A REMOTE-ACCESS LABORATORY FOR COLLABORATIVE LEARNING

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ABSTRACT
We present an example of a remote-access laboratory comprising real experimental apparatus, accessed remotely via the internet.

The experiment, in Mechanical Engineering, involves analysing the performance of a servo-motor and was designed to be particularly suitable for remote access. Students were provided with individualised experimental parameters to minimise plagiarism. However, they were also able to choose their working environment and work in the presence of peers or individually. They were able to access the experiment repeatedly as required. Automated submission and grading of students' results provided immediate, quantified, formative feedback.

The experimental design allowed students' results to be combined to generate a collaborative, emergent result giving a full frequency response analysis of the servo motor. This outcome could not have been achieved with a traditional lab access mode. Students were furthermore able to assess their performance against their peers, and learn from their own mistakes and those of others, with anonymity.

Remote labs have supporters and detractors; we argue that when used appropriately they have a valid place in the curriculum, and have demonstrated unique advantages over traditional lab access methods.

KEY WORDS
Web-labs, Remote, Distance, Engineering, ReLOAD

1. Introduction

In engineering and physical sciences, laboratory-based teaching sessions form a key part of the curriculum. These sessions are intended to have a positive effect on learning outcomes by providing physical evidence of theoretical principles. When used appropriately they can enthuse, motivate and inspire students [1].

In laboratory sessions, there are several different modalities by which a student interacts with apparatus, involving combinations of the following:

Student Group	Apparatus	Teacher
Individual Small group (2-6) Class (6-40) Auditorium (>40)	One unit Several duplicated units	One teacher Several teachers One teacher + assistants

The various ratios of student : apparatus : teacher encountered in practice depend on the total number of students, the nature of the experimental apparatus, and the institution's resources of time, funding, space and staffing. So, unfortunately the method of delivery is frequently determined by logistical and resource limitations instead of educational requirements.

An alternative means of conducting laboratory work is to use the internet to enable remote access to experimental apparatus. This technology is becoming more prevalent in the delivery of engineering in higher education institutions [2-6] and the expectation is that this will very soon expand out to other scientific subjects and to other levels of education. Remote-access laboratories have often been presented as a mechanism to avoid logistical problems and used as a substitute for real laboratories [7]. However as well as having self-evident procedural differences between remote labs and conventional "hands-on" labs, the two modes have been demonstrated to have differences in learning outcomes, all other factors remaining equal[4].

We propose that rather than simply attempting to make remote labs as "lifelike" as possible, the unavoidable differences can be acknowledged and even exploited. This paper presents an experiment whose remote access mode affords a number of specific beneficial features which would not be possible with traditional hands-on access.

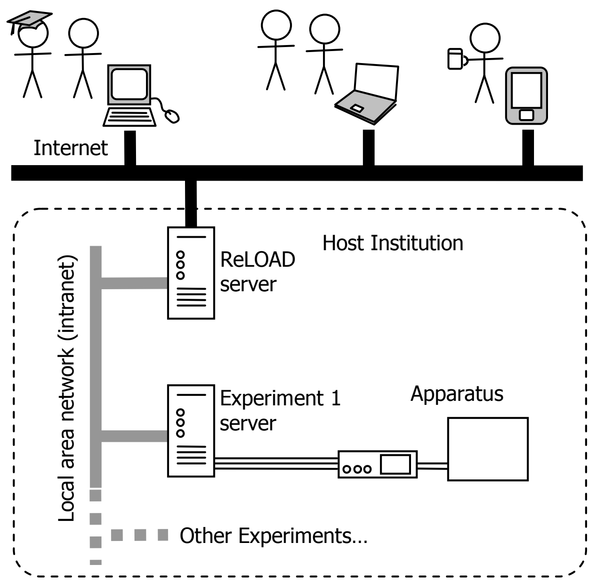

Figure 1: The remote laboratory schematic, showing some alternative access modes.

2. Structure and Implementation of the Remote Laboratory

The remote-access system described here forms part of the ReLOAD suite of experiments [8-10] and is presented via the interactive website reload.leeds.ac.uk. The site and experiment are accessible worldwide with a standard web browser; no extra software is necessary. The website is hosted on a dedicated server at the University of Leeds, UK, and the experimental interfacing is performed using LabVIEW software (National Instruments). For each experiment, an explanatory web-page provides background theory and describes the experimental protocol (and, optionally, provides links to class material). Then a further page presents a form on which the student enters the parameters of the experiment they wish to run. Upon clicking a "submit" button, this request is passed to the server, which then submits the request to the physical experiment. An automated queuing system operates if several students are submitting requests concurrently, however if the experiment duration is short (just 5-10 seconds in this example), then students seldom experience a delay. Experimental measurement graphs are returned to the student's web browser on a "results" page, which also contains links to download the data in spreadsheet format. A video clip of the experiment is also displayed, which is very valuable in demonstrating the dynamics of the system (a still from the video is shown in figure 2). In the background of the video, people can be seen coming and going within the department's entrance hall; this helps the students believe that they are operating real equipment, increasing their engagement [4]. Technical details of the software architecture and submission / return of results have been described elsewhere [10].

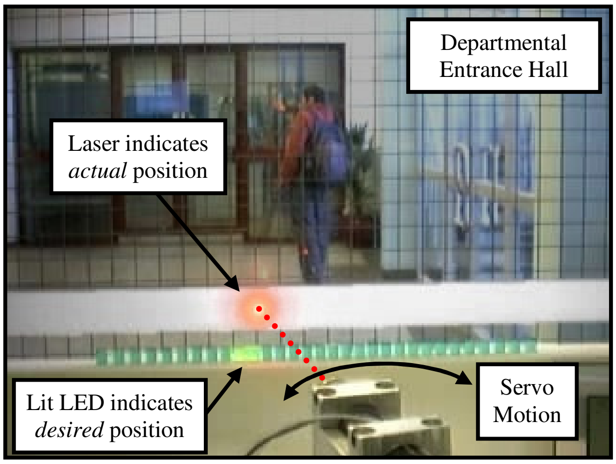

Figure 2: Example video still showing experimental setup

2.1 Experimental Design

The following description of experiment and results represent a case study from one particular course. However, many of the techniques generalise to a variety of applications. For example, the measurement and analysis of real-world data seen here are key techniques used across the spectrum of science and engineering. It is inevitable that readers from other disciplines will identify many more potential applications.

The experiment described herein is designed to teach the concept of "frequency response"♣ within the subject of dynamics. As with many topics in engineering, frequency response relies on the combination of several underlying concepts, all of which need to be understood by the students. Since the subject is dynamics – relating to motion – the mathematical theories are very helpfully illustrated with real, dynamic examples. Simulations and videos certainly have value in that they can provide an impression of motion [1]. However there are other important concepts involved in obtaining the frequency response of real world systems experimentally: data acquisition limitations (e.g. drift, quantization), electrical noise, and imperfect repeatability. We considered it important that students could link the theory with interactive observations of real world systems: a laboratory experiment. Along with promoting understanding, this was intended to increase motivation and engagement [4,11].

The laboratory equipment comprises a geared d.c. servo motor, on which is mounted a laser pointer to indicate position, see figure 2. This type of position control system has many real-world applications from satellite dish tracking to CCTV cameras. The applications all involve *remote* control of position, therefore controlling this experiment remotely is entirely appropriate, not contrived. The "desired" (input) position is indicated by a strip of green LEDs. See Weightman et. al. [10] for further details of the apparatus' construction.

Our learning aim was that the laboratory illustrated and reinforced the theories covered in class. Traditional hands-on labs can sometimes be viewed by students as being conceptually separate from the course material. This can arise from being presented in a different location and due to scheduling restrictions, it is often not possible to coincide the teaching of a particular concept with the relevant laboratory. The web-based environment encourages students to relate their learning material by presenting in the same format as their course handouts, and including a link to the lecture material from the laboratory web site. The Excel spreadsheet the students use to process data is re-used in a similar format for another class assignment.

♣ When a sinusoidal input is applied to a linear system, the response of that system will also be sinusoidal at the same frequency, but may have a different amplitude and phase (output often *lags behind* the input). These two features – amplitude and phase – depend on frequency, and that relationship is called the frequency response. Graphs of frequency response are called Bode plots.

Our learning objectives were that students were able to:
(i) Apply a "desired" motion demand signal (input) that was sinusoidal at a specified frequency.
(ii) Observe the motion of the servo motor (output).
(iii) Compare this visually to the desired position.
(iv) Relate the observed motion to the graphs of measured motion (e.g. figure 3).
(v) Describe the actual motion (output) in terms of its amplitude and phase lag compared to the desired motion (input).
(vi) Then finally, relate the amplitude and phase behaviour at individual frequencies to the Bode plot, which represents the frequency response of the servo system over a wide range of frequencies.

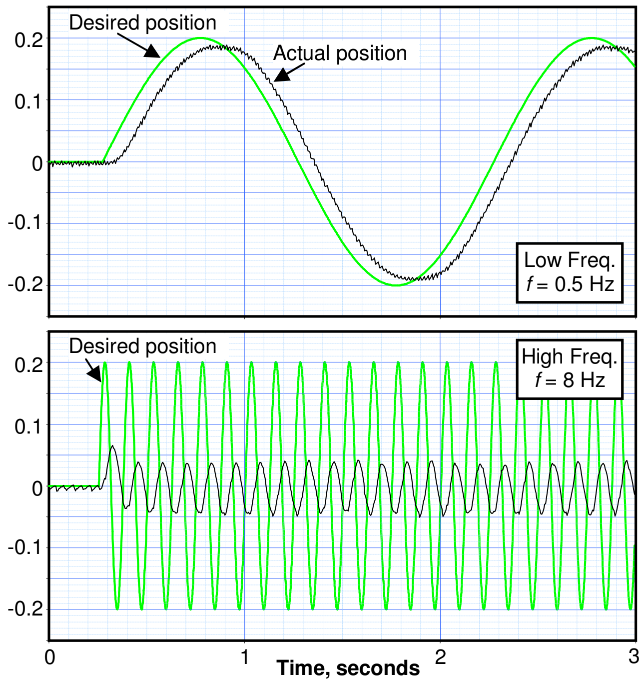

Figure 3: Two examples of measured position data

2.2 Access

The ReLOAD system was demonstrated in class and students' assignments were distributed at the end of term. Students then break up for a Christmas break and were able (but not required) to access the lab during that time – they also had at least one week during term time in which they could use university computers.

Students were assigned individual usernames and passwords to access ReLOAD. Individual access times are logged which provides staff with a facility for educational research into study methods. Upon logging in, they see personalised pages, and were issued with individualised experimental parameters. The students are therefore aware that they will have to produce results that are different from their peers and this was hoped to reduce any temptation to plagiarise. With unsupervised coursework, there is always the possibility of work being carried out by someone else. However, we see remote labs being better suited to use for formative purposes – where the purpose is to instruct rather than to examine [12]. In this example to get a pass mark students just had to access the system and submit values.

A well-publicised advantage of remote-operated laboratories is their accessibility 24 hours a day, 7 days a week. Since this particular experiment requires some time-consuming processing of data (measuring amplitudes and phases), remote-access made efficient use of the apparatus: it was not occupied while students were performing calculations.

2.3 Submission of Results and Automated Feedback

The traditional method of providing feedback to students' performance in a laboratory has been the submission of reports which are then graded and returned. Apart from the time required to grade these reports, there exists a necessary further delay in that no reports can be returned until the whole class has completed the laboratory. This restricts the utility of laboratories as a tool for providing formative feedback within a course.

In this remote-operated lab, the students obtain their experimental data from a web page. They take measurements and perform calculations, and then they submit their results via a web page. We created a system to provide immediate, quantified feedback to students, which compares the student's submitted values to the "model" values that should have been obtained. The grading algorithm takes account of the accuracy that could be reasonably expected of students; it does not intend to "punish" trivial mistakes. Different aspects of the experiment are itemised in the feedback, noting which are more or less important. Thus, the students receive feedback that is immediate, personal, specific and formative. This is intended to facilitate the students learning from their mistakes [12].

2.4 Collaborative Learning

The most desirable learning outcome is that students are able to observe the key features of the response of a real servo system at a wide range of frequencies*. However, in order to capture such a complete representation of the servo system's performance, a student would be required to repeat measurements at perhaps dozens of frequencies.

* Namely: at a low frequency, the servo tracks the demand with minimal change in amplitude and phase lag. Then as frequency increases the system exhibits resonance – when actual motion is greater than the desired motion – around one particular frequency. Then as the demand frequency increases further, the servo's motion increasingly lags behind the demand signal and becomes steadily smaller in amplitude.

This would not be an efficient use of their time and would distort the learning outcomes as the student would be spending a disproportionate amount of effort measuring the amplitude and phases of sine wave traces.

With a class of students, there is an opportunity for collaboration, where the individual results are compiled to construct a complete frequency response of the servo system, however the students must take measurements from the same set of apparatus (duplicated setups would not have identical behaviour). In a hands-on mode, this would require each student to set-up and run the experiment in turn: a very unappealing logistical exercise. In comparison, remote operation provides 24-hour access and an automated queuing system which enables a large class of students to access the same equipment, with individualised parameters that are automatically loaded each time they log on to the system and submit an experiment request [8,9]. The remote lab can be used to present identical experimental conditions to a large class in a way that hands-on labs could not.

In hands-on labs, teachers observe very different working styles from students. Some will rush through, barely reading the instructions; others will spend too much time concentrating on aspects of the apparatus that are relatively unimportant. There are often large variations in the duration of time required for individual students to competently complete the experiment. When students with very mixed learning styles are combined (arbitrarily) into lab groups, their individual experiences of the laboratory are far from ideal. Allowing some group members to take a very passive role in performing a laboratory has been shown to have a negative effect on motivation [11].

In contrast, the ReLOAD system empowers individual students to take an active role in choosing where and when to carry out their experiments, and they are free to proceed at their own pace. They have the option to perform part of the experiment, and then pause while they re-visit course material or seek advice from the teacher or from colleagues. Thus the ReLOAD system allows collaboration between very diverse individuals [13].

2.5 Students' Evaluation of Experiment

Finally, each student's experiment web page gives them the opportunity to provide feedback and comments on their experience with using the remote labs, as detailed by Gallagher et. al. [14]. This also provides the opportunity to provide a case for any extenuating circumstances, in confidence.

3. Results

3.1 Operation

In creating this experiment for the ReLOAD system, writing and editing course material only required changing one master document on the web, and any adjustments to the experimental hardware only had to be performed on one set of apparatus. This enabled the laboratory protocol to be evaluated and refined quickly and shortened the overall development time.

When running the experiment, ReLOAD provided the teacher with the means to continually monitor and evaluate the progress of the lab through student feedback and logs of student access.

These features resulted in the teacher having greater opportunity to maintain and continually improve the laboratory, ensuring that experimental and theoretical teaching materials are closely linked.

3.2 Access:

As has been noted elsewhere [13], this experiment was operated at all times of day and night, from locations around the globe (since many students returned to their home countries during the vacation period). The 24/7 availability of the remote lab meant that students' access was not impaired by restricted mobility nor by illness, or commitments of part-time work or religious attendance.

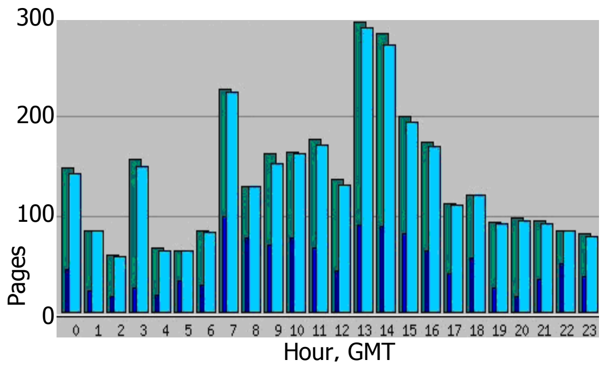

Figure 4: Visits to remote-experiment web server over 30 day period, by hour.

Since the students were assigned individual usernames and passwords to connect to the ReLOAD system, it was possible to monitor each individual student's access (we collected data with student names removed). Observing patterns of access times suggested that some students were working on their assignments together in small groups. This was indeed confirmed after the fact by discussions with the students. No particular working mode was prescribed by the teacher, so we take these results as evidence that the students were able to select whichever working mode that they preferred, or was convenient to them. In this case, the individualised parameters meant that one student directly copying a fellow student's work would have been futile: apart from being graded as incorrect, the duplicate submissions could be spotted automatically.

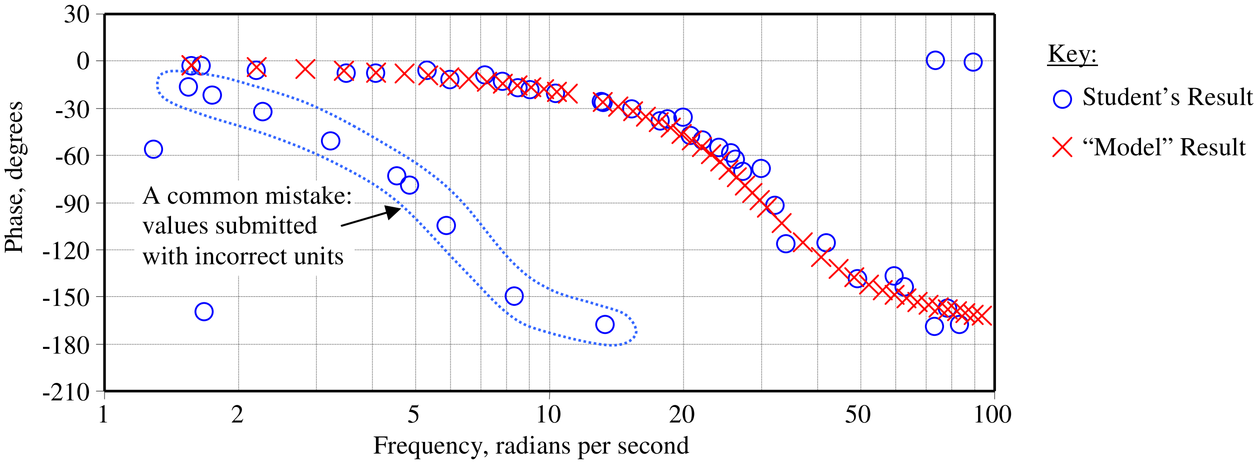

Figure 5: Compiled Student Results

3.3 Submission of Results and Automated Feedback

An example of the combined students' results is shown in figure 5. Compared to the "model" results, errors can be clearly picked out. In a number of cases a "common mistake" is identified; this is illustrated on the figure. Many students submitted their results using incorrect units for frequency – they would calculate a value from the graphs in Hz, but submission required conversion to radians per second.

These common mistakes were easily identified by the automated grading routine: if the frequency is incorrect, conversion to the correct units was performed automatically, then if the answer lay close to the model answer, the system had positively identified the source of the error and could therefore provide that feedback to the student.

A planned future improvement is that in cases where a student's results are badly wrong, they could be presented with an option to request help from the teacher.

3.4 Collaborative Learning:

Once they have submitted their own results, students were then able to view the cumulative graph of all results submitted so far. They could thus compare their performance against that of their peers, providing useful feedback of their relative performance in the class. The remote system enabled students to assess their relative performance in private, without fear of embarrassment in front of their peers. It is suggested that this feature could be important in the motivation of students and their engagement with the subject [11].

Students could re-visit the compiled results graph to see how the data submitted by the whole class built up to form a complete frequency response. The students were also able to see the types of mistakes made by their classmates and learn from these mistakes without individual students suffering any embarrassment.

Students may therefore have felt more freedom to experiment with changing various parameters of the laboratory, just to see what happened, and may have learnt to a deeper level. At the same time as protecting the self-confidence of less-able students, the more-interested students had unlimited opportunity to investigate the system in depth, without feeling restricted by time or by peer pressure.

3.5 Students' Evaluation of Experiment

Representative responses from the students are reproduced (verbatim) below:

"Works fine, user friendly and easy to use. No error messages, no bugs!"

"All in all I rather enjoyed the session as I had all the time in the world to try and understand what was happening… Nevertheless the loss of social interaction and discussion was definitely missed."

"…highlighted the lag of the mechanical output response to the electrical input. I would be happy to use it again."

"Although good, it is a bit detached from the user and so not always a useful method of conducting experiments."

"…good that the results were so readily accessible…"

4. Conclusions

Remote-access and hands-on laboratories have inherent and fundamental differences, beyond the mere format of their interface, which result in differences in the learning process. Because of this, the authors expressly recommend against the use of remote labs as a like-for-like substitution for hands-on laboratory work. Instead, these differences should be exploited to make most effective use of each method. An accompanying paper by the authors within these proceedings considers the more general educational issues associated with different laboratory access modes and offers suggestions for best practice.

This paper has demonstrated some features of a novel remote-access laboratory structure, which would not have been possible with a hands-on format:

- Individual, personalised experiments were presented
  - to encourage individual participation, and minimise plagiarism
- All students observed the same experimental rig
  - Experimental results were able to be combined to achieve a collaborative learning outcome
- Submission of results was automated
- Assessment was automated
- Feedback was automated, which was:
  - Prompt,
  - Specific,
  - Formative,
  - Private
- Students were themselves provided with the opportunity to comment on their experience and provide feedback to the teacher.

These features were exploited to provide advantages in achieving the course's specific learning objectives, namely the concept of "frequency response". In addition, the ReLOAD system enabled the laboratory to be designed to increase student motivation and participation and to provide a useful, formative learning experience.

5. End Note

What has not yet been mentioned in this paper is that in this case, the students and teacher were based in London, whereas the apparatus was over 300km away in Leeds. This fact had no bearing on the running of the lab, which is noteworthy and an indication of the level of development now reached by remote-access methods.

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