An Integrated Signals and Systems Laboratory at the University of Nebraska: Laboratory Philosophy and Study Design

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Introduction

The Department of Electrical Engineering at the University of Nebraska, Lincoln (UNL), is implementing an integrated signals and systems laboratory experience in its undergraduate curriculum. The laboratory experience uses a common experimental platform, the Telecommunications Instructional Modeling Systems (TIMS), throughout a sequence of four courses at the junior and senior levels. The four courses are in the systems area with an emphasis on communications systems. This laboratory and the associated study are funded by a Course, Curriculum and Laboratory Improvement (CCLI), Adaptation and Implementation (A&I) track, grant from the Division of Undergraduate Education (DUE) of the National Science Foundation (NSF). An essential component of this grant is a formal study of the effects of this laboratory experience on student learning and teaching efficacy. This paper discusses the philosophy behind the laboratory and the design of the study and presents results from the first semester study.

We begin with a description of the four courses that will use the laboratory and the motivation for the creation of a laboratory that could be used in a sequence of courses. This is followed by a description of the platform chosen for the laboratory and the rationale behind this choice. The study methodology is then described in detail. Finally, results from the study for the course ELEC 304 Signals and Systems are given for the Fall 2002 semester.

Course Descriptions and Laboratory Motivation

The new signals and systems laboratory at UNL will be integrated into four separate three credit hour courses that are taught at the junior and senior levels in the undergraduate curriculum. The laboratory experience will be part of the three credit hours and does not replace any existing laboratory courses. The four courses are:

1. ELEC 304 Signals and Systems: The primary objective of this junior level course 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.
2. ELEC 305 Probability and Random Processes: The primary objective of this junior level course is to teach students the fundamentals of probability and random processes with the goal of preparing the students for subsequent senior level courses in communications, control and signal processing.
3. ELEC 462 Communication Systems: The primary objective of this senior level course is to teach students the theoretical foundations of amplitude and frequency modulation

communication schemes and the effects of noise on these systems. Sampling, quantization and pulse code modulation are also covered.

4. ELEC 464 Digital Communications: The primary objective of this course is to teach students the fundamentals of digital baseband and bandpass modulation techniques in the presence of additive white Gaussian noise using signal space techniques and to understand equalization techniques for the transmission of signals on bandlimited channels. Several advanced topics, such as spread spectrum communications and channel coding, are introduced to provide students with some breadth of knowledge.

The first two courses (ELEC 304 and 305) are taken by approximately half of the junior class of electrical engineering students and by many computer engineering majors. ELEC 462 and 464 are taken by approximately one fourth of the senior class of electrical engineering students.

The motivation for the creation of the signals and systems laboratory with a common experimental platform that could be used in a sequence of related courses is twofold. The primary motivation came from the authors' experience in trying to establish an undergraduate communications laboratory for the senior level course ELEC 462 Communication Systems. The laboratory experiments were based on the typical block diagram of a communications system, which the students implemented block by block throughout the semester. Each block was built on a breadboard using a combination of integrated circuits and discrete electrical components. Student evaluations of ELEC 462 with the laboratory component consistently reflected two facts. First, the laboratories significantly reinforced the concepts taught in class and led to greater understanding of the material. Second, the majority of the time and effort spent in the laboratory was expended trying to make the circuits function and not on exploring the concepts at hand. This first observation is consistent with the literature detailing the increased learning associated with laboratory experiences in advanced courses[1,2]. The second is a common observation of both students and faculty and suggests that there should be a better way of implementing the laboratory.

Motivation for a single experimental platform that could be used throughout the four course sequence arose from the desire to improve student retention of key theoretical concepts from course to course. That is, faculty in the Department of Electrical Engineering frequently protested that students entering advanced senior level courses did not retain fundamental knowledge from prerequisite courses. On the other hand, students taking these courses often comment that ELEC 304 and ELEC 305 seem to be math courses with no engineering application and that they did not truly understand the material until it was used in ELEC 462 and ELEC 464.The authors believe that the introduction of a laboratory experience, based on a common experimental platform, into a course sequence would improve retention from course to course.

Experimental Platform

From, perhaps, a more student oriented perspective, the purpose of the laboratory is to connect theoretical, i.e., mathematical, concepts of signals and systems with the "real world". Though the initial communications laboratory achieved this, the goal was impeded by student frustration with the amount of time required to make a circuit function correctly. Thus, it was concluded that a successful laboratory experience for these courses required an experimental platform that avoid the traditional implementation pitfalls of a circuit-based laboratory without becoming the "black box" laboratory which turns students into passive observers rather than active discoverers. In addition, if the goals of prerequisite retention were to be achieved, the experimental platform had to be flexible enough to be used throughout the course sequence. The platform chosen is known as the Telecommunications Instructional Modeling System or TIMS.

The TIMS platform, pictured in Figure 1, consists of a basic system unit and card modules that implement components of analog and digital communications systems as well as ancillary functions, such as amplification, filtering and interfacing to external test and measurement equipment. Modules are robustly built and may be hot swapped into the basic system unit. By combining modules, virtually any basic analog or digital communication system may be realized. The modular design of the TIMS unit makes it extremely flexible and allows new functions to be added as communications technology advances. Thus, the useful lifetime of the TIMS equipment is substantially longer than many other platforms.

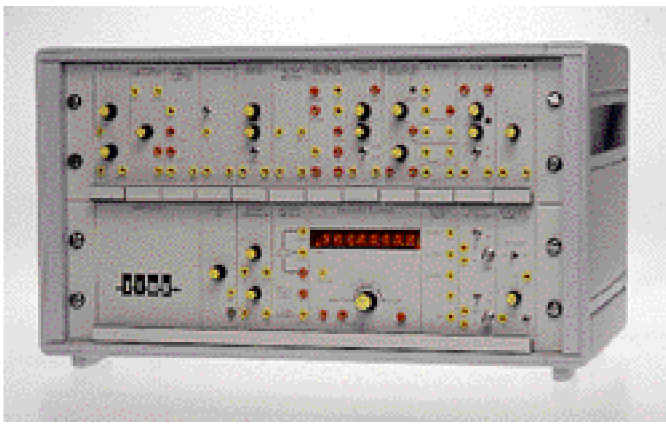


Figure 1: Photograph of the basic TIMS unit.

Each TIMS unit is supplemented with a multichannel digital oscilloscope, an arbitrary waveform signal generator and a spectrum analyzer. All of the test and measurement equipment is connected to a PC that enables real time screen captures and electronic laboratory notebook and report preparation. The TIMS unit also provides a software interface with MATLAB so that data maybe captured and further processed.

Study Design

In the course of designing the TIMS based Integrated Signals and Systems Laboratory 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 this section the study methodology is described.

The study protocol uses a mixed methodology that includes both quantitative and qualitative techniques. This mixed method study is designed to measure the extent to which we achieved the overarching goal of the proposed laboratory adaptation and curriculum. A combination of quantitative and qualitative methods will best measure student learning outcomes, and as such, more accurately measure differences in student comprehension resulting from the laboratory experience. 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[3]. Moreover, a mixed methodology study design can help improve the validity of data by using more than one method to study the same phenomenon. Combining the two methods pays off in improved instrumentation for all data collection approaches and in sharpening the evaluator's understanding of findings. A mixed method approach may also lead evaluators to modify or expand the evaluation design and/or the data collection methods. This action can occur when the use of mixed methods uncovers inconsistencies and discrepancies that alert the evaluator to the need for reexamining the evaluation framework and/or the data collection and analysis procedures used.

The quantitative study protocol is different for the two hypotheses. In order to test the first hypothesis, students matriculating from a prerequisite course to the subsequent course, e.g. from ELEC 305 to ELEC 462/862, will be given a prerequisite examination. These results will be compared between students who have had the lab experience in the prerequisite course and those who have not. The results will also be compared to historical data prior to the existence of the laboratory, when such data are available.

The quantitative study of the second hypothesis will include the use of voluntary control and treatment groups where approximately half of the students will be provided the laboratory experience while the other half will receive instruction using the current curriculum and teaching methods. Student's prior knowledge will be measured by their performance on identical baseline instruments administered to both the control group and the treatment group prior to the laboratory experience. An instrument tailored to scrutinize the effectiveness of the laboratory experience will be developed and administered to both groups after the laboratory experience. The difference in scores on the two examinations will be used as a measure of student learning outcomes. The control and treatment groups may exist for the entire semester or only for a single assignment or concept.

The qualitative component consists of interviews of selected treatment group participants who will be asked a series of questions after completion of the course. The interviews will be transcribed and analyzed for themes, which may provide insights regarding the effectiveness of the laboratory experience. The interviews will be especially useful in answering questions such as, What does the program look and feel like to the student participants? What does the program look and feel like to other stakeholders? What are the experiences of the participants? What do stakeholders know about the project? What thoughts do stakeholders, who are knowledgeable about the program, have concerning program operations, processes, and outcomes? What are participants, and stakeholders, expectations? What features of the project are most salient to the participants? What changes do participants perceive in them as a result of their involvement in the project[4]?

The use of interviews as a data collection method begins with the assumption that the participants, perspectives are meaningful, knowable, and able to be made explicit, and that their perspectives affect the success of the project. An interview, rather than a paper and pencil survey, is selected when interpersonal contact is important and when opportunities for follow-up of interesting comments are desired. The interviews should provide thick, rich descriptions of student experiences in the laboratory setting and their perceptions of program effectiveness[5].

The interviews are organized around the following guiding questions, however, as stated above, the follow-up questions also produced important thematic data. The designed interview questions are:

Overarching Question: Does the signal and systems laboratory experience improve student understanding of the fundamental systems and communications concepts?

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

The quantitative and the qualitative assessment outcomes will be used to update, adapt, and improve the overall learning experience of future UNL electrical engineering students. Further, the quantitative and qualitative outcomes will be used specifically to refine the laboratory experience of the electrical engineering undergraduate students at UNL. Through dissemination of the results of this laboratory adaptation in the College of Engineering and Technology at UNL, it is possible to influence the curriculum in other departments, possibly providing the impetus for future cross-disciplinary laboratory projects.

ELEC 304 Quantitative and Qualitative Results

This paper is the first report among several that will span the life of the study and the grant. The quantitative data shows performance differences between the treatment and control groups and early analysis of the qualitative results produced themes that we will study more deeply. However, the study will be conducted throughout the life of the grant and we believe that future data and deeper analysis will influence the conclusions suggested here. As such, this paper should be considered a first step in our attempts to understand the impact of the laboratory program on students in the signals and systems course sequence.

During the fall semester of 2002, the Signals and Systems Laboratory was implemented for one course, ELEC 304 Signals and Systems. A total of four laboratories were integrated into the course. In this study, the class was randomly divided into a treatment group and a control group for each of the four concepts for which a laboratory was developed. Both the treatment and control groups were reconfigured for each assignment. 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. Student learning on each assignment was measured by administering assignment specific pre- and post- quizzes. An example of this procedure is described below.

Fourier series analysis is an example of a topic covered in ELEC 304. The students are exposed to the analytical procedure of calculating the Fourier series. Subsequently, the students are lectured on how periodic signals pass through linear filters. The Fourier series of a periodic signal is obviously useful in understanding the effect of the filter on the signal. After the formal lectures on this concept, the control group was given an analytical homework assignment, which included the following problem.

Homework

Given an ideal low-pass filter, with a cutoff frequency of 5 rad/sec, compute the output response y (t) resulting from an input x(t).

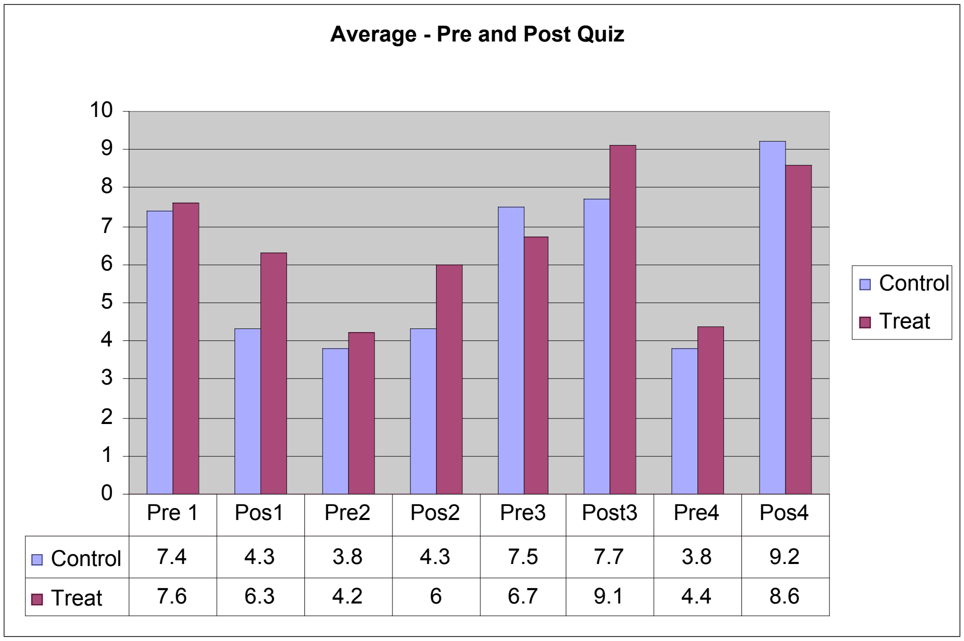
A figure of x(t) was given showing a square wave. The students had to analytically calculate the Fourier series and determine which frequency components passed through the filter. The final result was that the filter output was a pure sinusoid.

The treatment group was assigned a laboratory where they would pass a square wave from a function generator through a tunable low-pass filter. The output of the low-pass filter was simultaneously displayed on an oscilloscope and a spectrum analyzer. Students were then asked to adjust the cutoff frequency of the low-pass filter and observe the changes in the output signal. Of course, the students could see the effect in both the time and frequency domains simultaneously. The students were *not* asked to analytically calculate the Fourier series of the square wave. After completing the assignments, both the control and treatment groups were given the following post-quiz.

Post-Quiz

Sketch the magnitude response of a filter that can take either a square wave or a triangle wave input, with the same period T, and output a pure sinusoid.

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 2, 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 2: Quantitative results for ELEC 304 Signals and Systems.

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 advantage was laboratory #4. Unfortunately, based on a single sample t-test with a 0.05 confidence interval, the difference was not statistically significant. 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. Experimental design procedures are currently being implemented to mitigate this effect.

The qualitative data from the study are still being analyzed but has produced early insights about student performance and their perceptions regarding the laboratory experience. The initial emergent themes (grounded theory) produced from ten student interviews at the end of the 2002 Fall semester are discussed here. The qualitative themes are linked to the quantitative results only when relevant to the student responses. The following four themes are evident based upon a preliminary analysis of the student interviews.

First, nine of the students stated that they did not believe their performance in the class was positively affected by the laboratory experience. The students did say that the laboratory clarified some course concepts but they did not think that the laboratory program improved their scores or grades. Although the quantitative data have low statistical significance, they do suggest some degree of improvement in performance. Further analyses are needed to fully understand the relationship between the qualitative and quantitative data.

Second, 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. Third, the students stated that they liked being able to translate the theoretical concepts into "real" examples on the laboratory equipment. In fact, most stated that the laboratory helped them to "see" what was implied by the math used to describe signals and systems concepts in the classroom. None of them cited this as a performance factor. Fourth, four of the ten students claimed that they used the equipment to work on problems in other Electrical Engineering courses and worked in the lab beyond the required time needed to solve course assignments.

The emerging themes in the qualitative section of the study suggest some inconsistencies between student performance and their perceptions of the impact of the laboratory and our goal of improved performance. While the data analysis is not complete, the quantitative and qualitative results have led to new questions about why the students have limited metacognitive awareness regarding the possible impact of the laboratory. Is it sufficient that they may be performing better or should the students be able to identify the reasons for better scores? Does access to state of the art technology generate motivating factors for students, most of whom stated that the lab made the course more interesting but could not identify the source of any improvement when asked directly? Is it possible that the motivational influence of technology is a separate factor for this study and can this variable be isolated?

Conclusions and Future Work

Again, this paper is a first report of our study results and more should be known as the grant and the study progress. Here is what we can say at this point in the study. Overall, both the quantitative and qualitative data suggest that the laboratory experience increased student motivation in ELEC 304. However, preliminary data triangulation between the quantitative and qualitative results has raised two issues. First, since the treatment and control groups were rotated with each assignment the quantitative data, which measured improvement on specific concepts, cannot easily be translated to improvement in achieving the overall course objectives. Second, even though 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.

During the Spring of 2003 the laboratory experience will be repeated in ELEC 304 and implemented in ELEC 464. In order to address the two issues raised during the initial study, the new quantitative study will utilize control and treatment groups that will remain intact throughout the entire semester. Moreover, two more labs associated with course concepts will be implemented in ELEC 304 in order to provide a more consistent laboratory experience. This study structure should produce better data regarding the source of any future student improvements and will mitigate statistical anomalies due to carry over knowledge.

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