ASESSING LABORATORY EFFECTIVENESS IN ELECTRICAL ENGINEERING COURSES

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***Abstract** - A laboratory component is being added to a four-course sequence in the undergraduate electrical engineering curriculum at the University of Nebraska, Lincoln, in an effort to increase student learning and improve retention of prerequisite concepts. The lab and the study of its effects on achieving the course objectives in an undergraduate level course, ELEC 304 Signals and Systems, and a senior/graduate level course, ELEC 464/864 Digital Communications are discussed. The study uses a mixed method protocol in which the impact of the laboratory experience is measured through quantitative and qualitative techniques. This paper discusses the design of the study and results gathered to date.*

Index Terms –laboratory, assessment, electrical engineering

INTRODUCTION

The Department of Electrical Engineering at the University of Nebraska, Lincoln (UNL), is implementing an Integrated Signals and Systems Laboratory with a single experimental platform throughout a sequence of four courses at the junior and senior levels. This laboratory is funded by a Course, Curriculum and Laboratory Improvement (CCLI), Adaptation and Implementation (A&I) track, grant from the National Science Foundation (NSF). The laboratory experience uses a single experimental platform, the Telecommunications Instructional Modeling Systems (TIMS), throughout the four-course sequence. All four courses are in the systems area, with an emphasis on communications systems, and have significant mathematical and theoretical content. An essential component of the grant proposal is a formal study of the effects of this laboratory experience on student learning and teaching efficacy.

In this paper, the results obtained from this study to date are presented. The paper begins with a statement of the hypotheses posed concerning the impact of the laboratory and with a brief description of the courses being studied and the course objectives. This is followed by a description of the study protocol used in the Fall of 2002. Quantitative and qualitative results are presented for the Fall 2002 study. Finally, the study protocol used for the Spring 2003 semester is described. The conference presentation will contain results of the Spring 2003 study as well.

RESEARCH HYPOTHESIS AND COURSE OBJECTIVES

The undergraduate electrical engineering curriculum at UNL includes a four-course sequence with an emphasis in communications systems at the junior and senior levels. These four courses, ELEC 304 Signals and Systems, ELEC 305 Probability and Random Process, ELEC 462/862 Communication Systems, and ELEC 464/864 Digital Communications, have significant mathematical and theoretical content. In an effort to increase student learning in these courses, it was decided to add a laboratory component to each course. The laboratory component is incorporated directly into each course in place of a portion of the traditional homework assignments, computer projects and/or lectures; this is not a separate laboratory course and the number of the credit hours for each course remains the same. This required an experimental platform that avoids the traditional implementation pitfalls of a circuit-based laboratory without becoming the “black box” laboratory that turns students into passive observers rather than active discoverers. The Telecommunications Instructional Modeling Systems (TIMS) was chosen as the experimental platform [1]-[3].

In the course of designing the TIMS based Integrated Signals and Systems Laboratory and considering its impact on student learning, two basic hypotheses were posed:

1. A positive laboratory experience will increase student learning and facilitate achievement of the course objectives in each of the four courses.
2. A consistent laboratory experience will increase prerequisite retention from course to course in the four-course sequence.

As part of the NSF CCLI grant, the authors proposed to formally study whether or not these hypotheses were true. In order to do this, a mixed method study combining quantitative and qualitative methods was proposed. A combination of quantitative and qualitative methods is better suited to measure student learning outcomes, and as such,

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more accurately measure differences in student comprehension resulting from the laboratory. Further, a mixed methodology study design can help improve the validity of data by using more than one method to study the same phenomenon. The mixed method assessment instrument will facilitate data triangulation, which will help to ensure that any variance measured reflects the desired traits rather than the method[4],[5].

During the Fall 2002 and Spring 2003 semesters, the laboratory experience was incorporated into ELEC 304 Signals and Systems and ELEC 464/864 Digital Communications. The primary objective of the junior level course ELEC 304 is to teach students time domain and transform analysis of continuous and discrete linear systems with the goal of preparing the students for subsequent senior level courses in communications, control and signal processing. The specific course objectives for ELEC 304 are for the students to learn:

- to determine the total system response as the sum of the zero input response and zero state response.
- to use Fourier analysis.
- to determine the steady state response of linear time-invariant systems to periodic inputs.
- the equivalence of energy in the time and frequency domains.
- to determine the complete response of linear time-invariant systems using Laplace and z-transforms.

The primary objective of ELEC 464/864 is to teach students the fundamentals of digital baseband and bandpass modulation techniques in the presence of additive white Gaussian noise (AWGN) using signal space techniques. The specific course objectives for ELEC 464/864 are for the students to:

- become familiar with the performance capabilities of current digital communication systems.
- understand the conceptual and analytical differences between analog and digital communications.
- understand the significance and validity of the signal space model.
- understand the concepts behind single symbol and sequence optimal receiver design.
- be able to compute the probability of error of digital communication systems on the additive white Gaussian noise channel.
- understand the effect of nonideal channels.
- understand the design issues in a digital communication system.

(Please note these course objectives are the Departmental objectives and not objectives established by the authors.)

The motivation for creating the Integrated Signals and Systems Laboratory is to increase student achievement with respect to these objectives and to provide feedback on the validity of the course objectives. The studies to date are concerned with student achievement. During the Fall 2002 semester, hypothesis 1 was tested in ELEC 304.

ELEC 304 AND HYPOTHESIS 1, FALL 2002

Crucial to any teaching that aims to use real events from which students can learn, whether demonstration or hands on exercises, is the student's interpretation of their observations. Constructivism states that students come to the classroom holding personally constructed ideas and beliefs that are often at odds with the tenets of science[6]. One possibility with labs is that these ideas and beliefs can be simply restructured to become the ideas and beliefs of science by using practical work to cover inconsistencies. Thus, the laboratory exists not only to connect theoretical and/or mathematical concepts of signals and systems with the "real world", but also to clear misconceptions students might have because of their personally constructed ideas. The results provide evidence for increased student motivation.

Study Design for Fall 2002

During the Fall semester of 2002, the Integrated Signals and Systems Laboratory was implemented in ELEC 304 Signals and Systems. In order to assess the effect of the laboratory on student learning a study protocol using both quantitative and qualitative techniques was used. A mixed method was necessary due to the small sample size presented in this course and in order to accommodate the diverse cultural and educational backgrounds of the students.

The quantitative study uses a traditional scientific model that includes the use of voluntary control and treatment groups. Both the control and the treatment groups received instruction using traditional teaching methods. The control group undertook analytical homework problems and the experimental group had a laboratory component that replaced a part of the homework problems. Student's prior knowledge was measured by their performance on identical baseline instruments administered to both the control group and the treatment group prior to the laboratory experience. The control and treatment groups existed for a single assignment or concept. Both the treatment and control groups were reconfigured for each assignment. By reconfiguring the control and treatment groups for every lab assignment all the students who volunteered for the study had the same amount of exposure to the lab.

Each laboratory was designed to provide the students the underlying mathematical concepts and to illustrate the usefulness of the concepts. Both the control and treatment groups received traditional lectures over the concepts. Pre-quizzes were given in order to assess any baseline knowledge of the concepts. Post-quizzes were used as a measure of difference in learning between the control and treatment groups. The quantitative part of the study focused on student learning of particular concepts that are normally taught using class lectures and homework.

The qualitative component of the study emphasizes the perceptions of students as expressed through journals and interviews. The students sent electronic journals after every lab assignment. The journal questions were survey questions that gave an insight on how the students perceived the lab experience. At the end of the semester, ten students were selected from the treatment group for a 30 to 45 minute interview by an educational specialist and an electrical engineering professor familiar with the course, but who did not teach the course during the current semester. The ten students were chosen across a broad spectrum of academic performance. The interviews are transcribed and analyzed for themes, which can provide insights regarding the effectiveness of the laboratory experience. The questions posed to the students are open ended and students are encouraged to express thoughts not directly related to the questions asked. It is important to note that the qualitative study does not involve any students from the control group.

The following questions were asked of all students and provided the basic structure for the interview.

- Are there course concepts that have been clarified by the laboratory experience?
- What is your perception of the time spent versus understanding gained?
- Did the laboratory influence your dedication to the course? More interesting?
- Did the laboratory experience help you understand the utility (usefulness, practicality) or course materials?
- Did your laboratory experience give you a real or perceived advantage in the course?
- Any additional student comments and further follow up questions.

The overarching question is "Does the signal and systems laboratory experience improve student understanding of the fundamental systems and communications concepts?"

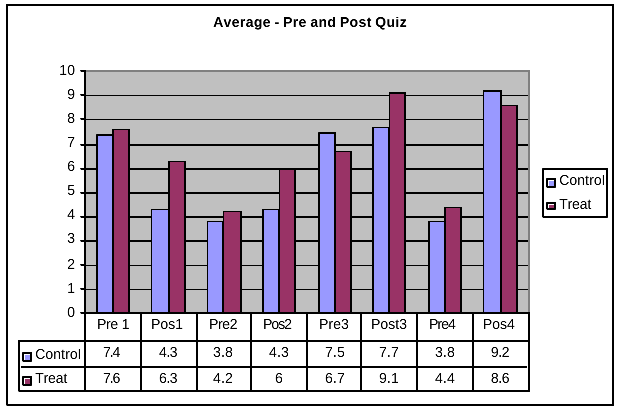
Results for Fall 2002

A total of four laboratories were integrated into ELEC 304 covering the following concepts:

- Frequency content of periodic signals, the Fourier series.
- Properties of the Fourier transform.
- Filtering of signals.
- Frequency response of systems.

The treatment group was given an assignment consisting of traditional analytical homework problems and the laboratory while the control group was given only traditional analytical homework problems. The laboratory was given to the treatment group in place of one or more traditional homework problems given to the control group. The deleted homework problems covered the same concepts as the laboratory. Student learning on each assignment was measured by administering assignment specific pre- and post- quizzes.

This sequence of lectures, pre-quiz, homework/laboratory, post-quiz was carried out on four independent concepts. The quantitative results from the pre- and post-quizzes, for the four assignments are shown in Figure 1, which do not include students who dropped the course or students who missed either the post- or pre- quiz.



	Pre 1	Pos1	Pre2	Pos2	Pre3	Post3	Pre4	Pos4
Control	7.4	4.3	3.8	4.3	7.5	7.7	3.8	9.2
Treat	7.6	6.3	4.2	6	6.7	9.1	4.4	8.6

FIGURE 1:
QUANTITATIVE RESULTS FOR ELEC 304 SIGNALS AND SYSTEMS.

The quantitative results suggest increased learning for the treatment group who received the laboratory experience. The only instance when the laboratory did not seem to provide an apparent advantage was during concept # 4. Unfortunately, based on a single sample t-test with a 0.05 confidence interval, the difference was not statistically significant. However, when the pre-test score differences are controlled (used as covariate) significant group differences exist in post test scores ($F(1, 46) = 5.216$, $P = .027$). This could be attributed to the carry over knowledge the students had from the previous laboratory assignment or a certain degree of contamination due to discussions between students in the two groups. Further there were only four labs assigned during the semester, so retention of knowledge gained from the lab experience was not possible in many cases. This was evident from the student interviews that were conducted at the end of the semester.

The qualitative data from the study are still being formally analyzed, but a preliminary analysis has produced some insights about student performance and their perceptions regarding the laboratory experience. Although most of the students stated that they did not believe their performance in the class was positively affected by the laboratory experience, they did say that the laboratory clarified some course concepts but they did not think that the laboratory program improved their scores or grades. Further all ten students, nine of whom stated no perceived improvement in scores, stated that the laboratory made the course more interesting. While the students were able to identify increased interest levels, they were not able to connect their increased interest with any real or perceived improvement in scores. The students stated that they liked being able to translate the theoretical concepts into "real" examples on the laboratory equipment. In fact, very few students manifest metacognition when they stated that the laboratory helped them to "see" what was described by the mathematics. None of the students cited this as a performance factor. Preliminary data triangulation between the quantitative and qualitative results from this semester has also raised questions about the study protocol. Why do students who believe the lab helped them understand concepts also say it did not improve their performance on quantitative instruments?

Another theme that has begun to emerge from the qualitative data, is a difference in perception between students and faculty as to what an electrical engineer actually is and does. It was clear after the interviews that some of the students perceived themselves to be technicians and gave more importance to the practical aspects involved in using the equipment over the theoretical concepts that were expected to be clarified by the equipment.

LAB IMPLEMENTATION AND STUDY DESIGN FOR SPRING 2003

In the Spring 2003 semester, the laboratory is being used in ELEC 304 and, for the first time, in ELEC 464/864. Though the results for the Fall 2002 study are encouraging, the lack of statistical significance in the quantitative data raised several issues about the study protocol. For example, are five minute pre- and post-quizzes sufficient to measure the higher level learning expressed in the course objectives? Is a single lab assignment sufficiently correlated with a course objective to have a lasting effect or is a more sustained laboratory experience required?

With the hope of obtaining stronger data, the quantitative protocol for the Spring 2003 semester is based on a pure treatment group and a control group. All students who volunteer for the study were divided on a random basis into a control group and a treatment group. As opposed to the Fall 2002 study, the groups will be maintained for the entire semester. The control group will receive the normal course lecture and homework assignments, while the treatment groups will receive a modified homework assignment in which a laboratory is substituted for one or two of the problems on the control group assignment. Student learning is being measured as the difference between the performance on a baseline exam given at the beginning of the semester and the normal course final exam.

The baseline exams were administered at the beginning of the semester to measure any previous knowledge of the current course's content. The baseline exam covered material that is to be covered throughout the current semester and is not used to measure knowledge of prerequisite material. The baseline exam was crucial for ELEC 464/864 because many of the graduate students in this class are international students with previous industrial experience. A typical student received a very low score on the baseline exam. The final exam is administered at the normal time and covers the same material as the baseline exam. The final exam will contain a few questions from the baseline exam. The difference in the performance between the two groups will be computed. Any statistical significance in grade between the two groups would then be cross checked with the course objectives and the concepts covered in the lab assignments to verify the hypothesis.

The qualitative study was also modified for the Spring 2003 semester. The qualitative study began with a journal entry in which members of the treatment group were asked to write on how they perceive engineers versus technicians. The aim of this journal entry was to learn more about the students' perceptions of the electrical engineering profession and its relationship to the current course. A similar question will be posed to the students at the end of the semester. During the Spring 2003 semester, the students in the treatment groups for both ELEC 304 and ELEC 464/864 will make a journal entry after every lab assignment. The journal entries will be guided by questions that seek to understand the impact of the lab on student learning with respect to specific course concepts and the overall course objectives.

At the end of the semester, a subset of students from each class's treatment group will be selected for a 30 to 45 minute interview. The interview will be conducted by an education specialist and an electrical engineering faculty member familiar with the respective course, but who is not currently teaching it. In addition to the questions posed during the Fall 2002 interviews, specific questions will be formulated for each interviewee based on their journal entries throughout the semester.

It is believe that the modified mixed method protocol used during the Spring 2003 semester will yield stronger data with respect to hypothesis 1 than the Fall 2002 protocol. In addition, the qualitative study is revealing interesting themes concerning student learning that were not envisioned in the original study proposal. The final version of this paper will contain the data from the Spring 2003 semester.

HYPOTHESIS 2

The second hypothesis is that the laboratory experience will increase prerequisite retention from course to course in the four-course sequence. This hypothesis is being tested by administering prerequisite exams in subsequent courses throughout the duration of the three-year study. This exam will be used to assess prerequisite retention in conjunction with interviews off a sample of students chosen across a broad spectrum of academic performance. The grades on the prerequisite exam will be cross checked with student grade point averages to look for evidence of an increase in prerequisite retention due to the lab experience.

CONCLUSION

This paper discusses the implementation of an Integrated Signals and Systems Laboratory in the electrical engineering curriculum at the University of Nebraska, Lincoln, and the study of its effectiveness in increasing student learning and enabling students to achieve the stated course objectives. Quantitative data from the Fall of 2002 suggest that the laboratory experience increased student learning in ELEC 304, but is not conclusive as the data is not statistically significant. Qualitative data from the Fall of 2002 suggest that the laboratory experience increased student learning and motivation in ELEC 304. Although increased motivation was a common theme in the student interviews, it is not clear that where that motivation was directed. It is possible that the students found the laboratory interesting and were highly motivated to perform well in the lab, but did not translate that motivation to achieve the course objectives.

The laboratory is being used in two courses during the Spring 2003 semester with a modified study protocol. It is anticipated that the modified protocol will yield stronger data concerning the primary research hypothesis as well identify other significant themes impacting student learning.

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