AC 2009-160: THE EFFECTS OF COMPUTER INTERFACE ON LEARNING OUTCOMES IN REMOTE-ACCESS LABORATORIES

M. Reza Emami, University of Toronto

Michael G. Helander, University of Toronto

THE EFFECTS OF COMPUTER INTERFACE ON LEARNING OUTCOMES IN REMOTE ACCESS LABORATORIES

Abstract

Remote access laboratories are increasingly being integrated into undergraduate engineering curricula on a global scale. Despite the vast body of literature dealing with remotely-accessible laboratories, the majority of papers have focused on the technical merits of a particular implementation, rather than on the implications of remote access experimentation on engineering pedagogy. Recently, a few studies have attempted to quantify the effects of the remote access modality on students' learning outcomes. These initial pedagogical studies have indicated that there is indeed a difference between proximal and remote experimentation in terms of learning outcomes. However, the question still unanswered is if these observed differences are a result of the physical separation between student and hardware, or rather are a result of the computer-mediated interface used to control the remote hardware. This paper discusses the results of a comprehensive study comparing the pedagogical effects of remote vs. proximal experimentation that includes control over the effects of the computer-mediated interface. Two groups of students performed the same experiment proximally and remotely using the *same* computer interface, and the learning outcomes are examined.

1. Introduction

The computer is ubiquitous across all engineering disciplines, and has had dramatic impact on the nature of the engineering profession. No longer is the computer a mere tool in the engineer's toolkit, but rather it has become a fundamental component of an engineer's daily work. More recently, the rapid expansion and maturation of the internet, has resulted in the computer also being adopted as a powerful collaborative medium for global engineering.

The computer and the internet have also been widely adopted in education, increasing both students' learning efficiency and scope of experience[1]. Web-based education, labelled as *eLearning*, has begun to be integrated into most undergraduate engineering programs both heuristically[2] and systematically[3]. However, the instructional laboratory—an essential element of engineering education—has not followed the same trend. Although the computer has significantly changed the nature of the instructional laboratory[4], the practical experience students gain through laboratory instruction has remained relatively untouched by the global scale of the internet.

Since the early days of the internet, numerous universities have attempted to introduce web-based remotely-accessible laboratories into the engineering undergraduate curricula, with only limited success. Despite over a decade of research and development, most remotely-accessible laboratories have remained as isolated technical novelties, with most projects being shutdown once their initial funding runs out. This point is reflected in the fact that most works in the literature address only the technical merits and potential benefits of remote access technologies, rather than addressing the impact of remote experimentation on engineering pedagogy. Clearly, a new fundamentally different approach to remotely-accessible laboratories is required.

Recently, a new paradigm for remotely-accessible laboratories, namely the *eLaboratory*, was introduced by the authors[5]. This new paradigm represents a crucial step towards multi-faceted curricula that bring together global resources at the undergraduate level, in order to prepare students for the emerging shift towards global engineering. However, since the effectiveness of the remote access modality in comparison with proximal experimentation has only recently been studied, it is still unclear what effect this new paradigm will have on students' learning outcomes.

The initial pedagogical studies have indicated that there is indeed a difference between proximal and remote experimentation in terms of learning outcomes. However, it is still uncertain if these observed differences are a result of the physical separation between student and hardware, or rather are a result of the computer-mediated interface used to control the remote hardware.

This paper discusses the results of a comprehensive study using the eLaboratory paradigm to compare the pedagogical effects of remote vs. proximal experimentation that includes control over the effects of the computer-mediated interface.

Section 2 presents a review of the current pedagogical studies of remote access laboratories. Section 3 summarizes the eLaboratory architecture that connects students to the remote experimental hardware. Section 4 presents the specifics of the study itself, including the relevant evaluation methods that were used. Section 5 presents the results of the study, including student feedback surveys, test scores and report scores, and discusses whether and how the physical separation from the hardware impacts students' learning outcomes. Finally, Section 6 concludes the paper and highlights areas for future research.

2. Literature Review

Remote access laboratories have been addressed extensively in the literature over the last decade. Early works tended to focus on the technical merits and potential benefits of remote access technologies, whereas more recent works have begun to investigate the effectiveness of the remote access modality in comparison with proximal or simulated experimentation. Despite the increasing interest in remote experimentation research efforts being somewhat fragmented and *ad hoc*.

The majority of the literature in the field only reports the technical merits of remote access laboratories, with most works being presented as feasibility studies to demonstrate that a particular experimental setup can be controlled remotely. The few papers that do attempt to evaluate the effectiveness of remote experimentation usually only report student feedback, with little or no systematic analysis of the results. In fact, it wasn't until recently that the theoretical implications of remote experimentation on learning outcomes were discussed. Clearly there is a deficiency between the technical and pedagogical development of remote access laboratories. However, despite this deficiency a few recent works have attempted a systematic approach to evaluating the effectiveness of remote access laboratories.

Corter *et al.*[6] compared the effectiveness of proximal vs. remote experimentation based on students' perceptions measured using student feedback, and learning outcomes measured using

composite test scores. The results were correlated against students' Standard Aptitude Test (SAT) scores, Grade Point Average (GPA), and preferred cognitive learning styles measured using the VARK catalyst. The study found that students with a *visual* cognitive preference tended to give a lower rating to the importance of being physically present in the lab, whereas students with an *aural* cognitive preference tended to feel more immersed in the remote experiment. Interestingly, these findings also correlated with a higher total VARK score (i.e., a strong preference for multiple cognitive modes). Overall, the study found that 90% of students rated remote experimentation as equally effective as proximal experimentation.

Tzafestas *et al.*[7] investigated the effects of different access modes on the *quality* of training for a robotic manipulator. The emphasis of the laboratory was on training students to program a robotic manipulator such that they could operate the physical hardware proximal. The study evaluated the effectiveness of proximal vs. remote and virtual access to the robot manipulator based on a final test of operating the real hardware. The study found that despite no statistically significant difference between access modes, there was still an identifiable trend in the degradation of low-level skills for the remote modality, over the other two access modes. However, the control interface provided to the virtual test group was far more comprehensive and provided a more accurate replica of the actual robot interface than for the remote test group. Therefore it cannot be assumed that the remote modality itself is to account for the observed trends in student performance.

Lindsay *et al.*[8] conducted an in-depth systematic study of the learning outcomes for different laboratory access modes as an extension to the work previously reported by Ogot *et al.*[9]. The study compared the effects of performing a piezoelectric accelerometer calibration experiment in three different modes; namely virtual, remote and proximal. Learning outcomes were evaluated based on student feedback and *granular* laboratory report scores. The report marking scheme was based on a systematic break-down of learning outcomes into criteria necessary to achieve each outcome. The criteria were then subdivided into specific behaviours required to demonstrate each criterion. The report scores represented an unbiased granular representation of student learning outcomes rather than an aggregate measure of overall performance. The study found that access mode did affect some learning outcomes, with different modes offering improved or degraded performance for different outcomes. The study also found that students' perceptions of the learning *objectives* were affected by access mode, whereas students' perceptions of their learning *outcomes* were unaffected. Interestingly the study found that 30% of students preferred the mode that they had experienced, whereas 60% of students preferred the proximal mode.

The results of these recent studies seem to indicate that there is indeed a difference between proximal and remote experimentation in terms of learning outcomes. However, the question still unanswered is if these observed differences are a result of the physical separation between student and hardware, or rather are a result of the computer-mediated interface used to control the remote hardware. All of the previous studies have compared proximal experimentation with the physical hardware to remote experimentation through a computer-mediated interface. In the comparative study reported in this paper both proximal and remote students interact with the hardware using the *same* means to isolate the effect of the computer-mediated interface from the effect of the physical separation from the hardware.

3. The eLaboratory

The eLaboratory paradigm[5] is an extension of the traditional physical laboratory environment to a web-based domain that includes the social interactions and collaborative constructs that transcend any particular classroom, laboratory or course. Students, instructors and teaching assistants (TAs) access the eLaboratory through a centralized engineering portal gateway. A schematic of the eLaboratory architecture is depicted in Fig. 1.

The experiments in the eLaboratory consist of computer-controlled hardware setups, each hosted on a dedicated Target Personal Computer (PC) equipped with a number of Data Acquisition (DAQ) boards. The user interface for each experiment is published to the portal using the Remote Desktop Protocol (RDP). Live video from the experiments is accessible from a number of webcams throughout the physical laboratory.

If a student encounters difficulties during an experiment they can use an Instant Messaging (IM) web client, and contact the TA or instructor for help. The TA can then log onto the experiment to take control of the user interface and show the student what to do. During the course of an experiment any data files, images or videos that the student collects are saved to the portal. After completing the experiment the student can remotely access engineering software applications through the portals web-based application server. Completed laboratory reports are submitted, graded and archived through an automated paperless workflow.

4. Evaluation

The study was conducted for a stand-alone laboratory course (AER303) for third-year undergraduate Aerospace Engineering students at the University of Toronto. This course introduces students to the fundamentals of experimentation in the context of Aerospace Science and Engineering. Students are also exposed to computer-aided data acquisition and control for the first time in this course. The course spans one semester in the fall term and is composed of two experiments that focus on aerodynamics and structural materials.

4.1 The Course

In AER303 students perform two experiments over the course of the fall semester. The first experiment illustrates some applications of strain gages using pre-gauged cantilever beams to determine the Elastic Modulus, Poisson's ratio and the material loss factors for a variety of materials including several advanced composites. The second experiment, which is the focus of this study, illustrates some experimental applications of a subsonic wind tunnel using static and dynamic pressure measurements to determine the section lift and drag coefficients of a symmetric airfoil.

The learning objectives for AER303 are to teach students proper data analysis techniques and to introduce them to formal scientific writing. The procedure and expectations for each experiment are explicitly defined at the start of the course to ensure students are not overwhelmed by their first experience with computer-aided data acquisition and the remote access modality. Comprehensive experiment manuals are provided that explain the background theory and have

step-by-step instructions on how to complete each experiment and analyze the resulting data. In this respect the experiment manual servers as a script for students to follow.

4.2 The Airfoil Experiment

The airfoil experiment demonstrates some basic concepts of subsonic flow using a nominal 50 m/s wind tunnel. A variable pitch NACA 0015 symmetric airfoil equipped with 11 surface pressure taps spans the tunnel test section and a multi-tube water manometer board is used to monitor the surface pressures and provides a visual display of the dynamic changes associated with varying angles of attack. A Pitot-static (Prandtl) tube is mounted at the front of the test section to measure the static and impact pressures required to determine the flow velocity. The dynamic pressure from the Pitot-static tube is measured using a Betz manometer, which is remotely observable using a webcam.

The pressure from the airfoil pressure taps is measured using a Scanivalve® pressure transducer system that converts pressure values to a voltage that can be read by the Analog-to-Digital (A/D) converter on the DAQ board. The angle of attack of the airfoil in the tunnel test section is changed using a pitch system that can rotate the airfoil through a full 360˚. The pitch system consists of a stepper motor, controlled using digital Input/Output (I/O) from the DAQ board, and gear transmission to rotate the airfoil with an angular resolution of 0.18˚. The user interface for the airfoil experiment is depicted in Fig. 2.

4.3 The Students

The student cohort in this study was composed of 42 third-year undergraduate students in the Aerospace Engineering option of the Engineering Science program at the University of Toronto. The first two years of Engineering Science provide a rigorous background in engineering fundamentals, with students specializing into a particular option in the third and fourth years. Hence, all students had an identical background in terms of their undergraduate engineering education.

4.4 Student Feedback Surveys

Students were advised to complete two feedback surveys—one at the beginning of the course and a second after completing the airfoil experiment—in order to determine their perceptions of the effectiveness of the eLaboratory. Both surveys were conducted online through the portal. Students were asked to complete the pre-experiment survey as part of the user registration process for the portal. The post-experiment survey was given as part of the online submission process for the airfoil experiment laboratory reports.

In the previous evaluation of the eLaboratory paradigm[5], only the second survey was given at the end of the course. In this study two surveys were used to investigate how students' perceptions of remote experimentation are altered by their experiences in AER303.
The following seven questions were asked for the pre-experiment survey:

1. *What do you think the learning objectives of this course are?*

2. *If given a free choice between proximal (in person in the laboratory) or remote which access mode would you choose and why?*
3. *To what extent do you think physical interaction with an experiment setup influences your learning outcomes?*
4. *How extensively have you played video games in the past or present?*
5. *How many hours do you spend online (e.g. internet, MSN, facebook, etc.) each day for* <u>academic</u> *purposes?*
6. *How many hours do you spend online (e.g. internet, MSN, facebook, etc.) each day for* <u>non-academic</u> *purposes?*
7. *How many hours on average do you spend online each week (weekend included)?*

The following seven questions were asked for the post-experiment survey:

1. *What do you think the learning objectives of this course were?*
2. *If given a free choice between proximal (in person in the laboratory) or remote which access mode would you choose and why?*
3. *Did you feel that the data you collected was accurate?*
4. *What was the most important thing you learned from this course?*
5. *Did you enjoy this course? Why or why not?*
6. *Do you think that remote access experimentation should be used in undergraduate engineering education? Why or why not?*
7. *Did you find this course intellectually stimulating? Why or why not?*

4.5 VARK Catalyst

In addition to the feedback surveys, students were also asked to complete the VARK learning style catalyst[10], which measures cognitive learning style preferences across four categories: namely visual, aural, read-write, and kinesthetic. The VARK catalyst (version 7.0) consisted of an additional 16 multiple choice questions at the end of the pre-experiment survey.

4.6 Lab Report Scores

Each student submitted a written laboratory report for the airfoil experiment, due two weeks after the completion of the laboratory. Each lab report was marked out of 100 using a granular marking scheme that reflected the learning objectives of the course. A heavier weight was given to the depth of data analysis and to the quantitative analysis of error. The TAs were instructed to mark the reports based on a fixed set of criterion that reflected students' learning outcomes.

4.7 TA Marking Surveys

In addition to the granular report scores, the three TAs for AER303 were asked to complete a survey for each lab report that they marked. The following six questions were asked for the TA survey:

1. *Did the student identify any pieces of equipment that contributed to experimental error?*

2. *Did the student identify any part of the computer interface that contributed to experimental error?*
3. *In the experimental procedure section did the student refer to the actual equipment or to the computer interface?*
4. *Did the student use the strings on the airfoil to identify stall? (i.e. a visual observation)*
5. *How many references did the student use in their report?*
6. *Based solely on the lab report, which access mode (proximal or remote) do you think the student used?*

4.8 Post-Experiment Quiz

Students also completed a short 5 question pop-quiz during the final discussion session for the airfoil experiment (approximately one week before the lab reports were due). The quiz was given on a single A4 sheet of paper and students were given 15 minutes to complete it. The following five questions were asked for the post-experiment quiz:

1. *How was the air speed of the subsonic wind tunnel measured in the Airfoil experiment?*
2. *Why were the measured pressure values in the Airfoil experiment negative in sign?*
3. *What are the approximate dimensions of the NACA 0015 airfoil used in the Airfoil experiment (i.e. span, maximum thickness, width)?*
4. *When the Scanivalve® takes a pressure measurement you hear a "clicking" sound. What do you think this sound is?*
5. *Why is there a limit on the maximum speed of the wind tunnel, and what happens when the speed goes above this limit?*

These questions were meant to test students' understanding of the experiment in terms of their perceptions of the physical hardware.

5. Results

No statistically significant (confidence level > 95%) differences were observed between student's that performed the experiment proximally or remotely. However, several interesting trends were evident in the data. Between the pre- and post-experiment surveys (See Fig. 7) the fraction of students that either preferred remote access or showed no preference increased from 33% to 48%. This result is attributed to students' increased experience and comfort level with remote experimentation *after* having used the system. This notion supports previous findings that suggest students tend to prefer proximal experimentation due to their familiarity with this access mode. Students' preferred access mode is depicted in Fig. 8.

There is a good agreement between the learning objectives identified by students in both the pre- and post-experiment surveys (see Fig. 3). This is not surprising given that we would not expect students' responses to change significantly after performing the experiments. However, similar to the results reported in the authors' previous study[5], there is significant dissonance between students' perceived learning objectives and their perceived learning outcomes, as indicated in Fig. 4. The majority of students indicated on the post-experiment survey that the primary learning objectives of the course were lab report writing and experimentation skills. However,

most students indicated that their most important learning outcomes were related to learning skills and data analysis.

Students' perceived learning outcomes, depicted in Fig. 5, showed no significant correlation with access mode. Interestingly, the post-experiment survey results indicate a difference in perceived learning outcomes for different access modes, although the results are not statistically significant (< 95% confidence).

Interestingly, despite no significant difference in report marks between the proximal and remote groups of students, there is strong correlation between student's access mode and the TAs' response to question 6 of the Marking Surveys (*Based solely on the lab report, which access mode (proximal or remote) do you think the student used?*). Clearly access mode can affect students' writing style, although the final marks for the reports were similar for both groups.

Several typical positive responses to the remote access modality include:

- *"definitely useful if there are students with mobility issues"*
- *"better access for the majority of the students"*
- *"more freedom"*
- *"it is simply convenient"*
- *"I see this as an opportunity to experience another dimension in the execution of labs"*

Several typical negative responses to the remote access modality include:

- *"Eyesight is superior to cheap cameras in speed and field of vision"*
- *"I would like to see things with my own eyes and touch things with my own hands"*
- *"I felt that I was just clicking buttons and that there was no experimental aptitude required"*
- *"I feel like a significant amount of freedom needs to be added for these to be beneficial learning experiences"*
- *"video and sound cannot fully replicate the feeling of being present in the lab"*

Finally, most students commented about the positive impact of integrating new technologies into the instructional laboratory. The comments focused mainly on the benefits of computer-aided data acquisition and the scheduling advantages. Several students also indicated that their experience with the remote laboratory gave them a better understanding of the challenges faced in conducting global engineering projects. An overwhelming majority of students indicated that remote experimentation should be included as part of the undergraduate engineering curricula, but not at the cost of traditional proximal laboratory experience.

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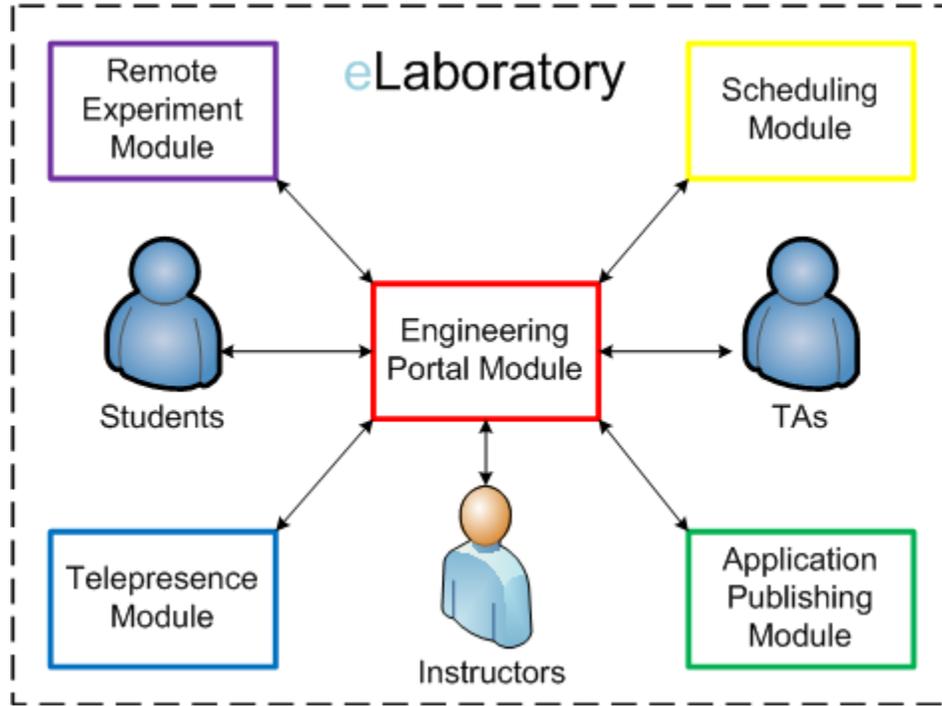
Figures

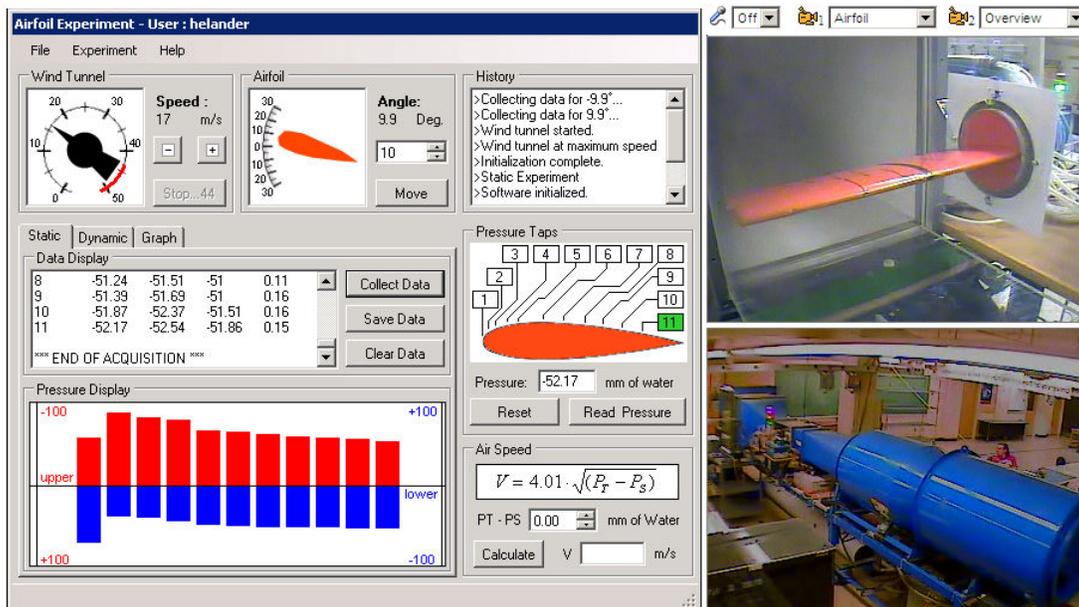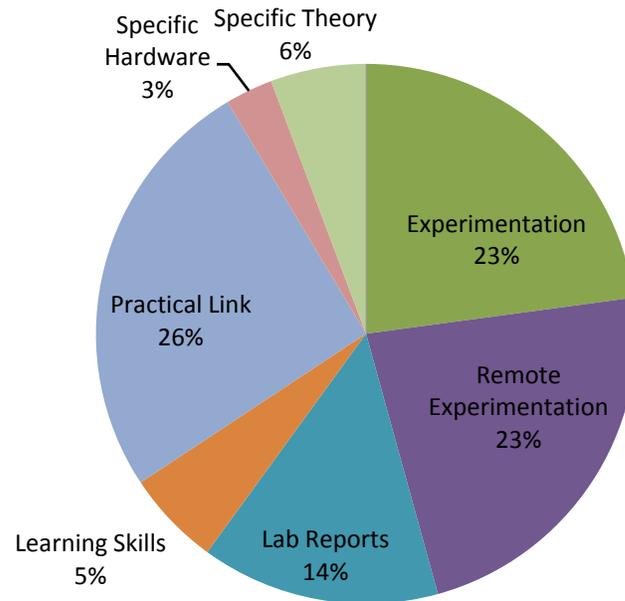Figure 1: Schematic overview of the eLaboratory architecture.

Figure 2: User interface for the airfoil experiment.

Pre-Experiment Learning Objectives

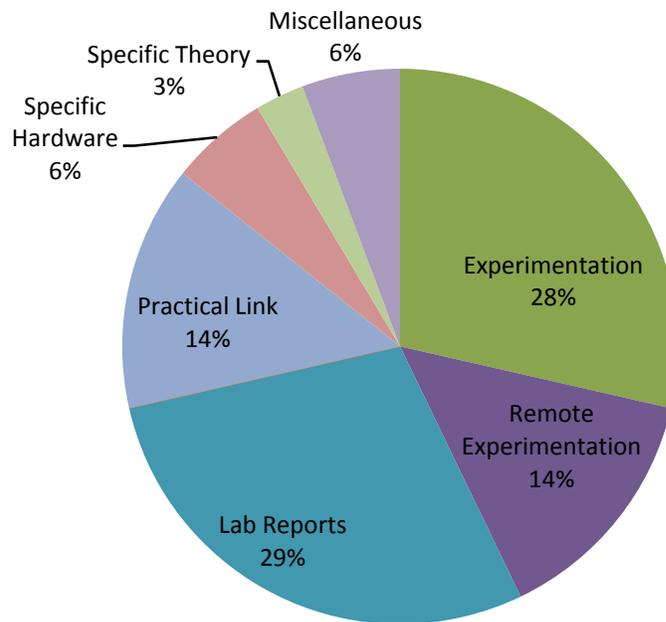## Post-Experiment Learning Objectives

Figure 3: Students' pre- and post-experiment perceived learning objectives.
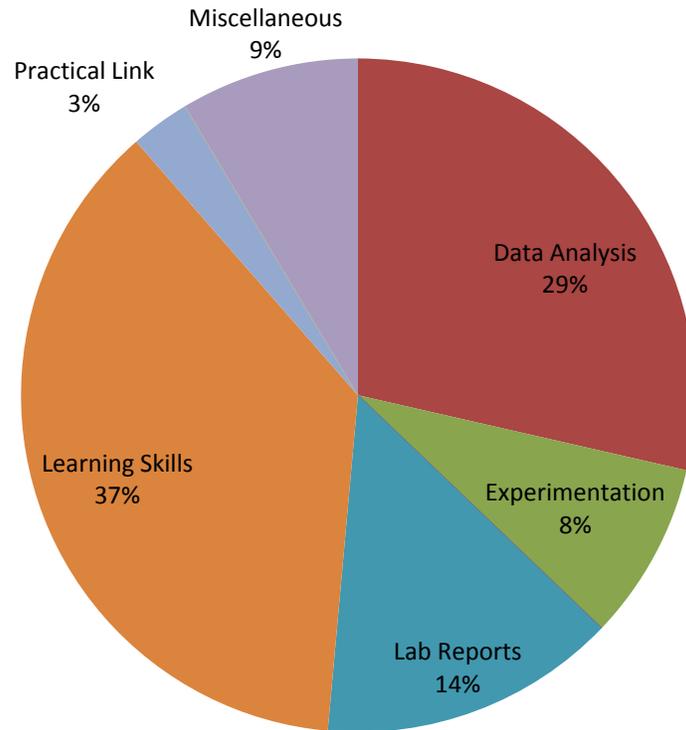
Post-Experiment Learning Outcomes

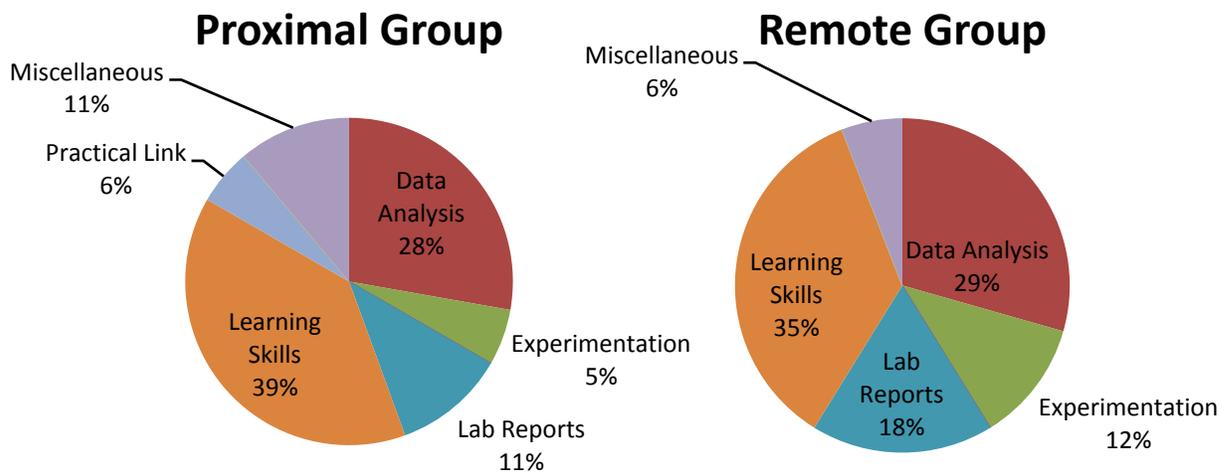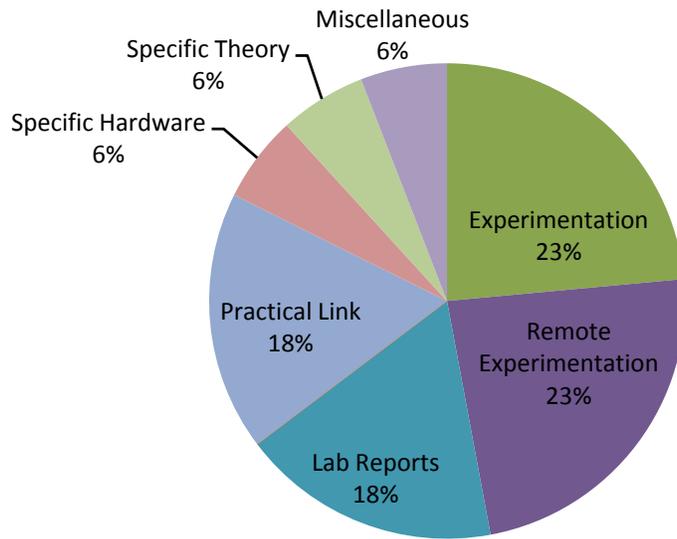Figure 4: Student's post-experiment perceived learning outcomes.

Figure 5: Students' perceived learning outcomes by access mode.

Proximal Group Learning Objectives

Miscellaneous 6%
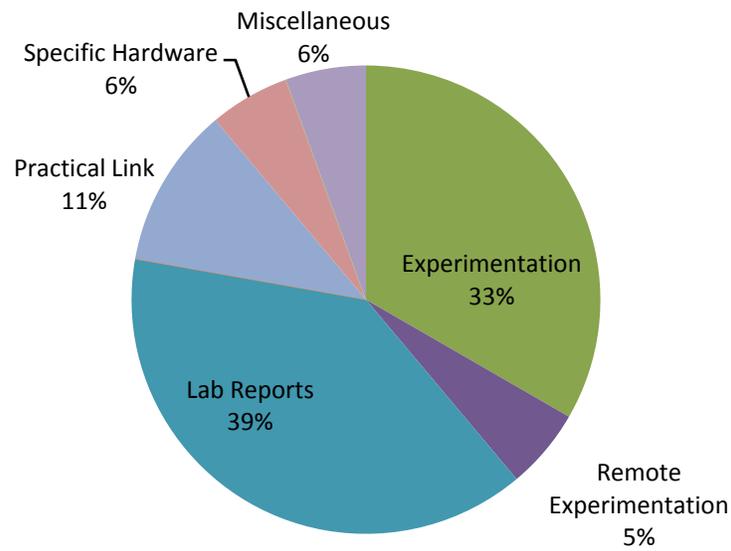Specific Theory 6%
Specific Hardware 6%
Practical Link 18%
Lab Reports 18%
Experimentation 23%
Remote Experimentation 23%

Remote Group Learning Objectives

Miscellaneous 6%
Specific Hardware 6%
Practical Link 11%
Lab Reports 39%
Experimentation 33%
Remote Experimentation 5%

Figure 6: Student's perceived learning objectives by access mode.

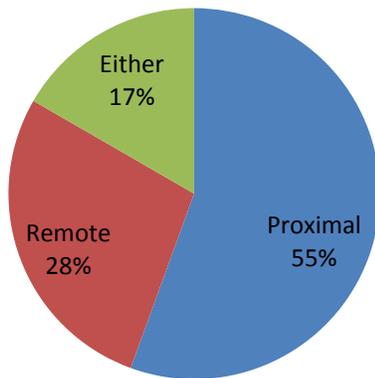## Pre-Experiment
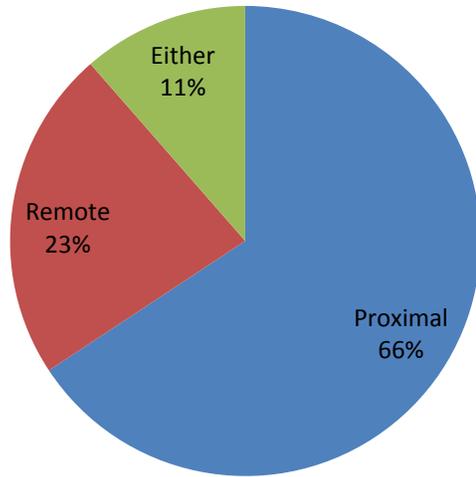
Post-Experiment
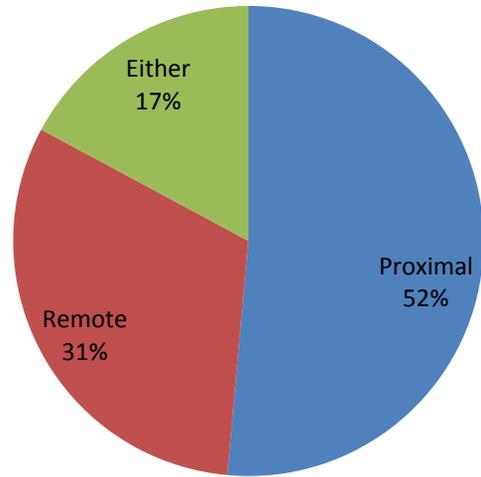
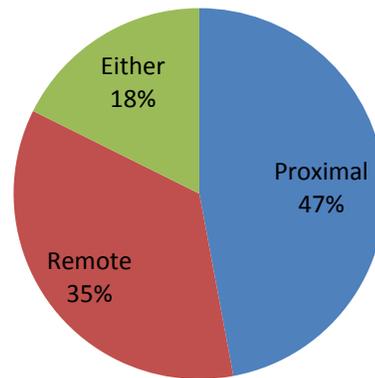Figure 7: Students' preferred access modality by survey.

Proximal Group

Remote Group

Figure 8: Students' preferred access modality by access mode.