked to record their calculated beam length, to assess their performance. A web-based student feedback system was developed to provide anonymous feedback. Initial results are very encouraging, with students able to undertake remote experimentation with high levels of measurement precision and feedback suggesting the system easy to use. Further experiments and international collaborations are underway using *ReLOAD*.

1 INTRODUCTION

In many engineering degrees across the world, particularly at undergraduate levels, extensive use is made of laboratory based teaching sessions. Within these sessions both *cognitive* skills (knowledge, information analysis etc.) and *psychomotor* skills (physical skills, such as the use of tools and equipment) are developed. Even in well funded universities, where numerous copies of laboratory equipment are available and the timetable allows multiple sessions, students find that access to laboratory equipment is still limited. For example, a student may find that after having collected some initial data, they may wish to repeat some part of their experiment in order to confirm their findings. With congested timetables and shortage of laboratory space, this may not always be feasible. As an alternative, some Universities have chosen to replace laboratory sessions with hi-fidelity simulations that can be accessed more easily, However restrictions on software licenses and increased pressures on computer clusters, does not guarantee unlimited access and allow students the ability to obtain results from *real* experimental equipment such as that they may encounter on leaving university. Moreover it is often the highly practical *'real world'* experiments that many engineering students find particularly interesting and exciting, rather than just simulations. In addition, with an increasing number of strategic alliances between major universities being developed, sharing learning resources makes economic sense, allowing more efficient use of equipment and a greater variety of learning activities. In addition to initiatives such as MIT/Cambridge iLab, A number of European institutions have begun to include web based experimentation as pert of their curriculum. Over the last 7 years, the University of Leeds has been developing a system that allows access to the School

C. Levesley M., Culmer P., Page K., Gallagher J., P. H. Weightman A., B. Bhakta B., Tennant A. and Cripton P. (2007).
DEVELOPMENT AND EVALUATION OF PERSONALISED REMOTE EXPERIMENTS IN AN ENGINEERING DEGREE.
In *Proceedings of the Third International Conference on Web Information Systems and Technologies - Society, e-Business and e-Government / e-Learning*, pages 330-337
DOI: 10.5220/0001278003300337

of Mechanical Engineering's excellent experimental equipment via the internet. Initially intended for Leeds students only, it has now been extended to students from other universities.

2 SYSTEM REQUIREMENTS

The following requirements were identified as being important to enable successful remote operation of experiments in an educational environment.

The system developed should be

- simple, reliable, robust and easily maintainable.
- modular, allowing existing experiments to be adapted and modified and new ones to be developed rapidly.
- able to deliver personalised experiments, either to a group or an individual user.

The user should be able to

- access experimental equipment remotely without the need for specialist software or hardware.
- plan and conduct either a single or a series of experiments.
- select and vary key input parameters and select which key measurements are to be taken.
- be convinced that the results are as a result of real experimentation and not simulation.

3 SYSTEM OVERVIEW

In recent years, data acquisition and data output to external sensors and devices has become more cost effective and reliable. Further, the development of computer communication networks now make it relatively straightforward for one computer to communicate rapidly with another across both relatively small and large distances, using local area networks (LANs) or the internet. There are numerous ways in which remote experiments can be configured. At Iowa State University for example, a program was developed for primary and secondary schools to access a Scanning Electron Microscope through the internet (Chumbley, 2002). This system allowed visual control of the microscope but didn't allow much user input or control. At the Stevens Institute of Technology distance learning modules were accompanied by LabVIEW programs to give virtual results and pre-recorded experimental results to compare (Esche, 2001). Another scheme developed by the Massachusetts Institute of Technology called iLab (Harwood, 2004) uses a downloadable Java applet to connect to a lab server and run experiments. The data is returned to the applet for analysis. All of these systems rely on a client machine for viewing, a central server and an experiment machine for data acquisition.

The approach taken here to fulfil the requirements identified in section 2 is depicted in Figure 1 (Levesley, 2006). Each piece of equipment is connected physically to a local computer (the Experiment Servers) via data acquisition cards and appropriate cabling. Each experiment server runs software to drive and monitor the particular pieces of equipment attached to it, this may be a single piece of equipment or multiple pieces. In addition each Experiment Server is connected to the school's local area network to allow it to communicate with a central server (the *ReLOAD* Server).

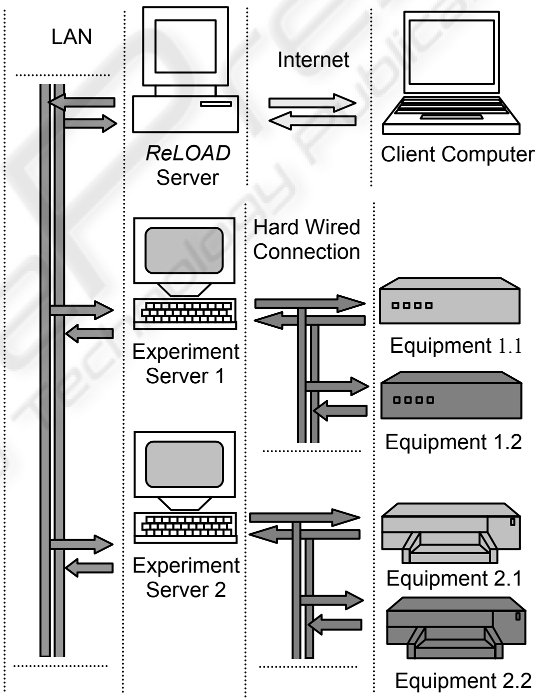

Figure 1: *ReLOAD* Remote Experiment Structure.

The *ReLOAD* Server is in fact split into two physical devices, a Server PC and a Web Server PC. The Server PC handles exchange from the Experiment Servers and a Web Server PC which acts as an internet website host allowing direct access from the remote client machines. In this way a remote client can select an experiment they wish to perform from those currently available on the *ReLOAD* Server, which passes their request to the appropriate Experiment Server. This then controls the correct piece of equipment and monitors and stores data from it. Data is then processed, which and passed back to the *ReLOAD* Server for final delivery to the correct client.

3.1 *ReLOAD* Server

The *ReLOAD* Web Sever receives and process requests from the client. The mechanism by which data is transmitted and received from the client computer has significant impact on the system's functionality and versatility. Several alternative methods have been proposed previously, ranging from the use of Active-X [Hites, 2002] to Java applets [Sanchez, 2000] to control experiments. To achieve the requirement of creating a reliable and easily maintainable system, the approach taken here has been to develop as simple a system as possible, while still allowing an appropriate level of interaction with the remote experiment. A standard web form is used at the client end to generate a request for an experiment, which is subsequently used to retrieve and view the associated results. The client computer requires standard Java support but only to view the video feedback if requested. Once a request has been sent to the appropriate Experiment Server the *ReLOAD* Server is free to process the next request, while the current experiment is run.

3.2 Experiment Server

The Experiment Server controls the experimental equipment attached to it and transfers data via the LAN to the *ReLOAD* Server. Upon receiving a request from the *ReLOAD* Server, the Experiment Server sends commands, via a digital to analogue data acquisition card, to initiate an experiment. Data from various sensors attached to the equipment is recorded via the data acquisitions cards and stored on the Experiment Server. In addition, data captured from a webcam may also be recorded simultaneously. On completion of the experiment the data is passed back to the *ReLOAD* Server and is then ready to receive another request. The Experiment Servers are located in close proximity to the equipment and are also used for display purposes, showing data regarding the experiment currently being run along with live video images from the webcam. This allows those at the hosting institute to observe the experiments being requested remotely.

3.3 System Software

The software platform LabVIEW, was selected to develop the software required on both the *ReLOAD* Server and the Experiment Servers. Although LabVIEW allows control panels to be embedded within web pages, using Active-X components or plug-ins, depending on the client browser type, an alternative approach was developed here. Using the Internet Toolkit, CGI (common gateway interface) scripts were developed to allow the client to enter data into various fields in a '*request'* web-page and then post it to the *ReLOAD* Server. Once posted the client's web browser will await a response in the form of a '*results'* web-page. This frees up the *ReLOAD* Server to process another request, making it more efficient but at the expense of allowing real-time, fully interactive control of the equipment. LabVIEW is also used for capturing data from sensors and controlling actuators. Software routines (known as VI's in LabVIEW) written specifically for each experiment, interpret commands received from the *ReLOAD* Server and convert these into analogue and digital signals which are outputted to actuators attached to the experimental equipment. Separate VI's record data from sensors, process and pass it back to the *ReLOAD* Server.

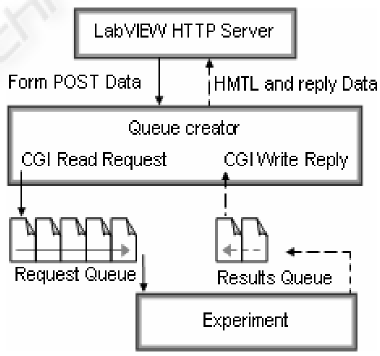

Figure 2: The Queue Communication Process.

One of the most important tasks for the software is to manage the requests for experiments in an efficient way. A queuing system has been implemented, see Figure 2, to ensure the experiments are conducted in an appropriate order. Two queues store and order incoming experiments and outgoing results. When the server receives data posted from the 'request' web-page it is added to the back of the request queue. When the experimental apparatus is ready to conduct an experiment it removes the oldest request from the queue and uses the parameters given. When the experiment finishes a 'results' web-page is placed at the back of the results queue. Both queues operate on a first in, first out basis. The queue creator constantly waits for entries in the results queue and sends them back to the user as soon as they are received.

4 EXPERIMENTAL EQUIPMENT

The example chosen to demonstrate the *ReLOAD* system is one in which students are asked to study how the vibration characteristics of a vibrating beam are changed, when a large mass is added to the *free* end of the beam. This experiment is based on one used as a *face-to-face* laboratory session in a level 2 module, Vibration and Control (MECH2170), as part of an undergraduate engineering degree programme at Leeds. In the *face-to-face* laboratory session, students manually displace the free end of the beam and then release it. The resulting vibrations are measured using strain gauges mounted on the beam's surface, which give a signal proportional to the displacement of the beam. The students are then given a permanent magnet which they attach to the free end of the beam. They then repeat the experiment. By observing the two sets of data, students can see the effect of adding mass to the system. Further, by careful measurement of the resulting frequencies of vibration and by knowing the exact amount of mass added, by weighing the magnet, students can then calculate experimental values for the stiffness and vibrating mass of the beam. They are then required to measure the size of the beam and from this data, determine theoretical values. Finally students are encouraged to compare their experimentally derived values of stiffness and vibrating mass with their theoretically derived values. Clearly, certain aspects to this *face-to-face* session can not be reproduced exactly, for example it is not possible for the *'remote'* students to physically measure the dimensions of the beam, the added mass of the magnet, or to displace the beam manually. Rather than simply try and reproduce the *face-to-face* experiment as closely as possible, the key learning objectives of the experiment were maintained while the tasks and equipment required were amended to suit the remote nature of the proposed session.

The purpose made equipment developed to allow this was designed and built by staff and students of the School of Mechanical Engineering at Leeds and is shown in Figure 3. A pulse sent to the electromagnet, is used to commence the experiment by displacing the *free* end of the beam, then releasing it. The user can adjust the magnitude of the pulse signal sent to the electromagnet so that tests at various amplitudes of vibration can be undertaken. In addition the user can select the period of time over which the experimental data is collected and whether or not they wish to see a video clip showing the movement of the beam.

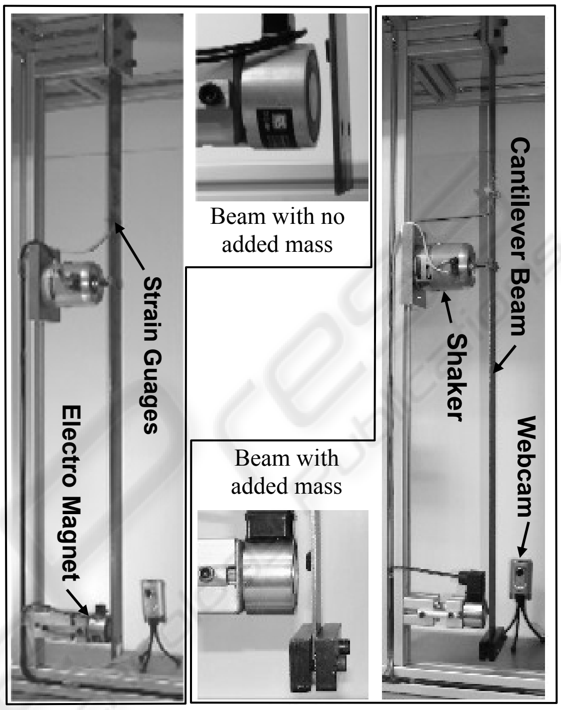

Figure 3: Experimental Equipment.

To allow the effect of adding mass to be observed, two identical beams are available for testing, the only difference being, that one has a know mass fixed to its free end. The exact value of this mass is given to the student. As in the *face-to-face* session, by careful measurement of the resulting frequencies of vibration and by knowing the exact amount of mass added, students can now calculate experimental values for the stiffness and vibrating mass of the beam, from a series of remote experiments. Rather than simply give students the dimensions of the beam and ask them to calculate theoretical values, students were only given two of the required three dimensions (width and depth). Using their experimentally derived values of stiffness and vibrating mass students were then required to use theoretical expressions to estimate the length of the beam. To add a competitive edge to the exercise, prizes in the form of free memory sticks were given to students who managed to estimate a value for length that matched most closely the measured value.

One of the key requirements of the *ReLOAD* system is that, if possible, students should have an individual experience of the laboratory session, despite the shared nature of the equipment. This means their results should be repeatable but different from any other students. This can help to prevent plagiarism to some extent and was achieved by using active vibration damping to adjust the level of damping applied to the beam. The signal from the strain gauge is used to derive a velocity signal, which was fed back into the electromagnetic shaker to provide damping of the beam. The level of damping was pre-selected for each student for each beam. These values of damping were encrypted and embedded within a personalised webpage that each student used to access their particular *ReLOAD* experiment page. A relatively simple system was developed to allow multiple pages to be generated automatically from a spreadsheet and a template HTML file. Students were informed that they would each have their own personal page and that, in their calculations, they would have to account for their particular level of damping. This ensured that despite all the calculations being of the same level of difficulty, no two student's calculations were the same. In addition the provision of individual pages made scheduling of the experiments relatively straight forward. To avoid delays to the students caused by heavy use at particular periods, usually in the period just before the submission deadline, groups of students were allocated a 3 day window, in which it was guaranteed that their personal pages would be accessible. In addition, all pages were made available over the weekends for students who were unable to make use of their allocated window.

5 THE CLIENT INTERFACE

The client computer can be any computer with appropriate internet browser software installed and is only required to send a relatively small amount of data to the *ReLOAD* Server. Upon entering their particular personalised experiment web-page the user is presented with an introduction and links to allow them to run the beam either with or without the additional mass attached. Once they have selected the type of experiment (with or without mass), they are presented with a *'request'* web page similar to that shown in Figure 4.

A standard HTML form is used to submit information to the *ReLOAD* Server. Parameters are entered into the text boxes, however it should be noted that in this particular experiment the users control of damping is blocked, since this is pre-selected and is something the student must determine as part of the experiment. In order to post the form to the server a 'Run experiment' button is used. Usually a submit button will directly post the information in a form to the defined address. However in this case a java-script function first checks to see if the user has already pressed the submit button. This is to help prevent the user from repeatedly clicking the submit button, causing spurious experimental requests.

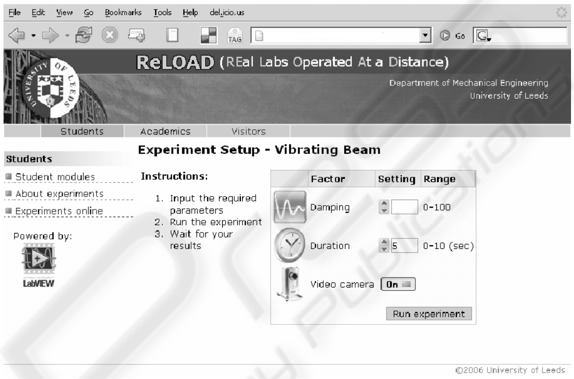

Figure 4: The Client Request Web-Page.

Once the experiment has been completed and the data returned to the *ReLOAD* Server the '*results'* web-page is posted back to the client. The *'results'* web-page, shown in Figure 5, presents data from the experiment to the user in a number of ways.

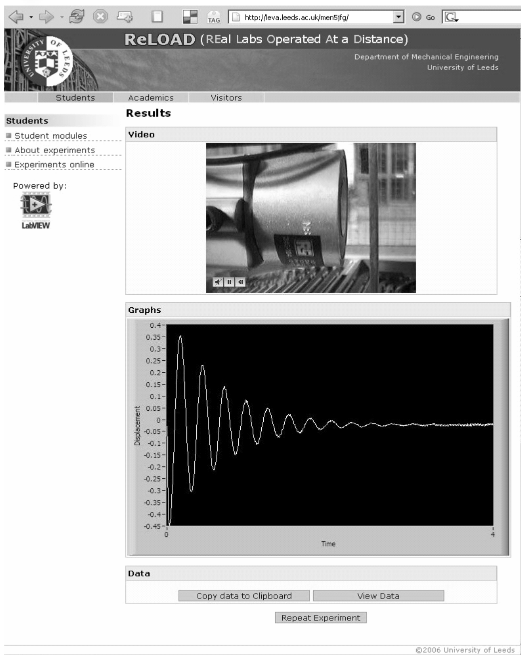

Figure 5: The Results Web-Page.

If requested, at the top of the page, there is a video clip of the experiment and a set of standard controls allowing replays, rewinding, fast-forwarding etc. The video, displayed using a java applet, provides a consistent experience across different browsers and does not require the user to download any special plug-ins. Below this, a graph is displayed showing the beam's displacement. Further links to enable the user to access the raw data are placed at the bottom of the page. A '*Copy data to Clipboard'* function is included, allowing users to import data into a spreadsheet for example and a '*View Data'* function is also included which allows the raw data to be viewed separately.

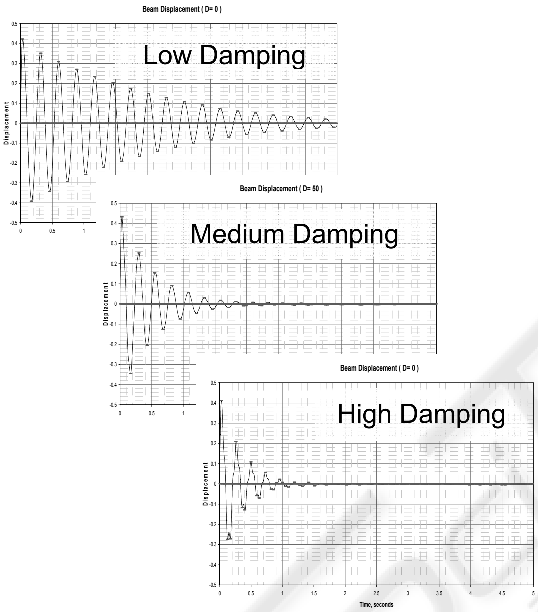

Figure 6: Experimental Results.

A preformatted Excel sheet is provided as part of the experiment to allow easy presentation and analysis of data. Figure 6 shows examples of a typical range of results that students may get. All were taken from the beam without added mass. The preformatted Excel spreadsheet is used to illustrate the range of data achievable from the same equipment. In Figure 6 the upper results represent a pre-selected low value for damping while in the mid and lower graphs, data is recorded from moderate and high pre-selected values respectively.

6 SYSTEM EVALUATION

The *face-to-face* version of the vibrating beam experiment has been running successfully within the School of Mechanical Engineering at the University of Leeds since 1999. In 2000 a remote *ReLOAD* enabled version of this laboratory session was developed for use by Leeds students. Leeds students are now offered the option of taking the *ReLOAD* enabled version, in situations where they find it impossible to attend the *face-to-face* session, due to illness or other unavoidable circumstances. Over subsequent years the system has been developed further to meet the specifications outlined in section 2. In 2006, as part of an international collaboration between the University of Leeds and the University of British Columbia (UBC) the *ReLOAD* enabled vibrating beam experiment was used as part of an undergraduate degree programme.

UBC currently maintains two vibrations courses in the undergraduate Mechanical Engineering curriculum. One is at the third year level (MECH 364) and one is at the fourth year level (MECH 465). Both courses incorporate laboratory experiments and both courses are large with more than 90 students registered in each. Classes this size render classic *face-to-face* experiments with small group sizes and adequate instruction, time-consuming and logistically challenging. The acquisition of psychomotor skills and '*mechanical intuition*' associated with *face-to-face* experiments is a priority at UBC but the requirement for small group sizes and adequate supervision combined with the large class sizes means that providing more than two *face-to-face* experiments in semester is not plausible.

The *ReLOAD* system was used as an ideal method to augment *face-to-face* experiments to provide extra experiments that can be done on the students' own timetable and on an individual basis. The same detailed lab reports and documentation of methods and results that is provided for *face-to-face* experiments was required for the *ReLOAD* experiments. In addition, it was possible to demonstrate the *ReLOAD* experiments in a class or tutorial environment with the same procedures and software as the students themselves will use.

In March 2006, 214 students from UBC undertook the vibrating beam experiment using *ReLOAD* enabled equipment located in Leeds. Virtually all students successfully completed the exercise. To help us evaluate the system, students were encouraged to revisit the website after completing their calculations to let us know two things; firstly to give their opinions of the *ReLOAD* system's performance, and secondly to let us know what length they calculated for the beam, this allowed us to check how well they had recorded and analysed the data. To encourage students to revisit the site, prizes for the closest answer to the beams length were awarded. This resulted in us obtaining feedback from 39 of the 214 students.

Feedback was obtained online by the use of a multiple choice questionnaire. This was done using an ASP (active server pages) web-form with the responses stored in a SQL server database. There were nine multiple choice questions with five possible responses, and one free writing question. Students were assured that their feedback would remain anonymous. The psychometric properties of the feedback system were investigated using the Rasch measurement model (Rasch G, 1960). The Rasch model is a unidimensional measurement model which in this application asserts that that the probability of a student giving a more favourable response about the *ReLOAD* system is a logistic function of the relative distance between the feedback question location and the students overall satisfaction location on a linear scale.

A drop down list for the user to select their name and a free writing area to enter the answer for the length of the beam was also provided. The drop down list containing student names was provided to ensure that the answers given for the length of the beam were attributable to the correct person, this was necessary to allow the allocation of prizes. Once a user had selected their name from the drop down list and submitted their responses, the name would be removed from the list and they would not be asked to complete the questionnaire again. If a response to a question had not been completed when the form was submitted an error message appeared asking for the missed question to be completed.

7 ANALYSIS OF PERFORMANCE

Of the 39 students that completed the on-line evaluation, 8 calculated a length for the beam from their experimental data that was within 1% of the measured value and a further 16 were within between 2% and 3% of the measured value.

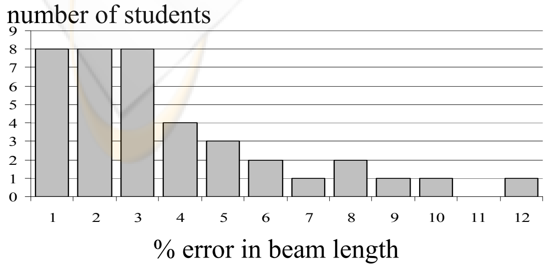

Figure 7: Analysis of Error in Calculation.

Figure 7 shows the distribution of % error from the measured length for all 39 students. Given the experimental nature of the data that the students were analysing, this result is very encouraging and suggests students were working to a high level of precision. However, further analysis of the data in Figure 8, which shows all 39 students errors, reveals that the group on the whole underestimated the length of the beam, reasons for this are currently being investigated.

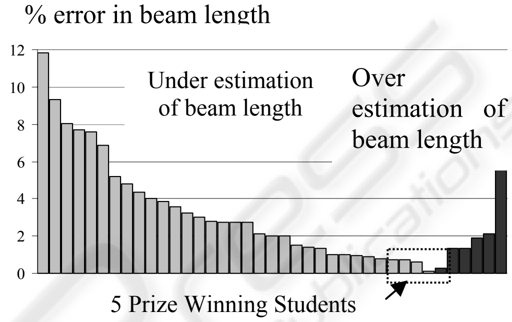

Figure 8: Errors Obtained for Each Student.

Analysis of student feedback was also encouraging, with students in general being very positive about their experience of using *ReLOAD*. Students particularly liked the fact it was easy to navigate the web-site and easy to understand the experiment. This, coupled with the fact many of the students were able to predict the beams length to a high level of accuracy, may suggest a more challenging example is needed at this level. Students also found having their own personalised page was useful and the scheduling of experiments on particular days did not cause any inconvenience. Regarding the use of Video to confirm the fact this is a real experiment and not a simulation, virtually all thought having video made it more realistic and again virtually all were convinced this was not a simulation. However it is interesting to note that despite having video available, two students were not convinced that it was not a simulation. Further the feedback showed that 20% of the group never used the video option, with the majority only opting to use it either on their first one or first few occasions. Regarding system performance, 85% reported being served their results within 30 seconds, with the remaining reporting having been served data within 30 to 60 seconds. However it is recognised that a limited response rate and suspicion over anonymity, could bias the pattern of feedback towards more favourable responses.

A preliminary investigation of the measurement properties of the online feedback questionnaire was undertaken using Rasch analysis. This suggested that seven of the nine questions in the feedback questionnaire formed a valid unidimensional scale. On this small dataset the five response categories for each item had to be collapsed to four as one of the options failed to discriminate across the construct. The two questions that were omitted from analysis were qualitatively different in that their response options looked at frequency and time as opposed to level of agreement.

The system has proved to be very robust and highly reliable, no inputs provided by students caused any problems for the software. The system was left running continuously for several months with only one system reboot required as a result of a campus power failure.

8 CONCLUSIONS

A system to allow remote access to experimental equipment in an education environment has been specified, developed and tested. The system, named *ReLOAD*, uses simple web-forms to allow user interaction and delivers experimental results also via standard web pages, hence no specialised client software or hardware is needed, apart from a java enabled web browser. Java is used to display video footage of the experiment, which helps to reinforce the '*real'* experimental nature of the results. A vibrating beam experiment has been used to demonstrate its efficacy as part of an undergraduate engineering degree course. 214 students from the University British Columbia (Canada) completed an experimental investigation using equipment located at the University of Leeds (UK). Each student's experiment was personalised, ensuring no two students obtained the same data. Initial results from a sample of those students who completed the session are very encouraging. Students report the system is easy to use and quick to return results, even from thousands of miles away. Preliminary analysis of the data suggest students worked to a high level of precision. The system has proved to be highly reliable and simple to maintain. It has allowed more widespread use of high quality experimental equipment and differences in time zones between the host and client universities has resulted in a more even spread of load on the host universities computer network. Further experiments have subsequently been developed and more are in the process of construction. Psychometric analysis of the student feedback system showed that seven of the nine items formed a valid scale which could provide a summary statistic. In addition future developments may include questions targeted at specific aspects which would give the students the opportunity to be more critical of the process. Rasch analysis could also be utilised to develop online student assessments that meet the modern educational standards. This approach would allow individualised nature of the assessment process to be accommodated through item banking. The item bank would be a set of questions where the question difficulty has been numerically calibrated with respect to each question. An important aspect of evaluation, planned for the coming year, is whether learning outcomes of those students undertaking the experiments remotely are different form those undertaking face to face experiments.

ACKNOWLEDGEMENTS

The authors would like to thank National Instruments and the Higher Education Academy Engineering Subject Centre for their support.

REFERENCES

Hites, M., 2002. Creating and running undergraduate experiments controlled through the internet. *American society for engineering education. IL/IN sectional conference*.

Sanchez, J., Morilla, F., Dormido, S., Aranda, J., Ruiperez, P., 2000. Virtual and remote control Labs using Java: A qualitative approach. *IEEE Control systems magazine*. pp 8 - 20, April 2000.

Levesley, M.C., Culmer, P., and Cripton, P. 2006. An Application of Remotely Controlled Experiments to Perform Feedback-Damping Control of a Vibrating Beam. *Proceedings of the 2nd IASTED International Conference on Education and Technology*, Calgary, Canada. pp233-238.

Chumbley, LS., Hargrave, CP., Constant, K., Hand, B., Andre, T., Thompson, EA., 2002. 'Project ExCEL: Web-based scanning electron microscope for K-12 education' Journal of Engineering Education, pp 203-210.

Esche, SK., Hromin, DJ., 2001. 'Expanding the undergraduate laboratory experience using web technology' 2001 ASEE annual conference and exposition.

Harwood, VJ., Alamo, JA, Choudhary, VS., 2004. 'iLab: A scalable architecture for sharing online experiments' international conference on engineering eduation.

Rasch G. Probabilistic models for some intelligence and attainment tests. Chicago: University of Chicago Press, 1960 (Reprinted 1980).