P023

ReLOAD-SAFE: A System for Submission, Assessment, Feedback and Evaluation of Remote Experiments

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Abstract

ReLOAD (Real Labs Operated At Distance), a system designed to grant Leeds students virtually unlimited remote access to experimental equipment, has been in use since 2001. In 2005, this was adopted successfully by the University of British Columbia (UBC) and as been in use ever since. With support from an HEA mini-project the system was substantially improved in 2007 enabling automated ***Submission, Assessment, Feedback*** *and* ***Evaluation****. This new system (ReLOAD-SAFE) has been used to deliver identical remote experiments to two different cohorts of students, one at Leeds and the other at UBC. This paper discusses the system with particular emphasis on submission of data, assessment, feedback and evaluation methods.*

Engineering experiments were made accessible online through a standard web browser, linked to a database running on a dedicated server. Students uploaded key results gathered from their remote investigations to the online database. Immediate feedback on their results was given graphically allowing comparison with their peer group. Academic staff had controlled access to the database allowing simple automated assessment based, for example, on accuracy of their results. This assessment was then be used as the basis of a marking scheme, allowing a very quick turnover from experiment to student marks and feedback.

For evaluation purposes, users were presented with an online questionnaire, highlighting key problems and benefits of the system. Through these and other evaluation methods, results show that the system is robust, popular and beneficial. One of the main outcomes shows that the system is best used in conjunction with, rather than completely replacing, regular laboratory sessions.

1. Introduction

Over recent years, the internet has become a vital tool in education. In engineering, tougher constraints have been applied to effective teaching aids and laboratory sessions. The development of web based resources has led to a new method for delivering engineering experiments remotely for use by students anywhere and at anytime. These new systems have become known as remote engineering laboratories.

Initial remote engineering laboratories were generally simulations that would mimic real experiments through mathematical equations and computational models. This method was found to be a good educational tool, but lacked the non-linearities and uncertainties found in real experimental data. With improved data acquisition, real experiments run through the internet were developed, allowing students to access data generally from anywhere and at any time. However, both remote and more traditional face-to-face laboratory sessions have benefits and constraints.

Some of the problems involved with face-to-face laboratories include (Karayel, D. 2007; Cedazo, R. 2007; Casini, M. 2007):

- Lack of resources, in cost and equipment
- Lack of personnel to setup and supervise sessions
- The process requires a lot of time in setup, running and assessment
- The education system may be based on theory and laboratories have little place
- Official feedback and assessment of lab reports can take substantial time from completing the experiment

Whereas benefits of remote laboratories (Baccigalupi, A. 2006, Cedazo, R. 2007; Maziewski, A. 2007) include:

- Access at any time
- Experiments can be repeated easily
- A tutor does not need to be present
- Resources can be optimised and spread amongst the community
- Students understanding can be improved
- The ease of use and accessibility to experiments for demonstration may bring more people into science and engineering

However, in face-to-face laboratory sessions students often obtain informal, yet frequent feedback from both supervisors and peers regarding their progress and accuracy of measurements for example. This mostly comes about by sharing, discussing and comparing results as they are generated. A good remote based system should take these points into consideration.

This in mind, students generally have only their own data to base their discussions and conclusions on, so access to more data may produce a deeper understanding and consideration of results.

The *ReLOAD* system, developed at the University of Leeds, encompasses remote laboratories in an easily accessible and user friendly way. Over the last couple of years the system has been tested in various establishments around the world (UK and Canada) with a vibrating cantilever beam experiment.

Some of the potential advantages and disadvantages will be discussed for students working remotely in this way based on collected feedback and assessment. As this area of education is relatively new, the results of the in-house and independent evaluation can highlight aspects of the remote approach which are successful and could be applied elsewhere in remote education.

2. Methodology

At both the Universities of Leeds and British Columbia, face to face undergraduate laboratory sessions are an integral part of a student's degree programme in engineering. However, given the limitations discussed in section 1, both universities have adopted the use of remote laboratories to augment their existing laboratory sessions rather than replace them. At Leeds for example, a similar face to face session takes place within the third week of the module. Students use this 2 hour session to develop their measurement and analytical skills. Following the laboratory and in place of writing a more traditional report (this is done else where in the syllabus), students use the *ReLOAD* system to demonstrate the skills learned in the face to face lab.

The heart of the *ReLOAD* system lies in the interactive website which is accessible worldwide (*reload*.leeds.ac.uk) with a standard web browser – no extra software is necessary. The website is hosted on a dedicated server at the University of Leeds, allowing fast interaction and processing of real engineering experiments.

Currently there are four main sections to the *ReLOAD* site; a ***Visitors*** section for general information which contains an interactive demonstration, a ***Students*** section for users from the University of Leeds, a ***Guests*** section for users from other institutes, and a ***Staff*** section for tutors.

Users are given a username and password which allows them to log in to specific experiments as defined by the tutor. The vibrating cantilever beam is one such example which uses two almost identical pieces of equipment as part of a single experiment. In both pieces of equipment, beams fixed at one end and free to move at the other, are attached to a shaker, so that an external dynamic force can be applied to the beam. In one however, a lumped is mass added to the free end of the beam to lower its natural frequency. For each beam it is possible to alter input parameters including damping ratio (via the shaker force), amplitude of vibration, duration of experiment and an option to view a webcam video. The system is described more fully in (Levesley M.C., 2007). Input parameters can either be defined by the tutor for each user or be left to the user to select them self. In this particular example the level of damping and amplitude of vibration is selected by the tutor for each student, and these are not made known to them. In this way no two students data will be the same which helps prevent plagiarism and encourage ownership of data.

Figure 1 shows a range of data taken from the two beams. On completing the experiment each student will have conducted an experiment on each beam and will hence have one set of data that lies somewhere between the extremes shown in figure 1A and 1B and a second set, lying between that shown in figure 1C and 1D.

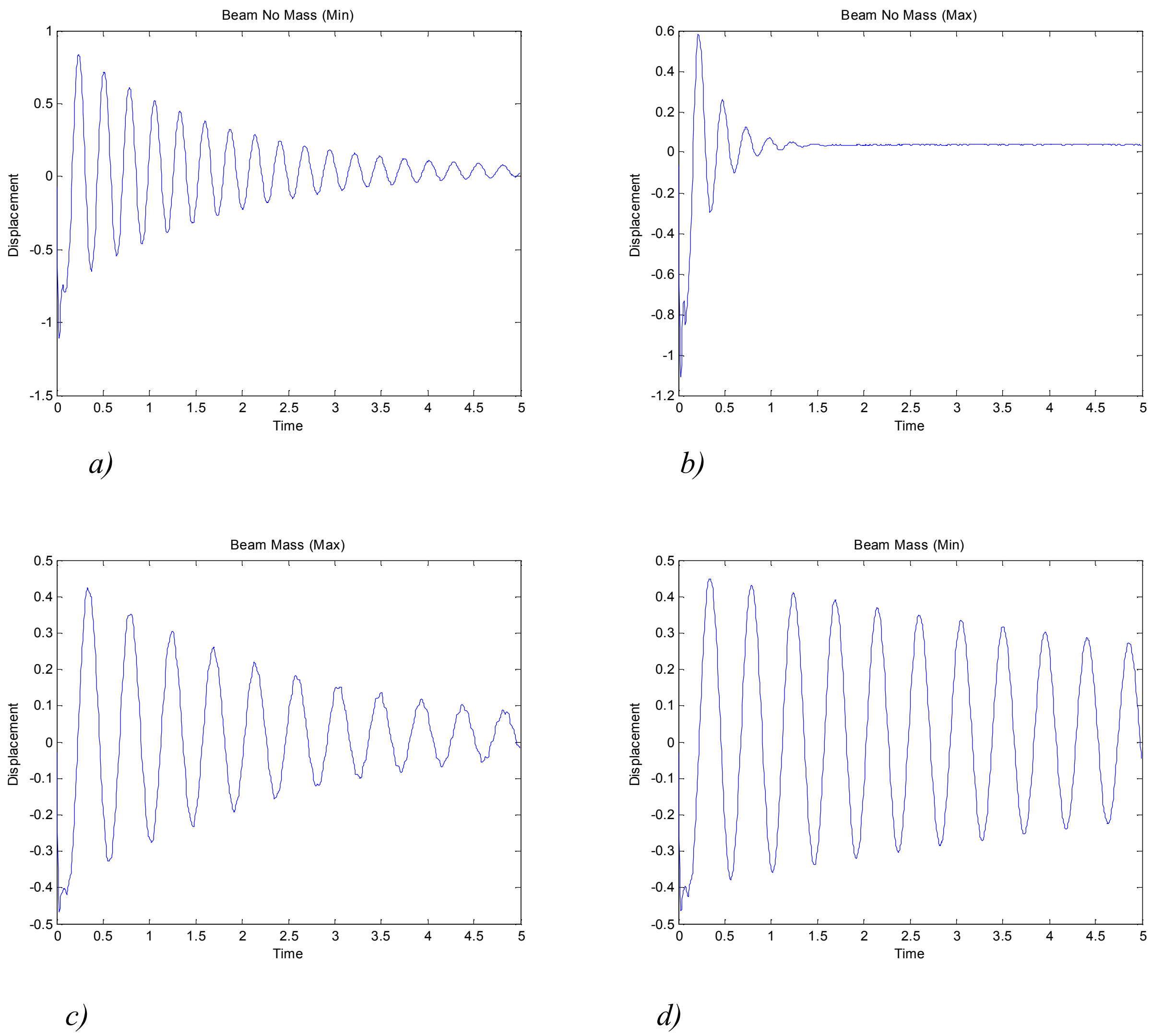


Figure 1: Example results from the vibrating cantilever beams

Data can be downloaded in a number of formats, the most popular being via a simple preformatted EXCEL worksheet. From this data, users are able to measure characteristics of the response and hence perform mathematical analysis as required.

2.1 Submission

Having conducted a number of experiments to gather data, calculated or measured results can then be submitted by the user back to the *ReLOAD* data base, via a simple web form. In this particular example, users are asked to calculate the system's roots for each experiment. The roots are expressed as a complex number, the real part of the complex number relates to the frequency of oscillation and the imaginary part relates the time taken for the systems response to return to its initial position. Students submit numerical values for the real and imaginary parts in separate boxes within the form. The form is then processed for errors using PHP scripts and, on satisfactory input, the data is stored in a MySQL database. In this example we would therefore expect each student to submit two complex numbers. For the beam without added mass the root would be expected to lie somewhere between the extreme values illustrated by points A and B in Figure 2, its exact position being determined by how much damping had been assigned to the students particular experiment. Root A would represent the most heavily damped response and correspond to the type of response seen in Figure 1A, where root B would correspond to a lightly damped response, as seen in Figure 1B. Likewise, for the beam with additional mass, the root would be expected to lie somewhere between the extreme values illustrated by points C and D.

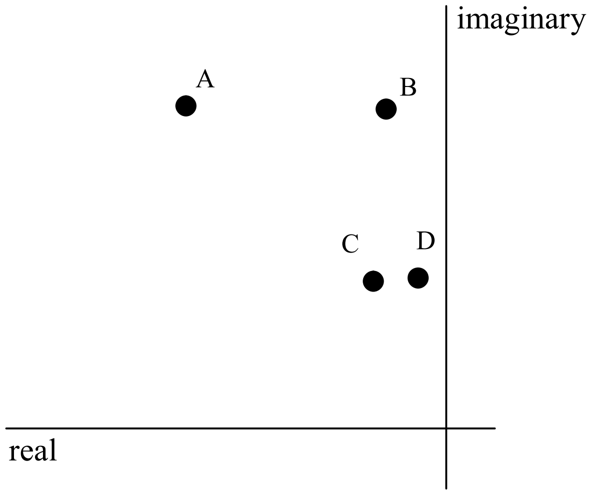


Figure 2

2.2 Feedback

Upon submission of data, instant feedback is available graphically in the form of a root locus diagram (also referred to as an s-plane diagram). A personalised root locus plot is generated upon request, from the data base of submitted complex numbers. This shows a user's own data points (highlighted in one colour) compared to their peers (all in a second colour to provide anonymity). This root locus plot performs a number of important roles i) it gives instantaneous feedback as to whether their data is comparable to their peers'. ii) it shows the variability of data collected by a number of different peer users and iii) in this specific example, it shows how the system roots vary as the damping is changes and also how the roots are affected by adding mass. Students who submit data early can return at regular intervals to the website to see how their data compares to the peer database that is developing. In this way, feedback is given very rapidly regarding the consistency of their results compared with their peers and each user is able to see results from a wider range of parameters than if they were conducting the experiment alone. Once the deadline for submission of data had passed, further automated feedback is given relating to how their data compares to that calculated, not by their peers but by an "expert", in this case their tutor, using tools described in 2.3.

2.3 Assessment

In the **Staff** section, group results can be displayed in tabulated and graphical form and various analysis functions are made available, allowing the data to be evaluated. For the vibrating beam experiment an iterative curve fit routine was written to allow a precise mathematical model to be fitted to the data. This performs a number of key functions, amongst them being i) it allows staff to monitor the state of the equipment over a period of time, ensuring consistency and ii) it allows a piecewise mathematical model to be developed for the system, without the need to perform experiments for every combination of input parameters.

Once a mathematical model of the experimental system has been established user's submitted data can be assessed automatically against it using a marking scheme defined by the tutor. The tutor may choose to emphasise accuracy in measuring frequency of oscillation or in determining the amount of damping in the system through the scheme. In this particular case a marking scheme was developed by the tutors based on previous experience with this experiment. This scheme was applied automatically to both cohorts of students, the robustness of this marking scheme is now the focus of a further statistical study. Though the mark could be delivered to the student the instant they submitted their data, tutors thought that this information could be passed on to other students in their group and hence provide an unfair advantage to students submitting later in the assessment period. Hence it was decided to release all marks via the web once the class submission deadline had passed.

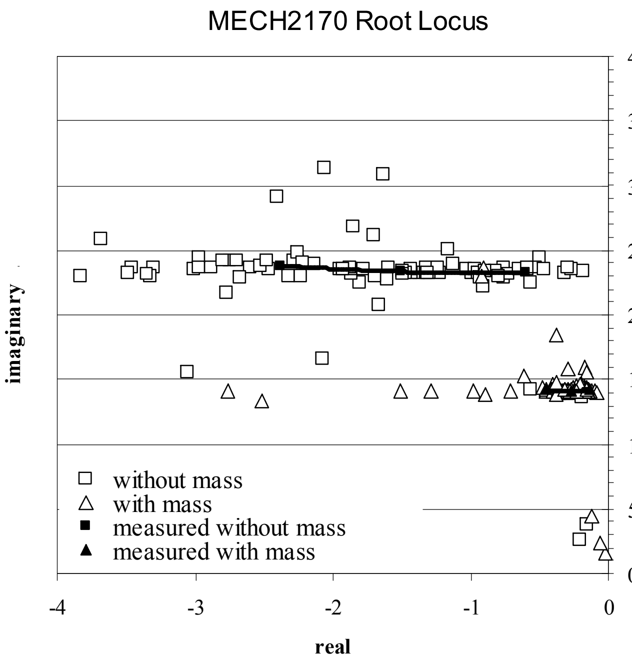
The convenience of submission, coupled with immediate feedback and rapid and possibly instantaneous assessment, should be contrasted with that experienced in more traditional labs where feedback and marks are often returned weeks after the lab was conducted. This rapid turn round of feedback and assessment of submitted work is one of the major advantages of the new *ReLOAD*-SAFE system.

2.4 Evaluation

Student evaluation and feedback is collected via online questionnaires which users are encouraged to fill out before they see the peer group results. The questionnaires form a large part of the evaluation process and take the form of a number of tick box response questions and a freeform textbox. Results from the evaluation are anonymised prior to being returned to tutors via simple tools available on the Staff section.

3 Experimental Results

The vibrating beam experiment described in section 2 is now firmly embedded in the undergraduate engineering curriculum at two HE institutions. At the University of Leeds (where *ReLOAD* is housed) it is a key component in the level 2 module, MECH2170 Vibration and Control (typically this has around 120 students). At the University of British Columbia in Vancouver it forms a key part of the level 3 module MECH 364, Mechanical Vibrations (typically this has around 100 students). The *ReLOAD* system has been used at both sites for many years, and to date, personalised experiments have been delivered to over 500 students. In 2007 the new *ReLOAD*-SAFE system was used for the first time, enabling submitted results, marks and students perceptions of the system to be compared across a significant cohort of students.



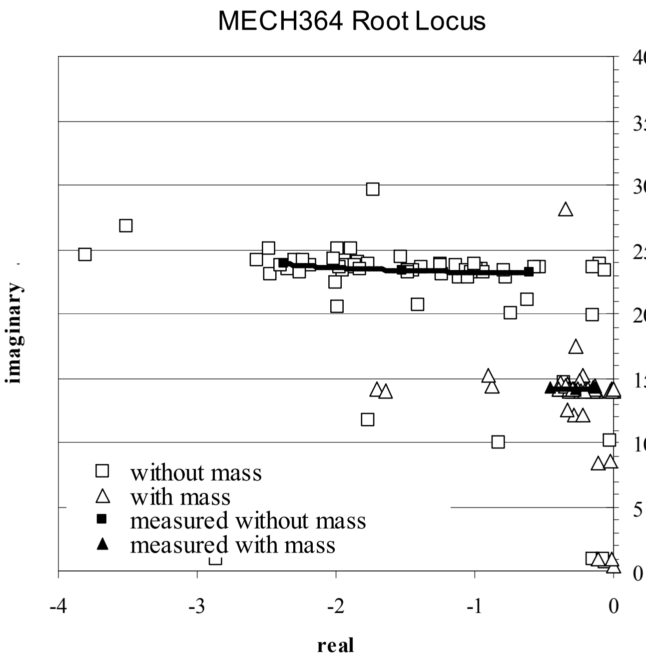


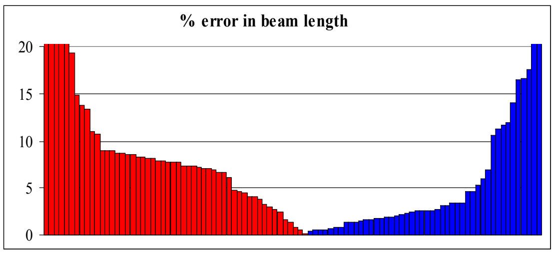
Figure 3: Module results

Results submitted from each group are gathered on the root locus (s-plane) diagrams. Figure 2 shows the responses from 100 students from the University of Leeds' MECH2170 module and Figure 3 shows data from 82 students taking the University of British Columbia's MECH364 module. In each figure, the hollow square markers represent data submitted for the beam without mass and the hollow triangles represent data submitted for the beam with added mass. The solid lines represent data "measured" by an expert, in this case the tutor.

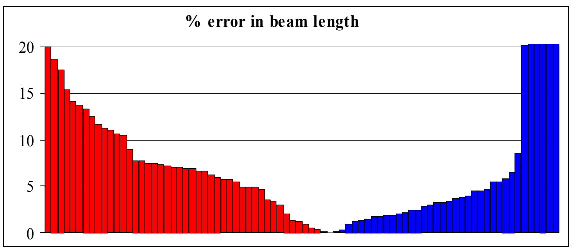
Careful examination and comparison of the data reveals a number of interesting points.

1. In general, the students' ability to calculate frequency of oscillation to a relatively high degree of accuracy is good. This is as expected given the fact this is a relatively simple thing to calculate. There is a small but notable group who have submitted data that appears in the bottom right hand corner. This is most probably caused by not using SI units i.e. using Hz rather than rad/s.
2. There is a greater spread of data in the horizontal data. Again this is as expected given that determining the amount of damping is more difficult.
3. It would appear that in some cases students have confused the data they collect from the beam with added mass for that collected from the beam without.
4. On the whole, there does not appear to be a large variation in the accuracy to which the students from each cohort work, though this is something that a more rigorous examination of the data would reveal.

In addition to calculating roots of the characteristic equation for each beam, students are also asked to take their data and by comparing it to a relatively simple mathematical model, calculate the length of the beam. This provides a further challenge for the students requiring accurate measurement in addition to an understanding of the mathematical model. Results showing the percentage error between the true length of the beam and the value calculated for each student is shown in figure 3. In general it would appear that the majority were able to estimate the length of the beam easily to within 10%. Data on the left of each graph indicates an underestimate of the length while that on the right reveals an overestimate.



% error for MECH2170 (Leeds) cohort



% error for MECH364 (UBC) cohort

Figure 4: Percentage error in beam length calculation

Once again, on the whole, there appears to be little difference in the accuracy to which the students from each cohort work, though a more rigorous examination of the data may reveal more subtle differences.

4. Evaluation Results

The main user evaluation method was based on an online questionnaire that users filled out before retrieving their peer group results. The questions were independently designed to illicit a range of responses from the users. Measurement properties of the questionnaire were tested on a small initial sample using Rasch analysis (Rasch G. 1960, Tennant A. 2007) and subsequently reworded to ensure robustness. Notably, using Rasch analysis on this small initial dataset, suggested that the five response categories used initially (as with the Likert scale for example) should to be collapsed to four, as one of the options failed to discriminate across the construct (Levesley M.C. 2007). A number of questions deliberately designed to promote a “negative” type response (questions 9&10) were also added.

Below are the combined questionnaire results from two modules, Table 1, the first from Leeds and the second from the University of British Columbia. The first two results show the respective percentages for Leeds and UBC for comparison. Bold numbers highlight the highest responses from students for each question.

Table 1: Questionnaire results

	Leeds	**UBC**	**Combined**
Navigating and accessing material on the *ReLOAD* website was straight forward			
Agree strongly	27.6%	**60.7%**	44.15%
Agree	**66.7%**	38.1%	**52.4%**
Disagree	5.7%	1.2%	3.45%
Disagree strongly	0%	0%	0%
Compared to other "hands on" experiments I've done, it was easy to understand the *ReLOAD* experiment			
Agree strongly	9.5%	**48.8%**	29.15%
Agree	**73.3%**	44%	**58.65%**
Disagree	17.1%	7.1%	12.1%
Disagree strongly	0%	0%	0%
I liked having my own personalised experiment on *ReLOAD*			
Agree strongly	18.1%	42.9%	30.5%
Agree	**62.9%**	**45.2%**	**54.05%**
Disagree	17.1%	10.7%	13.9%
Disagree strongly	1.9%	1.2%	1.55%
Analysing the data downloaded from *ReLOAD* was straight forward			
Agree strongly	18.1%	**47.6%**	32.85%
Agree	**75.2%**	46.4%	**60.8%**
Disagree	6.7%	3.6%	5.15%
Disagree strongly	0%	2.4%	1.2%
Being allocated a personal deadline to help spread the load on the server, did not cause me any great inconvenience			
Agree strongly	18.1%	28.6%	23.35%
Agree	**63.8%**	**53.6%**	**58.7%**
Disagree	8.6%	7.1%	7.85%

	Disagree strongly	9.5%	10.7%	10.1%

I am convinced the data I received is from a real experiment and not just a simulation				
	Agree strongly	28.6%	35.7%)	32.15%
	Agree	**61.9%**	**51.2%)**	**56.55%**
	Disagree	9.5%	9.5%)	9.5%
	Disagree strongly	0%	3.6%)	1.8%

Being able to see a video clip made the experiment appear more realistic				
	Agree strongly	30.5%	**50%**	40.25%
	Agree	**55.2%**	42.9%	**49.05%**
	Disagree	12.4%	3.6%	8%
	Disagree strongly	1.9%	3.6%	2.75%

Compared to other "hands on" experiments I've done, the *ReLOAD* experiment was effective in helping to get concepts of vibration across				
	Agree strongly	7.6%	20.2%	13.9%
	Agree	**76.2%**	**60.7%**	**68.45%**
	Disagree	14.3%	16.7%	15.5%
	Disagree strongly	1.9%	2.4%	2.15%

I think I learnt more by using *ReLOAD* than I would have from traditional "hands on" laboratory session				
	Agree strongly	5.7%	4.8%	5.25%
	Agree	36.2%	32.1%	34.15%
	Disagree	**46.7%**	**53.6%**	**50.15%**
	Disagree strongly	11.4%	9.5%	10.45%

I would rather do a remote *ReLOAD* lab than do a traditional "hands on" laboratory session				
	Agree strongly	5.7%	11.9%	8.8%
	Agree	**45.7%**	**39.3%**	**43.5%**
	Disagree	35.2%	36.9%	36.05%
	Disagree strongly	13.3%	11.9%	12.6%

From pressing the "run experiment" button to receiving my data, took about				
	0-30 seconds	**64.8%**	**77.4%**	**71.1%**
	30-60 seconds	21.9%	14.3%	18.1%
	1-2 minutes	8.6%	6%	7.3%
	2-5 minutes	1.9%	2.4%	2.15%
	More than 5 minutes	2.9%	0%	1.45%

When running an experiment I used the video option				
	Never	23.8%	22.6%	23.3%
	Only the first time	**28.6%**	**26.2%**	**27.4%**
	On the first few times	16.2%	19%	17.6%
	Most of the time	8.6%	6%	7.3%
	All of the time	23.8%	**26.2%**	25%

Please use this section to let us know about your experience of using the *ReLOAD*, how did it compare to your other labs? Would you be happy to use it again? How it could be improved? (In particular please let us know if you received any error messages or found any bugs). We are also particularly interested in your opinions of working individually on a personalised experiment rather than working in groups.

Representative sample of comments:

> "It's a neat idea, but I still prefer regular labs more."
>
> "Very straight forward instructions. No confusion in the background information. Overall a good experience. I think individual labs are more beneficial from a learning perspective since you are required to do all the analysis, rather than splitting the work off and only gain partial experience. Perhaps a solution is to replace numerous group labs with in depth less frequent individual ones."
>
> "This was a good lab, and helped improve my understanding of vibrations."
>
> "It was alright, better than I expected, still prefer real hand on labs."
>
> "I personally enjoy to do hands on experiments. If too many experiments are done from in front of our computers we may become a generation of engineers that are unfamiliar with how mechanical systems work. This is clear when other engineers have to do hands on work and have never seen simple mechanical systems."
>
> "I like doing a lab while I am at home relaxing on a sofa :D"
>
> "Yes I would be happy to use it again."
>
> "It's perfect, but I still prefer the old fashioned lab when you work in a team and you can also use other team members ideas."
>
> "I think working in group is more effective as you can compare your idea with your mate and get a better result and understanding. being more involved with lab equipments is the thing make me more attracted to the subject. So in general i prefer to do it in proper lab rather than the online one. However it's been so much easier & faster to work on *ReLOAD*."
>
> "I feel I got a lot out of this lab because i had time to sit down on my own and have a go at each bit. This I found much more useful than the initial hands on lab we did earlier."
>
> "I prefer to do experiments in the lab. I like to be able to ask the demonstrators questions."

As both of the results for Leeds and UBC are recorded separately a comparison of responses can be observed as well as the overall results. Firstly, it can be seen that most of the results lie within two categories, positive (Agree strongly and Agree) and negative (Disagree and Disagree strongly). All of the questionnaire data shows that both Leeds and UBC are in the same of these two categories giving very similar answers. Generally the results show that the UBC students are slightly more positive than the Leeds students. The reasons for this are not fully apparent.

The overall questionnaire results show that the system was easy to use (questions 1, 2 and 4). The personalised web page with an individual deadline was generally found to be useful (questions 3 and 5). It was interesting to note that although most agreed that the ability to see a video clip if requested, convinced them that this was a real experiment, around a quarter elected not to request it (questions 6, 7 and 12). This may be due to the fact that the default position is set to having the video clip switched off and users may have had concerns regarding the amount of time it would take to retrieve data if this option was selected. However, results confirm most had a relatively short wait for their data to be delivered to them (question 11).

The recorded differences and benefits of a remote system are fundamental to it’s evaluation. The responses show that the students believed the experiment helped their understanding of vibration compared to some hands-on sessions (question 8), but over half thought that *ReLOAD* was a suitable replacement for hands-on sessions (question 9). The proportion of users who would rather do remote labs to hands-on was very similar (question 10), just over half.

The final question allowed the users to give direct feedback about the system and report any problems in using it. In conjunction with question 10 and the comments from question 13 information implies that remote sessions may not be a replacement for hands-on laboratories, but work well in conjunction with them.

On top of internal evaluation through questionnaires, an independent evaluation was sought through the Engineering Subject Centre. This independent evaluation will show feedback from staff and students in the various establishments using *ReLOAD*.

Case studies and papers have also been produced on the *ReLOAD* project (Levesley M.C. 2006, Levesley M.C. 2007). The visitors section of the website holds copies of these and also allows anyone to access an interactive demonstration.

5. Discussion

The *ReLOAD* system, which has been in operation since 2001, has been successfully improved in an attempt to address some of the limitations identified with traditional labs and incorporate some of their advantages. The enhancements were identified through user feedback from both students and staff and the system has been developed to better suit user needs. The current version was developed in part with funding from an HEA mini-project grant to allow the automated submission of data, assessment of submitted data, feedback to users and staff and evaluation of the system.

Submission: This section of the system is a vital precursor to delivering rapid assessment and feedback. Experimental data gathered by the user after performing an experiment can now be submitted directly to the *ReLOAD*-SAFE database. This collection of data is then used for assessment and peer related feedback.

Assessment: A number of tools have been developed in the staff section of *ReLOAD* to enable rapid assessment of submitted data to be performed. After users have submitted their data, individual and group submission can be evaluated using the *ReLOAD* functions, each user can be marked automatically on the accuracy of their results for example. Using this section of *ReLOAD* has enabled very rapid and if desired, instant assessment of results. Tests carried out at both Leeds and UBC have shown that operating equipment from a considerable distance has negligible effect on the ability of students to work accurately and effectively.

Feedback: There are two types of feedback in the current system. The first comes when results are submitted to the database at which point a graph is returned showing their submitted points alongside peer results. This allows a very quick graphical comparison of accuracy of results and was developed to act in a similar way to the informal peer group comparisons that have been reported as being useful in traditional labs. This aspect of *ReLOAD*-SAFE proved so popular with students at Leeds it has now been incorporated as an augmentation to face to face labs.

The second form of feedback comes from a comparison of a users submitted results to an "expert's" measurement. This can be used by the tutor to provide an appropriate grade for the submitted work based on accuracy for example. This allows the user to receive feedback within a short period of time, and allows the tutor to obtain an objective assessment of each student's submission, quickly and consistently.

Evaluation: The system has been evaluated thus far by questionnaires and feedback from users. The results have shown that such a system can be used stand alone, or in conjunction with hands-on laboratory sessions. User feedback suggests that the latter is more favourable. Comparison of evaluation data from UBC and Leeds suggest a good correlation between feedback given by each.

Independent evaluation is currently being undertaken with assistance of the HEA engineering subject centre and the Royal Academy of Engineering using small focus groups.

6. Conclusions

The *ReLOAD* system has been proven to be an efficient, effective and well received tool for delivering remote laboratories as part of an engineering degree programme. Users from the University of Leeds and University of British Columbia have tested the robustness of the system and helped it develop into the current version. Other institutes such as, University Collage London and Manchester Metropolitan University are currently developing and testing further experiments using this system for their engineering modules.

These approaches to remote experiments have been shown to be popular and efficient ways of learning engineering (Lang, D. 2007, Nickerson, J.V. 2007) and there is definite scope for such systems to be embedded more widely in the engineering curriculum. The lessons leant through these trials can also be extended to other fields of remote education.

For those interested in trying the *ReLOAD* system, an interactive demonstration is available at *reload*.leeds.ac.uk/visitors/.

7. Future use

The success achieved with the vibrating beam experiments has encouraged interest in developing and expanding the *ReLOAD*-SAFE system to other dynamic experiments. One such example is a servo-positioning system: control of position using an electric motor and gearbox. Here, remote operation of the laboratory is particularly appropriate as that is representative of the situations in which servo-positioning systems are used: remote position control of devices ranging from CCTV cameras to robots used in nuclear industries.

The planned experimental setup will teach and evaluate students' ability to determine a "frequency response" of the servo system. A frequency response defines the behaviour of the servo system and experimentally involves applying an oscillatory demand position signal as an input and measuring the oscillatory position response of the servo. This measurement should be repeated dozens of times at different frequencies, which would be very labour-intensive for an individual student.

However, as with the “root locus” methods described here, the group of students will be able to collate their data, thus the overall result will represent the combined effort of the whole group.

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