2006-535: VIRTUAL AND DISTANCE EXPERIMENTS: PEDAGOGICAL ALTERNATIVES, NOT LOGISTICAL ALTERNATIVES

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Virtual and Distance Experiments: Pedagogical Alternatives, not Logistical Alternatives

Abstract

Remote and virtual access to laboratory classes are increasingly prevalent in undergraduate engineering courses, but as yet there have been few, if any, studies, that adequately evaluate the learning outcomes of these alternative access modes. The move to alternative access modes has been driven primarily by logistical imperatives such as increased flexibility of delivery, and potential cost reductions. This focus on the "how" of implementing the laboratories has come at the expensive of the "why" – the impact upon the students' learning has been largely overlooked.

This paper reports a study into remote and virtual access to laboratory equipment, and shows that there are statistically significant differences between the students' achievement on a number of learning outcomes. In particular, it shows that certain types of learning outcomes are impacted differently in different modes. This fine-grained analysis avoids the common pitfall of simply comparing overall aggregated marks, and shows that rather than no effect upon outcomes, there are instead multiple changes in learning outcomes whose combined effects upon the students' marks cancel out.

The transparency of the interface was found to be a key factor in determining the quality of learning outcomes in the remote mode; however, it was not found to be significant in the simulation mode. This finding, whilst surprising, is explained when the theory pertinent to separation is considered.

The take home message of this paper is that moving to remote and virtual access to laboratory hardware leads to significant changes in the learning outcomes of the students who experience this laboratory. In the face of such changes, these alternative access modes must be considered pedagogical alternatives, rather than simply logistical conveniences.

Introduction

Laboratory classes are a key element in undergraduate engineering teaching. They serve a number of valuable roles, such as validating analytical concepts, and providing exposure to professional practice [1]. One of the drawbacks of laboratory classes is that they are expensive, in terms of both time and money. Another drawback is the significant logistical challenge of scheduling access to hardware for potentially large groups of students. Remote and virtual laboratory classes provide an attractive solution to these drawbacks. They offer flexibility in delivery, with students able to access their laboratory class whenever and wherever they wish.

Since the first remote laboratory classes in 1996 [2], there has been a steady climb in the amount and variety of laboratory hardware that is available online. The field has matured to the point where there have been overview summary papers published in the literature [3], and even conferences dedicated to the area [4]. MIT in Boston are pursuing a world-wide network of remote laboratories – the iLabs project [5].

Whilst there has been substantial technical growth, the pedagogical aspects of the field have lagged behind – "Unanswered is the question on the effects of learning outcomes" [6]. This absence of proper evaluation is highlighted in its absence even from the summary papers dealing with the field. Trevelyan [3] refers to the preliminary publications from the present research [7] as "an unusual experiment" dealing with evaluation of outcomes, with no other references to studies involving evaluation of outcomes. The majority of the literature in the field is published as feasibility studies, showing that the chosen experiment is technically feasible in a remote mode. A few of the papers show preliminary intentions of how evaluation **will** be done (eg Tuttas & Wagner [6]), but on the whole there is a complete absence of concrete evaluation of actual outcomes.

One of the reasons for this lack of focus on evaluation is the potentially prejudicial views that staff and students bring to the experience, most likely based in the loss of the psychomotor domain outcomes. The first ever remote laboratory [2] was named "Second Best to Being There" – an explicit assumption that the remote experience was inferior to the proximal one. The assumption of inferiority was also propagated as an outcome from a forum discussing the future of control education – whilst acknowledging the opportunities offered by remote laboratories, ' "hands-on" laboratory experience remains the best way to educate students' [1] – a contention presented without any supporting evidence. This assumption that any remote implementation must be inferior, and only used as a "better-than-nothing-at-all" substitute, supports the lack of adequate evaluation – after all, if we know it is inferior, why waste time proving this?

More recently the assumption of inferiority has come into question. Studies have been performed in which the outcomes of alternative modes have been compared, such as that of Ogot [8]. This study compared the overall marks of students in both the remote and proximal modes, and concluded that there is no difference between the modes – a finding that would be valuable, were it not for the blurring caused by the mark aggregation process. There are many valuable outcomes of a laboratory class, and comparing only an aggregated mark introduces the risk that multiple effects may "cancel" each other. In order to gain a meaningful understanding of how the learning changes, a finer-grained analysis of a remote laboratory class is required.

The Laboratory Class

The laboratory which was investigated in this instance was the calibration of a piezoelectric accelerometer. This class forms a practical component for a third-year Mechanical Engineering unit in Data Acquisition and Control.

In this laboratory experiment, the accelerometer is mounted on an electrodynamic shaker, which is excited using signals generated by a spectrum analyzer. The velocity of the accelerometer is also measured by a laser Doppler vibrometer. This velocity signal and the accelerometer's own acceleration measurement are analyzed using the spectrum analyzer. The spectrum analyser calculates a transfer function between the two signals, $H(\omega)$, that is dependent upon the frequencies, ω, of the excitation signal. Using this experimentally-derived transfer function and the theory relevant to the experiment, students are then able to determine a calibration constant, A, for the accelerometer.

The laboratory is conducted primarily through a single point of control, the spectrum analyzer. As a result, the alternative access modes are simply a matter of providing a remote mechanism for controlling the spectrum analyzer, achieved in the remote implementation using a General Purpose Interface Bus (GPIB) connection. A MATLAB Graphical User Interface was constructed to represent the spectrum analyzer and to provide the user with access to the functionality of the spectrum analyzer that was necessary to perform this experiment. A simulation of the system was also constructed, using the same GUI as the remote interface. This simulation used recorded data from the system to generate responses interactively for the user. The simulation access mode differed from the remote mode only in the students' belief of whether there was actually real hardware involved. All other factors were kept the same. In this way some insight into the importance of the students' awareness of the access mode could be gained.

Two comparative trials were conducted with this laboratory. In order to gauge the importance of the audiovisual feedback in establishing the transparency of the interface, the first trial was conducted without audiovisual feedback, whilst the second trial included audiovisual feedback. As far as possible, the two trials were conducted in exactly the same manner, with the same equipment, the same handouts, the same marking scheme and the same post-test surveys. The only difference was a change in laboratory demonstrator.

The results of the second trial, incorporating audiovisual feedback, have previously been published elsewhere [9], reporting statistically significant differences between the modes. This paper reports the differences found between the modes in the first trial, without audiovisual feedback.

A range of tools were used to measure the changes between the modes. The tools that showed the most meaningful differences were the distributions of the students' perceptions of their learning objectives and of their learning outcomes, and the quantitative measures of these learning outcomes. Not all of the students involved in the study provided an equivalent amount of data to the study – some did not complete the post-test; some did not submit their assignments. A net total of 114 data points are used in the quantitative analysis.

Perceptions of objectives

As part of the post-test survey, the students were asked the question "What did you think the learning objectives of the laboratory class were?" Their responses to this question were allocated to seven categories, and the distributions of these responses compared (Figure 1):

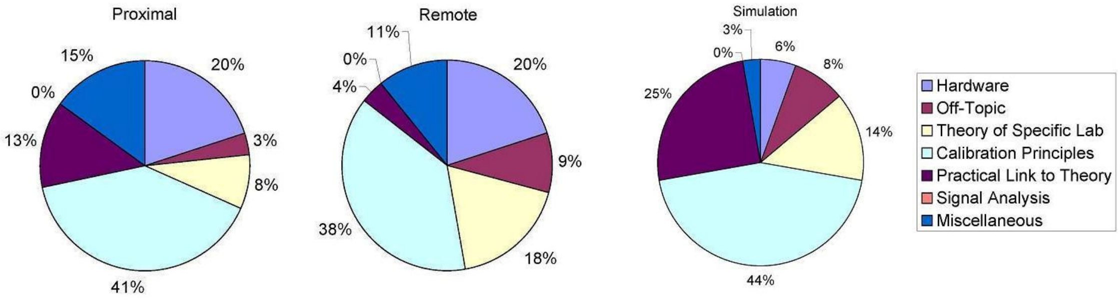

Figure 1: Perceptions of Learning Objectives

None of the modes generated any responses in the Signal Analysis category, reducing the number of degrees of freedom for the contingency table analysis to 10. The χ^2 statistic for this distribution was 18.55, which is larger than 18.31, the threshold value for significance at the p=.05 level [10]. This indicates that there are statistically significant differences in the distributions of students' perceptions of the objectives of the laboratory class, based upon their access mode. To determine where the differences in the distributions were, a z-technique analysis was performed, finding five differences were statistically significant, as shown in Table 1.

Table 1: Significant z-test results - Objectives

Category	Higher Mode	Lower Mode	P Value
Hardware	Proximal (20%)	Simulation (6%)	< .05
Hardware	Remote (20%)	Simulation (6%)	< .05
Practical Link to Theory	Proximal (13%)	Remote (4%)	< .05
Practical Link to Theory	Simulation (25%)	Remote (4%)	< .01
Miscellaneous	Proximal (15%)	Simulation (3%)	< .05

Table 1 shows that for the simulation mode, the absence of laboratory hardware served to reduce the importance of Hardware in the students' minds, whereas for the remote mode, physical separation from the hardware reduced the importance of linking theory to practice.

Perceptions of Outcomes

As part of the post-test survey, the students were asked the question "What was the most important thing you learned from the laboratory class?" Their responses to this question were allocated to seven categories, and the distributions of these responses compared (Figure 2).

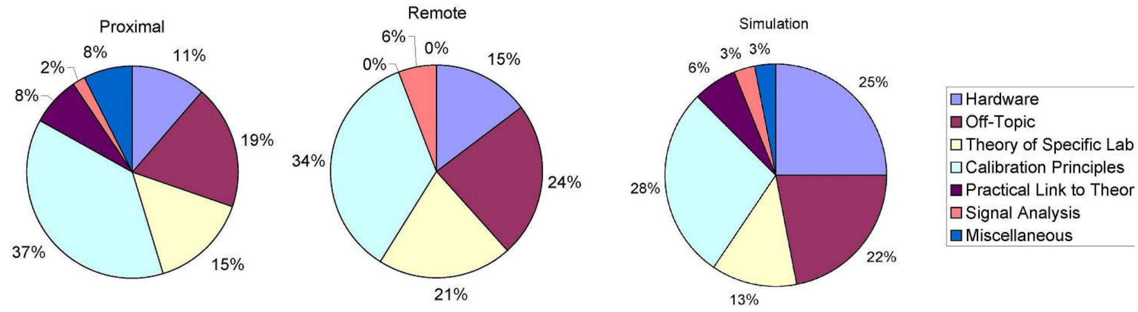

Figure 2: Perceptions of Learning Outcomes

The analysis of the students' responses indicated that their perceptions of their learning outcomes did not vary substantially between the three access modes - the χ^2 statistic for this distribution was 10.27, well below the 21.03 threshold of significance. There were some minor, possibly indicative differences in the distributions, but nothing that reached statistical significance. This is in contrast to their perceptions of the objectives of the laboratory class, which do differ according to access mode.

Upon initial inspection of Figure 1 and Figure 2, it appears that there are differences between the distributions of the responses for the two questions – that the students' perceptions of the objectives of the laboratory differ from their perceptions of the actual outcomes. Contingency table analysis generates χ^2 values of 12.259, 11.618 and 12.534 for the proximal, remote and simulation modes respectively – all very close to the threshold value of 12.59 for significance at the $p = .05$ level.

The z-technique analysis shows that whilst the overall distributions are not significantly different, four of the seven categories have at least one mode where there is significant dissonance between the students' perceptions of objectives and their perceptions of the outcomes (Table 2).

Table 2: Significant z-test results - Objectives vs Outcomes

Category	Mode	Objectives	Outcomes	P Value
Hardware	Simulation	6 %	25 %	< .05
Off-Topic	Proximal	3 %	19 %	< .01
Off-Topic	Remote	9 %	24 %	< .05
Practical Link to Theory	Simulation	25 %	6 %	< .05
Miscellaneous	Remote	11 %	0 %	< .05

Figure 2 shows that all three modes displayed similar distributions in the students' perceptions of the outcomes of the laboratory, suggesting that the dissonances are due to their perceptions of the laboratory objectives. Table 2 shows all three modes have a category that displays a statistically significant dissonance, but these dissonances are spread over four of the seven categories. Each mode induces specific dissonances, but these dissonances vary between the modes – each access mode alters the students' perceptions, but does so in a different way.

Marking Criteria Results

The students each submitted a written report on their laboratory class, due two weeks after the completion of the laboratory. The reports were marked according to whether specific behaviors were represented. From these behaviors, eleven criteria marks were determined. The student's mark for a criterion is simply the number of associated behaviors displayed in his or her report. Neither which of the behaviors are included, nor where the behaviors appear in the report matter. For example, the behaviors for Criterion Seven, the Resonance / Anti-resonance pair, are as follows:

There is a resonance around the 200 Hz frequency, and an anti-resonance around the 220 Hz frequency.

I. The student identifies the existence of the resonance and the anti-resonance
II. The student indicates that these resonances compromise the calibration they have just completed.
III. The student notes the range of frequencies (180 Hz to 230 Hz) that are affected by the resonances
IV. The student explains that the operating envelope for the accelerometer must not include the frequencies affected by the resonances.
V. The student indicates that these resonances will alter the gradient of the $|H(\omega)|$ vs ω curve.
VI. The student lists possible causes of these resonances
VII. The student postulates possible remedies to correct these causes of resonance.

Thus, for example, a student who indicates that the resonance and anti-resonance are present, and identifies the range of frequencies that are affected, but does not include any of the other behaviors, will score two for criterion seven. This fine-grained approach to marking the reports reduced the potential confounding impact of the marker. Marking is a digital yes-no process rather than a continuous "feels like seventy percent" approach.

Statistically significant differences were found in four of the eleven marking criteria:

- Criterion 1 - The relationship between the transfer function, $H(\omega)$, and frequency, ω.
- Criterion 2 – The Calibration Constant A

- Criterion 7 – The Resonance / Anti-resonance pair
- Criterion 9 – The Laser Doppler System

The 95% confidence intervals for the means of each mode are shown in Figure 3.

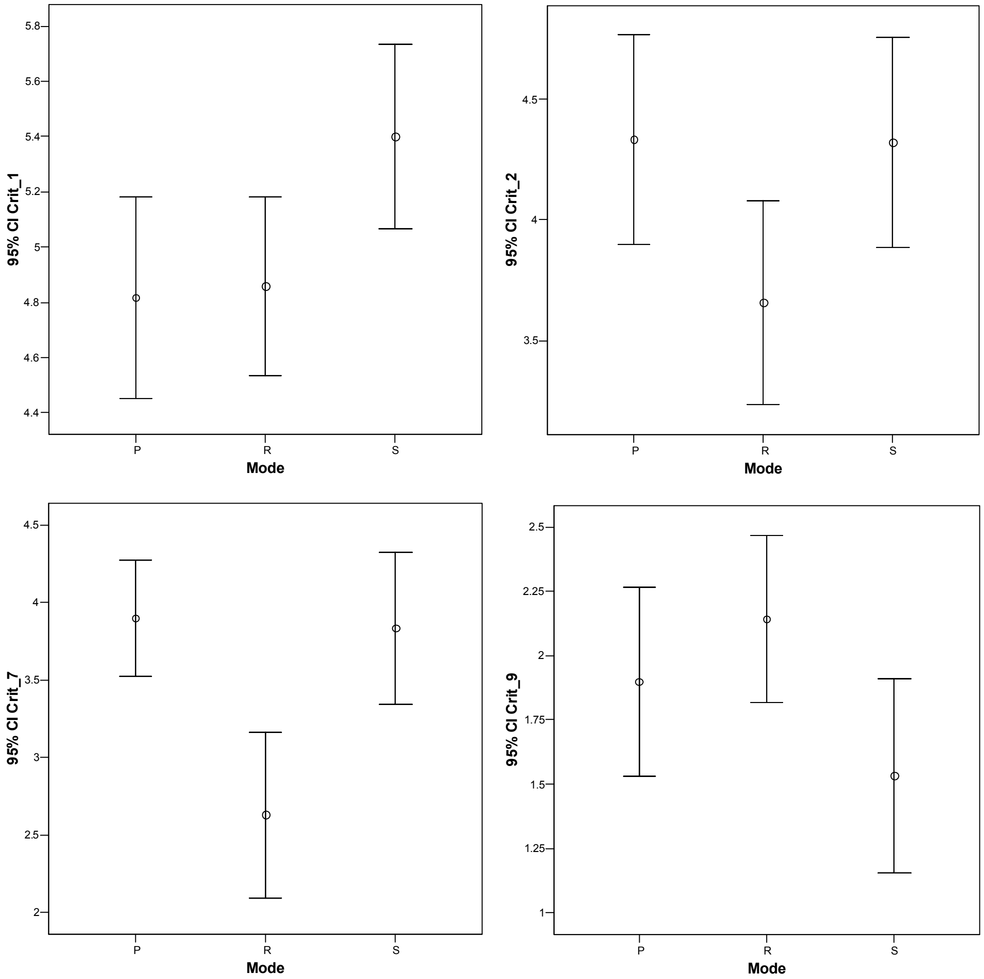

Figure 3: Confidence Intervals for Criteria Means - 1, 2, 7 & 9

The students display different performance based upon their access mode. There is no clearly superior mode, with different modes enhancing different criteria. Both the simulation and remote modes showed differences from the proximal, and from each other.

The students in the simulation mode showed a stronger understanding of the transfer function H(ω) and it's relationship with the frequency ω (criterion 1), but a poorer understanding of the laser Doppler system (criterion 9).

The students in the remote mode were much less able to handle unexpected results within the laboratory – demonstrated by highly significant differences for criterion 7, The Resonance/Anti-resonance pair. Students in the remote mode were less likely to indicate that they had detected unexpected results, and to demonstrate the consequences of these deviations.

Students in the remote mode also performed less well on criterion 2, the Calibration Constant – indicating that they were less likely to produce a correct value for the calibration constant, and to understand the limitations upon this calculation.

Perceived Impact of Alternative Mode

The students' perceptions of the change of mode were also surveyed via the question "What effect did you think your access mode had upon the laboratory class?" Transparency of the interface was a significant factor in the responses from the Proximal and Remote modes, but surprisingly absent from the Simulation mode responses. Around of a third (15 out of 44) of the Proximal mode students indicated that the unmediated interaction with the equipment made their mode superior. 29% (10 out of 34) of the remote mode responses indicated that the opaqueness of the interface had detracted from their learning. Responses of this nature, however, were almost entirely absent from the simulation mode.

The differing perceptions of the students towards their laboratory experiences is also implicit in the differences in perceptions and outcomes between the remote and simulation modes. Both modes are implemented using an identical interface, in an identical location, with identical resource materials. The key difference is the students' perceptions of the reality of the experience – in one mode, the hardware actually exists, and in the other it does not.

This difference in beliefs leads to significant differences in some of the desired outcomes of the laboratory class. This importance of perceptions is supported by the constructivist learning paradigm. Students create meaning by assimilating new information into the context of their prior learning [11]. Students encountering the laboratory class in a different context will assimilate the experience differently – and in doing so will learn differently.

A different kind of difference

Both this study, and the previously reported study with audiovisual feedback, show that there are significant differences in the learning outcomes of students exposed to remote and virtual access to laboratory hardware. This study has shown that the students' different beliefs regarding the hardware, and whether it is real, lead to significant changes in their perceptions of the objectives of the class, in their learning outcomes, and in their perception of the importance of the transparency of the interface.

Remote and virtual access are viable learning experiences, but they lead to different learning outcomes. Just as laboratories achieve different goals than lectures or tutorials, remote and virtual laboratories are different again – they must be considered as pedagogical alternatives, rather than merely logistical conveniences.

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