IMPLEMENTATION OF AN INTEGRAL SIGNALS AND SYSTEMS LABORATORY IN ELECTRICAL ENGINEERING COURSES: A STUDY

by

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A laboratory component was being revised 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 in a four-course sequence. The lab and the study of its effects on student learning in one undergraduate course (ELEC 304) Signals and Systems and in one senior/graduate level course (ELEC 464/864) Digital Communications are discussed. A mixed method protocol including quantitative and qualitative techniques was employed.

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Chapter I

Introduction

The Department of Electrical Engineering at the University of Nebraska, Lincoln (UNL), has revised its undergraduate curriculum by implementing an integrated signals and systems laboratory experience. The laboratory experience uses a common experimental platform, the Telecommunications Instructional Modeling Systems (TIMS). This platform is used throughout a sequence of four courses at the junior, senior and graduate levels. The four courses are in the systems area and emphasize on communications systems. The lab and the study of its effects on student learning were funded through a grant from the Course, Curriculum and Laboratory Improvement (CCLI), Adaptation and Implementation track from the Division of Undergraduate Education of the National Science Foundation (NSF). The grant focused on a formal study of the effects of this laboratory experience on student learning. This thesis discusses the philosophy behind the laboratory, the design of the study, and the results from Fall 2002 and Spring 2003 semesters.

Course Description and Laboratory Motivation

The Two Courses

The signals and systems laboratory at UNL is integrated into four separate three-credit-hour courses. These courses were taught at the junior and senior levels in the undergraduate curriculum. The lab component was added to be a part of the three credit hours and did not replace any existing laboratory courses. The two courses discussed in this thesis 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.
3. ELEC 464/864 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 (AWGN) using signal space techniques and to understand equalization techniques for the transmission of signals on band limited channels. Several advanced topics, such as spread spectrum communications and channel coding, are introduced to provide students with some breadth of knowledge.

Approximately half of the junior class of electrical engineering students and some computer-engineering majors take ELEC 304. One fourth of the senior class of electrical engineering students take ELEC 464/864. Typically students who express a strong interest in a career in the communications area take these courses.

Impetus for adding the laboratory

Two reasons lead to the creation of the signals and systems laboratory with a common experimental platform. The primary reason stemmed from the instructors' experiences in establishing a communications laboratory for a senior level course - ELEC 462 (Communication Systems). The experiments in this lab used the conventional block diagram in communications system. The students implemented the experiments block by block throughout the semester. Using integrated circuits and discrete electrical components, students built each block on a breadboard. From student feedback it was inferred that, though the laboratories reinforced significantly the concepts taught in class and led to greater understanding of the material, most of the time in the lab was spent in trying to make the circuits function. Hence the primary focus of the students was not on exploring the course concepts[1]. This observation is consistent the observation made by Buck et al[2] when studying the impact of an optical communications laboratory on student learning and by Yurkovitch[3] in studying the impact of a laboratory on fuzzy control.

In order to improve student retention of important theoretical concepts from one course to another the faculty at UNL chose a single experimental platform. The faculty in the Electrical Engineering department frequently noted that students entering advanced senior level courses were not retaining the basics concepts from their pervious courses. Further students in ELEC 304 and ELEC 305 commented that these courses were math courses with no engineering application. Only when the students reached these advance courses (ELEC 462 and ELEC 464) and used the material form ELEC 304 and 305 did they really understand the material. [1].

One of the desired requisites of the laboratory was to connect theoretical, i.e. abstract mathematical, concepts of signals and systems with the "real world". The initial communications laboratory achieved this desired aspect. But the student frustration caused by the large amount of time involved in making the circuits function correctly diminished the positive outcomes of the lab. This led to the need for an experimental platform that avoided the drawbacks involved in a traditional circuit based laboratory. It was also important for the faculty to avoid turning the laboratory into a "black box" laboratory that would make students passive observers. They desired students to be actively investigating the course concepts in the laboratory. Further to achieve the goal of improving prerequisite retention the chosen experimental platform had to accommodate its usage in all the courses in the systems and signals sequence. The Telecommunications Instructional Modeling System (TIMS) allowed this to happen[1].

Experimental Platform

The TIMS platform is pictured in Figure 1 and consists of a basic system unit and card modules. The card modules implement various components of analog and digital communications systems and ancillary functions such as amplification, filtering and interfacing to external test and measurement equipment. Modules are hot swappable with the base module and are quite robust. 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. This feature significantly increases the useable lifetime of the TIMS equipment[1].

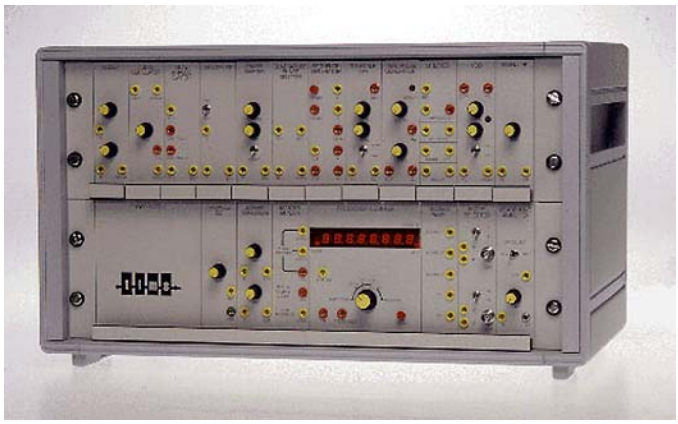


Figure 1. Photograph of the basic TIMS unit

A multichannel digital oscilloscope, an arbitrary waveform signal generator, a spectrum analyzer and a PC connected to a printer along with the TIMS basic unit makes up a TIMS station. The PC enables real time screen captures as well as electronic laboratory notebook and report preparation[1].

Chapter II

Literature

Ferman and McCafferty[4] suggest curriculum reform for college level math education by relating mathematics to other disciplines and demonstrating to students the coherence in the curriculum as well as the applicability of mathematics. Research on adult learners indicates that learners are most motivated when they see relevance to their learning, when they have ownership in the process, and when they feel it is tailored to meet their immediate interests and needs[5]. Thompson and Thornton indicate that a sense of ownership and relevance of content may intrinsically motivate the college level student to achieve a higher level of academic excellence[6].

Reflection on matters of logic may enhance metalogical understanding for college students[7]. Historically, there is abundant research done on the effectiveness of lab on facilitating and improving student learning[8].

Cognitive approaches to learning science recommend that science be presented to students as a problem solving process rather than as a knowledge (vocabulary or facts) acquisition process. Because scientific schemata often appear to be in conflict with experience-based schemata (naïve beliefs), experiments or demonstrations are usually necessary to challenge preconceptions. Hands-on activities promote opportunities for students to engage in metacognitive self-questioning of their learning strategies and conclusion[9].

Constructivists such as Novak and Resnick, propose that the constructions of new knowledge starts from one's observation of events through past experiences one already has. Learning something new involves changing the meaning of one's previous

experiences. Or learning could imply to construct or modify one's inner knowledge structure. During this process learners actively acquire, not passively receive or discover knowledge[10].

Bruning[11] advocates Paivios's claim that imagery can be a powerful tool for increasing memorability of information that students need to acquire. Thompson and Thornton interpret Gardner's theory of multiple intelligences and suggest that engaging students in the process of deciding how and why to visually or spatially represent their understanding is key to capitalizing on visual and spatial intelligence[6].

Maitland and Linda suggest that in order to measure student growth in metacognition the first step would involve surveying students regarding their perceptions of personal growth in the ability to act on their own volition[12]. According to Kerka[13], journal entries can provide tangible evidence of mental processes because they make thoughts visible and concrete, giving a way to interact with, elaborate on, and expand ideas. Journals can be an effective tool to enhance student learning and simultaneously provide the instructor with unique insight into students' mental processes[14].

Gribbons and Herman advocate that the using multiple evaluation methods, evaluators should be careful in collecting the right kinds of information when using experimental frameworks[15]. Measures must be aligned with the program's goals or objectives. Additionally, it is often much more powerful to employ multiple measures. Gribbons and Herman suggest that triangulating several lines of evidence or measures in answering specific evaluation questions about program outcomes increases the reliability and credibility of results[15].

A mixed method assessment instrument would help triangulate data. Data triangulation would also ensure that any variance in scores measured reflects the desired traits rather than the method[16]. Combining the two methods improves the quality of instruments and it helps the evaluator in understanding the results.

Using interviews has been suggested as good means for acquiring data. Bogdan, R.C., & individuals or circumstances. They further state that the primary difference between qualitative and quantitative data analysis is the simultaneous collection and analysis of data[17]. Biklen suggest that the interviewer can be flexible in administering interviews to suit particular circumstances. The National Science Foundation also supports the use of interviews as a data collection techinque[18].

Chapter III

Methods

Hypothesis

Two basic hypotheses supported the design the TIMS based Integrated Signals and Systems Laboratory,

1. The positive laboratory experience will increase student learning and facilitate achievement of the course objectives in each of the three courses.

2. A consistent laboratory experience will increase prerequisite retention from course to course in the four-course sequence[1].

A part of the NSF CCLI grant proposal involved the formal test of these hypotheses to be true[1]. This thesis focuses on verifying the first hypothesis in two of the four- course sequence.

Research Methodology

This study used both quantitative and qualitative techniques. This mixed method study was designed to check the extent to which the goal of the proposed laboratory adaptation and curriculum revision was achieved. This mixed method approach lead the researchers to modify and expand the study design and/or the data collection methods as needed. This is possible when the use of mixed methods uncovers inconsistencies and discrepancies that create the need for reexamining the evaluation framework and/or the data collection and analysis procedures used[1].

Quantitative Methods

The quantitative study included the use of voluntary control and treatment groups where the control group students followed the traditional curriculum and the treatment group student had a lab component that replaced a part of the traditional curriculum. Student's prior knowledge was measured by their performance on identical baseline exams administered to both the control group and the treatment group prior to the laboratory experience. The baseline examinations are part of the standard course syllabi. Course final exams were used as the exit measure. The study was conducted on ELEC 304 over two semesters – Fall 2002 and Spring 2003. The ELEC 304 course over the fall semester followed a methodology that is slightly different from this. The control and treatment groups were reconfigured after every lab assignment. Pre-quizzes and post-quizzes were used to measure the differences in learning between the control and treatment group students. The only demographics information requested included the participating students' ages and previous courses related to prerequisites.

Qualitative Methods

The qualitative component consisted of interviews and journals. Interviews were conducted on treatment group participants at the end of both the semesters. The interviews were transcribed and analyzed for themes, which provided insights regarding the effectiveness of the laboratory experience. The interviews were especially useful in answering questions such as[1,19]:

- 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?

The use of interviews as a data collection method is presumed to provide truthful and meaningful perspectives from the participants and would eventually affect the success of the project. The advantage of an interview over a paper and pencil survey is the possibility of interpersonal contact and the opportunity to follow-up of interesting comments[1,21]. Students in the treatment group kept journals regarding their perceptions of the laboratory sessions.

Students who did not volunteer for the study remained in the class in which he/she enrolled but did not receive the laboratory experience or be included in the data. The test results were included in grades as specified by the course syllabi[1]. The final exams were developed from materials covered in the class and did not test over laboratory experiences.

Chapter IV

Qualitative measures of Learning

The qualitative component of the study is based upon the perceptions of students expressed through their journals and interviews.

Themes from Interviews

Interviews were conducted at the end of both the semesters. Interviews were conducted in December 2002 for ELEC 304 and in May 2003 for ELEC 304 and ELEC 464/864.

Guiding Questions

The questions posed to the students were open ended. Students were encouraged to express their thoughts were assured of confidentiality as stipulated by the Institutional review board. The interviews are organized around the following guiding questions and follow-up questions whenever relevant.

The designed interview questions are:

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

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[1].

Transcription and Coding Process

The Instructional Design Center performed the transcription for ELEC 304 over the fall 2002 and spring 2003. The interviews from ELEC 464/864 were transcribed by the researcher. The interviews were transcribed and analyzed for themes which provided insights regarding the effectiveness of the laboratory experience. The digital copies of the interview transcripts were read several times before the transcripts were coded. The digital copies of the transcripts were color-coded using text color changes. The answers to the guiding questions and the follow up questions produced important thematic data. There was a general pattern of themes arising in most interviews from any given course. Additionally, there were unique themes that pertained to particular interviews. The interviews were recoded to ensure that no major themes were overlooked.

Presentation of Themes

The qualitative section is presented in a narrative form. Each theme is presented as a section. Both the courses ELEC 304 and ELEC 464/864 have been addressed in each section. In each section, the themes and the sub-themes common to all the three courses are presented initially. Each course is then examined separately. The themes and sub themes are supported with quotes from interviews representing the student's voice. In certain cases, a cumulative account of the most popular student views is presented. Some of the student's opinions are presented in an indirect voice to provide a concise account

of their narration. Respondents' names have been changed. Some participant quotes were edited for conversational flow to improve readability.

Demographic details

Nine students were selected from the ELEC 304 (fall semester) treatment group for a 30 to 45 minute interview. An education specialist, an electrical engineering professor familiar with the course but who did not teach the course during the current semester, and the researcher conducted the interviews. The students reflected a broad spectrum of academic performance. Interviews did not involve any students from the control group.

For ELEC 304 (spring semester), ten students were picked randomly and interviewed. Each interview lasted for approximately 30 minutes. The electrical engineering professor who conducted the ELEC 304 (fall semester) interviews during the previous semester and the researcher conducted the interviews.

For ELEC 464/864 it was decided that three graduate students to one undergraduate student would be sampled and interviewed to represent the population of the class. Three graduates and one undergraduate were randomly selected from the pool of students in the treatment group. An electrical engineering professor who did not teach the course during the current semester and the researcher conducted the interviews. Different electrical engineering professors conducted ELEC 304 and ELEC 464 / 864 interviews.

The Themes

Concept Clarification

The primary influence of the lab on their learning, as expressed by the students, was the clarification of course concepts. Most students from all the three courses claimed that they learn better visually and that the lab experience was very helpful in converting abstract mathematical concepts into concrete illustrations that they could understand better. Some students who said that they were able to understand the abstract mathematical concepts from the class lectures and/or the textbook claimed that the lab helped in reinforcement of concepts. For some students, the lab created an opportunity to go beyond the curriculum, experiment with the equipment, and gain a deeper understanding of the subject itself.

ELEC 304 - Fall 2002

All the nine students from ELEC 304 who were interviewed spoke about the concept that was most difficult for them to have been clarified after performing the lab assignment.

> Yeah, I'm not a very good math student, math is a very abstract thing to me and I am a very visual learner and when I get to see the stuff on the oscilloscope and the function generator, that makes it more real to me, it makes it more understandable.
>
> *Jack*

The ELEC 304 course is very difficult for almost all students including those who are taking it for the second time. This is an extract from a student interview from ELEC 304.

> You get to see it from a different angle here in the lab and you can also apply the exact same concepts and see how they actually work. You know, that kind of oh, I understand how this formula actually works.
>
> *Harry*

Almost all students from ELEC 304 noted that the concept of white noise was either clarified or reinforced after performing the lab. One such student mentioned that he realized it was something real in contrast to his prior belief that white noise was only an abstract concept. A few students from ELEC 304 told us that the lab helped in elaborating on the concepts because of the visual representation of the mathematical concepts. One interesting comment from a student in ELEC 304 was that the lab avoided the tension of getting the math correct and allowed him to focus on the concept itself.

One student from ELEC 304 told the interviewers that he would come to the lab over his free time and experiment with the equipment and gain knowledge on concepts that were not covered in class.

ELEC 304 Spring 2003

All the students who were interviewed from ELEC 304 (spring 2003) indicated that the lab was especially helpful in understanding the time domain and frequency domain concepts better. The following is quote from a student in ELEC 304.

> The biggest thing I think would be helping me see the transition from the time domain to the frequency domain. I really wasn't sure in class but then when I came to the lab I thought I understood better how a signal looked once it was in the frequency domain.
>
> *Calvin*

One student from ELEC 304 said that he was often able to recall a specific concept in the course from his experience working in the lab on that particular concept. The following quote is from a student's response when he was asked if the lab had any effect on his perceived retention.

> Oh, I would say definitely. May be five years from now I'm not going to remember how to find the co-efficient or anything like that, but what I will remember though is the output of the spectrum analyzer. And may be how it applied to our frequency and the frequency domain out of the analyzer.
>
> *Ivan*

ELEC 464/864

All the four students who were interviewed from ELEC 464/864 emphasized two concepts – Quadrature amplitude modulation (QAM) and Biphase shift keying (BPSK) where the lab was particularly helpful. One student pointed out that it was only when he was able to see the cloud formation in the oscilloscope that he could understand how a decision on probability of errors could be made. He acknowledged that, though this concept was presented clearly in the class and textbook, it was only when saw it on the oscilloscope that it was clear to him

The following quote is from a student who was explaining to the interviewers about how the lab helped him gain a deeper understanding of the course concepts.

> With the filter you could see as it is the frequency being cut off as it goes along and that was kind of interesting to see because you actually see, you know how

> much frequency you are cutting off when you are sitting there messing with filters.
>
> *Steve*

All the four students from ELEC 464/864 were asked if the lab affected the memorability of the content. Three students told us that there was positive influence on their memorability while one student said that there was no impact. The following is a quote about the impact of the lab on memorability:

> I mean when you are speaking about long term memory obviously repetition is a good thing. Even not just because of the lab. When you are doing experiments and actually try it out using real life instruments I think it really puts it in your memory a little more. It is really a hard question to answer but I think it has had an effect. I think it really helped it sticking there.
>
> *Bob*

Sean from ELEC 864 had an interesting comment. He told us that, while he was answering the technical questions during the interview, he used mental pictures of what he had seen in the lab when he did the assignments. Hence, it was easy for him to draw on those pictures and answer the interviewers. He also told us that if we were to ask him about a problem that was discussed in class there is a relatively less chance for him to answer that question successfully. Sean also felt that if he had completed ELEC 304 with the lab it would have helped him a lot to register clearly the basics on signals and systems.

Visual Validation of Math concepts & Reinforcement of Course Concepts

All the students who were interviewed said that the lab gave them an advantage of having hands on experience with mathematical concepts. Most students identified concept clarification as the advantage of having a lab. But for many, it was helping them to validate the equations. Another interesting insight was offered by more than half the students who were interviewed. They noted that the lab helped them reinforce the concepts they learnt in class. Many students expressed a trust issue involved in believing the abstract mathematical concepts after the lab experience.

ELEC 304 - Fall 2002

The following two quotes from ELEC 304 interviews offer two different perspectives on the advantages of having hands-on experience in an engineering course that is highly mathematical.

Patrick is the pseudonym for the professor who taught ELEC 304.

A: "Patrick had mentioned once in class and it clicked when I actually saw it happen."

Q: "So, again, what do you mean by clicked?"

A: "It made perfect sense. I understood it on a deeper and more meaningful way. I could explain it to somebody else without skipping a beat".

Jack

As opposed to just having a set pattern and you know when you can kind of tweak stuff yourself it helps you understand it more.

Harry

For some of the interviewed students, the lab experience gave them a chance for them to do the math in a practical way and there by gain confidence over their knowledge. Most of the students from ELEC 304 (fall 2002) expressed that they trusted the mathematical concepts to be true when they worked on it themselves with any intervention.

ELEC 304 Spring 2003

All ten students interviewed from ELEC 304 (spring 2003) did mention that the lab helped them reinforce their understanding on course concept(s). The students of ELEC 304 (spring 2003) also expressed the trust issue involved in working with the mathematical concepts, and felt the concepts to be more real after seeing the graphs on the oscilloscope and the spectrum analyzer.

ELEC 464/864

Like the other two courses the ELEC 464/864 students also felt that their belief on theoretical concepts on signals was increased because of having the lab experience.

> And here you can actually see the frequency and that makes you believe it a little bit more.
>
> *Sean*

Stephen told us that he had a better idea of the different properties that each modulation scheme would have by just turning knobs and seeing the effect on the oscilloscope or the spectrum analyzer.

Learning through Images

All the students from ELEC 304 at some point during the interview mentioned the importance of having visual representation of concepts.

ELEC 304 Fall 2002 and Spring 2003

All nine students from ELEC 304 who were interviewed were very confident that they learnt better when they had a visual representation of the concept. One student from ELEC 304 (spring 2003) commented that a relation like inverse proportion was obvious when he looked at a graphical representation of an equation, but it was not the case when he was presented with the equation itself. According to him, the laboratory experience clarified the equations for him and elaborated the functions involved in the equation.

> Yeah, I'm not a very good math student, math is a very abstract thing to me and I am a very visual learner and when I get to see the stuff on the oscilloscope and the function generator, it makes it more real to me, it makes it more understandable.
>
> *John*

It was interesting to note that no student in ELEC 464/864 spoke about being a visual learner.

Advantages of the Lab Set-Up

Lab Schedule

The students stated that they enjoyed the fact the lab had 24-hour access and that the TIMS equipment did not have many pitfalls of a traditional laboratory. They utilized the absence of a time limit for the students to be in the lab to its fullest. The students did acknowledge this aspect over the interviews. They indicated that they had no pressure

with regard to time to complete an assignment. One student from Fall 304 interviews pointed out that the lab avoided the conventional frustration of a student in getting the correct answer in a given time frame without being able to concentrate on the learning itself.

> Yeah, I mean, it would be frustrating to have to come into a lab and complete it in an hour, hamper the experience a little bit because you have to concentrate more on actually getting the answers down than actually looking at what you're doing
>
> *Jack*

Advantages of the TIMS Hardware

Students appreciated the ease involved in working with equipment, and were happy that there was no equipment failure that normally frustrates them in traditional engineering laboratories. One significant aspect pointed out by many students was to have the graph displayed on a monitor and being able to print it simultaneously. The print facility removed the need to graph correctly in lab notebooks.

> And what the TIMS machine allows us to do is be that engineer that's already built all the parts that's needed and then use all of the analytical techniques that we've been learning in class to see how the sinusoid and frequency and signal respond to each other on the various systems. I think that that was a very useful experience. Most of the time in labs you don't get the small parts to work anyway so you've never looked at the system as a whole to see where it goes.
>
> *James*

The signals generated by a TIMS machine are simulated. It was misleading for three students from ELEC 304 (fall 2002) who thought that the signals were real and pointed to this as an advantage of the TIMS machine. One student from ELEC 304 told the interviewers that the difference between doing a similar assignment on MATLAB and doing the same on TIMS machine is that with the TIMS machine he was doing all the plug-in, whereas in MATLAB, he felt the program was doing it. Hence, for him, it was working with the TIMS machine that increased his confidence level in understanding the concept. The following is a similar comment from a student from ELEC 304 when asked to compare TIMS with MATLAB.

> I think so because when I think of the MATLAB I just think of a program that could just have been manufactured by somebody whereas in here, I feel like these are actual more physically real.
>
> *Chris*

Two students from ELEC 464/864 were asked to compare the TIMS lab experience with the MATLAB experience as follow up questions. *Sean* pointed out that if the codes he writes for a MATLAB were not correct, then his simulation wouldn't be correct. *Alec* told us that he was not sure if he would be able to see the QAM system on a MATLAB and so it was advantageous for him to work on the TIMS equipment.

Only one student from ELEC 304 mentioned difficulty in working with the TIMS equipment. He mentioned that it was hard for him to get the spectrum analyzer to focus on the portion of the frequency curve that he wanted to look at. He found it difficult to scale it, and to report values of the peaks and the width of peaks. No student from ELEC 464/864 mentioned about any problem with the equipment.

Utilitarian Nature of the Lab

When students were asked to comment on the utilitarian nature of the lab the students from ELEC 304 pointed out that the lab was true representation of what they would see in a work setting once they graduate as an Electrical Engineer.

> I thought this lab was one of the first ones I'd done where there's a lot of application kind of to the real world.
>
> *Calvin*

When students were asked to comment on their thoughts over the time spent in the lab in relation to the understanding gained out of the experience, many different answers were presented.

Some of them felt that it was proportional, whereas some pointed out that they spent less time in the lab than they would have if they had done homework problems. Many felt that the flexibility with regard to being able to stay in the lab and experiment with the equipment helped them go beyond their assigned task and thus helped their learning and interest level in the course.

Change in Dedication Level and Interest Levels

All students were asked if the lab had any influence on their dedication to the course. Seven out of the nine ELEC 304 students (fall 2002) indicated that it did not increase their dedication in the course. These students said that they were very dedicated to the career choice they made, and the lab had not influenced their dedication levels. For some the course material was interesting enough to keep their dedication to the course. One of

the two students who had a positive influence on his dedication gave us the following explanation.

> Yeah, you kind of feel more confident when you are presented with a concept in class and then you're . . . you come in the lab and it comes pretty easy to you, like, oh, this isn't so hard. It's pretty . . . it comes to you easier and then you're more willing to put more time into it to understand something that you're more accepting of. I looked at the lab and it's like, okay, well, that's cool. And then went back to the map and, like, ahhh. So, kind of introduce it to you first and then ... then you get it afterwards. It kind of pays off ... very helpful also.
>
> *Antony*

Another student from ELEC 304 (fall 2002) said that his dedication increased because of the lab and attributed it to the fact that he enjoyed the course better because of the lab. Eight out of the nine students from ELEC 304 (fall 2002) said that their interest level in the course was significantly increased because of the lab component. One of them felt only a slight increase in interest level because of the lab.

All students from ELEC 304 (spring 2003) except Calvin pointed out that there was no change in their dedication to the course. Calvin told us that he has always been a last minute person except for this lab experience. He would get the homework problems done before he came to lab and felt that in this way he was better prepared for the lab. But all the ten students ELEC 304 (spring 2003) expressed that there was definite increase in their interest levels in the course itself because of the lab.

All the four students from ELEC 464/864 were asked if there was any change in their dedication level to the course because of the lab experience. *Stephen* and *Alec* told us that

lab had a positive influence on their dedication. *Bob* said there was no change in his dedication level because he was very dedicated himself. *Sean* said he was not sure if there was any change in his dedication to the course.

> Yeah, I think it did. I mean … it gives you motivation to know that stuff that we do in class can be … can be used in a real world setting and experimental setting that might later on have to be used if I were a to become a communications engineer or something to do occupationally.
>
> *Stephen*

All four students from ELEC 464/864 did acknowledge that their interest level in the course was increased of the lab component.

> Seeing the things sometimes did because it gave me more satisfaction when I could actually get the things done and see them on the screen when I am actually computing in class.
>
> *Sean*

Perception of Advantages

When students were asked if they perceived any real or perceived advantage because of having a lab component in the course, most of them replied that there was none on their grades but there was a definite advantage on their learning.

ELEC 304 Fall 2002

Six out of the nine students from ELEC 304 (fall 2002) said that it helped their learning in some way or the other but did not improve their grade. One of them was not sure while one student said that his grades were increased slightly but he would have done well even

with out the lab. Only one ELEC 304 (fall 2002) student saw the connection between what was taught in class, the lab experience and what was tested.

> Yeah, cause it helps you understand the concepts so that when you understand them and you come to a test or something like that you're like, when you get the answer out on a test you can like think back to what you did in the lab and it would be like "Oh, it should be something like that." So you know it's right or you're in the right direction, you know, it kind of gives you direction and it helps you double check stuff, even on homework and stuff like that. You are like I remember when I did this square wave in the lab, it came out to be something like this so it's probably right. It was a lot of reinforcement on the actual coursework.
>
> *Harry*

ELEC 304 Spring 2003

All students except one in ELEC 304 (spring 2003) perceived no effect of the lab on their grade, but there was a positive effect on their learning either in the form of clarification or reinforcement of concepts. One student mentioned that there could have been a slight increase in grades because of the lab. One of the students brought out an interesting aspect of the course that there could be a possible misalignment in the course between what was expected out of the students at the end of the semester (course objectives), what was taught (lecture) and what was tested (assessment).

> In actual classroom though we were graded on our math ability. It is not really what you know. If you can prove it, that is one thing. If you can do the math then…Everything you are graded on in the classroom is based on your

> mathematics and how you do that rather than you understand it.
>
> *Chris*

Contentment with Lab Experience

At the end of the interview when students were given a chance to express their thoughts over the lab, most of them were happy to have a facility like the TIMS equipment in their curriculum. Some of them felt that the lab experience was going to help them in the long run. Most of them were happy that they had a chance to have the lab experience. Some of them of were curious to know when the lab would be integrated with the curriculum.

Role of the Lab as perceived by the Students

At several points during the interviews, many students spoke on the role of lab on student learning.

ELEC 304 Fall 2002

> It helps the understanding a lot more as opposed to just getting a grade.
>
> *Harry*

> I've always appreciated something of a hands-on approach just because it's nice to hear all the theory, but it doesn't really stick until you've had a chance to do it yourself, build something. You go to Radio Shack, you buy some parts, you put it together or in some of the electronic classes, you have the lab, you come in here and it's nice when the instructor and the lab TA parallel what they're teaching or the person who wrote the lab manual knows what the course is going to be like so

> that each week when you do a new lab it lines up perfectly with the course materials and you say, okay, now you have a chance to introduce new things but you can only really show in practical applications. And you build it all together in your mind as one solved picture and that's something that I think I always do is I have sort of a conceptual map in my head that I can stick new concepts into very easily and I build sort of a tree that explains everything to myself so I don't have to ask myself the question, why does this work? I figured it out. I added it to my concept map and now I'm done. And so I do that when I have a chance to see more of the concepts that makes a fuller tree in my head, therefore, better understanding for understanding the topic as a whole. So, if it came to it, like standing in front of the class, I could more effectively convey the message.
>
> *Cori*

ELEC 304 Spring 2003

> I guess I don't know how to say this because this lab helped me with the visual standpoint. But I don't think I can take it backwards. I can't take the lab material backwards and learn the homework. This is more like the lab adds on to the class.
>
> *Chris*

One student from ELEC 304 (spring 2003) who had prior work experience said that there definitely was an effect of grade because of change of attitude from a technician to an engineer in placing emphasis on the concepts.

> I could see what was going on, I had more of a hands on approach. I guess dealing with the circuits on the spectrum analyzer and seeing ok, this is what the filter does, and then going into the class and figuring the numbers out to make it work.

The number had more meaning that way and I was anxious to see, oh now we have this second order of circuits which had a pretty good response and should look like this.

I came to the lab thinking I'm just going to get to these labs as fast as I can because its one or 2 less homework assignments a semester, and I'd rather be doing it in the lab. But after I did may be the first one or two labs I realized that this lab is really way more beneficial than I originally thought. So I came into a skeptic and came out a believer.

Ivan

Obviously there I mean like I said before when you are actually doing in the lab there are so many things going on that become a lot clear when you actually look at it compared to somebody else trying to describe it to you in the board. So the way to go is well … I still think the way he does is probably the best way. He kinda explains the theory a little bit. You may not totally get it but you may kinda understand the concepts and when you actually take it to the lab everything kind off comes together. So both ways have got their advantages and disadvantages. But I still think its kinds important to do the lab because you probably would not understand what is going on actually.

Bob

Analysis of Journals

Students expressed their thoughts on the labs through electronic journals. The journal format was different for both semesters. Every time a lab assignment was announced, an email containing the journal questions was sent out. The researcher was the contact for students to report equipment failure and other issues involved with the course. The researcher was responsible for maintaining confidentiality regarding the details on students when communicating with the professors teaching the course. The researcher would not reveal if a student belonged to the control group or the treatment group to the professor teaching the course. The students in the control group undertook analytical homework problems. The students in the treatment group had a laboratory component that replaced a part of the homework problems. The homework problems that were replaced by the lab component covered the same concepts as the laboratory.

A teaching assistant graded the assignments. Thus the IRB guidelines regarding confidentiality were maintained. The researcher sent a reminder to students when they failed to submit the journal component of the course. Though the journals were not graded, an assignment was considered complete only upon the receipt of the journal component. Students sent their journal entries through email to the researcher.

ELEC 304 - Fall 2002

A descriptive account of the first two surveys from students is presented in this section. All students who volunteered for the study were randomly divided into two groups. The two groups were called the 'Tigers' and the 'Panthers'. For the first homework assignment the 'Tigers' were the treatment group. Treatment involved replacing a part of the homework problems by the lab component. The 'Panthers' were the control group

and received regular homework problems. The control and treatment groups existed for a single assignment or concept. Both the treatment and control groups were reconfigured for each assignment. Thus for the second homework assignment the 'Panthers' received the treatment. By reconfiguring the control and treatment groups for every lab assignment, all the students who volunteered for the study had the same total amount of exposure to the lab. The journal was a part of the lab component. It consisted of answering five survey questions and one open-ended question. Since both groups had the opportunities of doing two lab assignments each student was responsible for two journal entries.

The histograms show the perceptions of students from both the groups who answered the same survey questions after performing the lab.

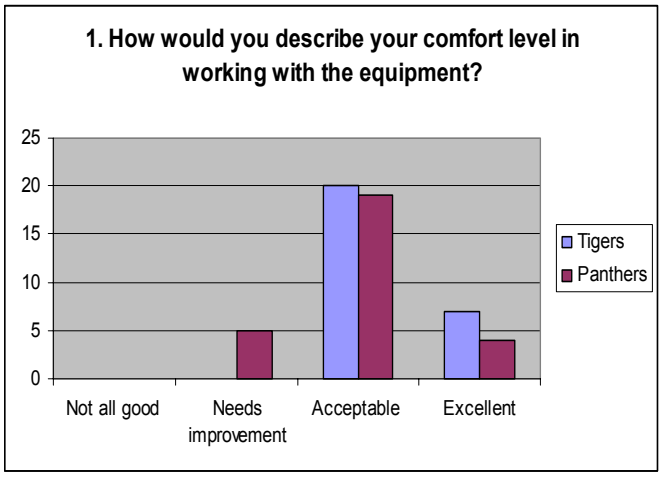


Figure 2. Histogram describing student's comfort level with TIMS

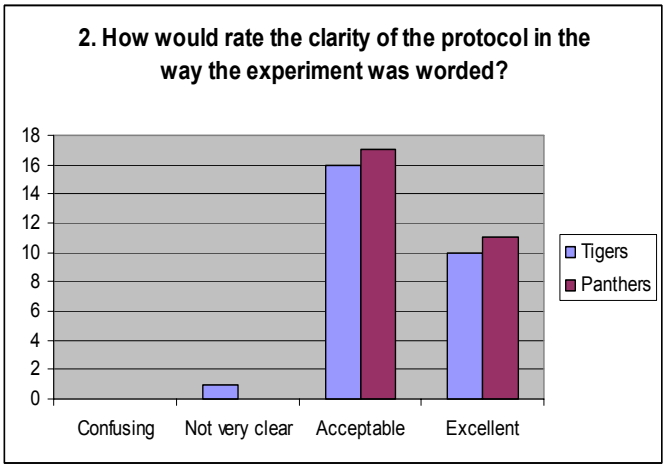


Figure 3. Histogram describing the clarity of the lab protocol

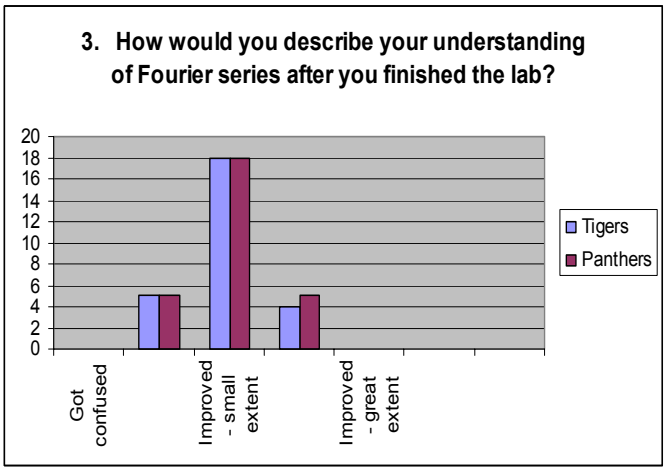


Figure 4. Histogram describing usefulness of lab on student's understanding of a course concept

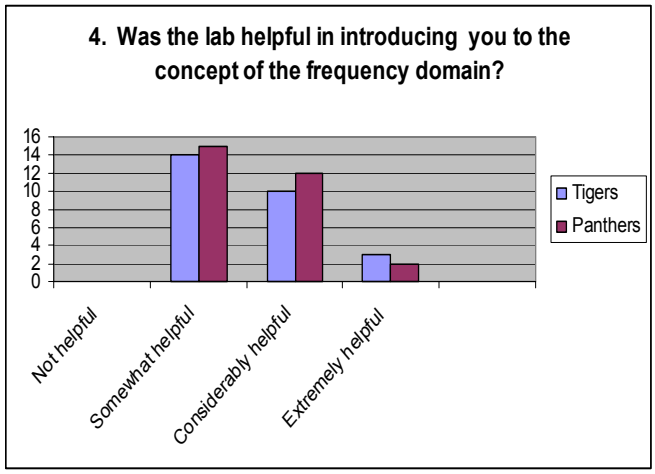


Figure 5. Histogram describing usefulness of lab on student's understanding of a course concept

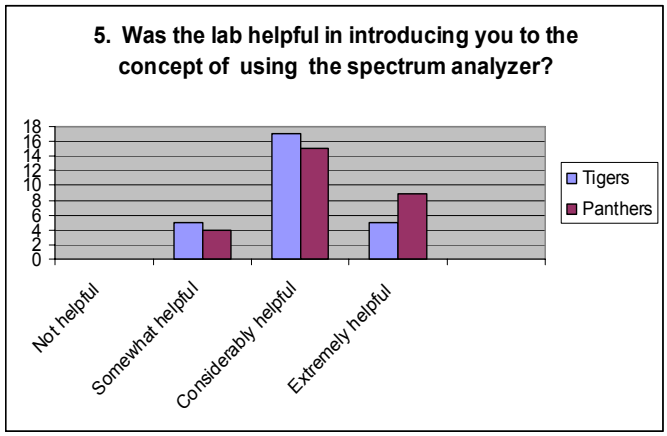


Figure 6. Histogram describing usefulness of lab on introducing the spectrum analyzer

The sixth question was open ended where they were asked to express their thought on the lab and its impact on them without any hesitations.

The following are a few comments.

> This lab didn't really directly teach me anything new, but it made me think about what is going on. So I understand it better just from seeing it from a different view.
>
> *Mike*
>
> The lab is more helpful than a sheet full of math equations!!
>
> *Jim*
>
> I feel if there was more instructions on what exactly the spectrum analyzer shows, or showed would have helped a little bit. Other then that I think the lab will be very helpful.
>
> ***Patricia***

Some of the students expressed problems with the printer. One student felt that if there were more instructions on the spectrum analyzer it would have been very helpful.

ELEC 304 (Spring 2003) and ELEC 464/864

Over the Spring semester, students were sent journals. The ELEC 304 (spring 2003) students had five assignments. The ELEC 464/864 students performed four labs over the semester. This section deals with the journal component involved in both the classes. Each of the lab assignments involved a journal component involved. Each journal had five to six questions which was comprised of both open-ended questions and specific questions. The specific questions targeted both the specific lab assignment and the lab experience in general.

Journal Questions

Some of the questions pertaining to the impact of the lab as listed below. Most of these questions on the lab experience were similar to the interview questions. They were worded differently from the interview questions.

- What changes (do you perceive) you will have at the end of the semester as a result of your involvement in the lab?
- How would rate the clarity of the protocol in the way the experiment was worded?
- Is there anything else you would like to let me know about the lab or the course? Or how was the overall experience in the lab?
- Do you think the lab helps you to remember the concepts?

The following are some of the questions that were targeted to a lab experience.

- In what way, if any, did the lab further help your understanding of frequency doubling and frequency shifting property of the Fourier transform compared to the class lectures?

- How comfortable and competent are you with the concept of Fourier series?
- Which aspect of the Fourier series in particular are you good at, and which aspect of the Fourier series in particular are you not good at?
- And how did the lab influence (help or not help) in the above?

Observations on Journal entries

All the students' journals were compiled and read. The following are the observations from the journals of both ELEC 304 (spring 2003) and ELEC 464/864.

- For many students the lab was helpful in reinforcing their knowledge / understanding on frequency domain
- The lab avoided the frustration of a traditional Electrical Engineering lab that focuses on answering the questions but does not provide a chance to repeat the procedure.
- There were many students who had never used a spectrum analyzer before and felt that the lab was helpful in introducing them to using a spectrum analyzer
- Some students were worried about the homework problems they missed out by doing the lab. They were concerned that they might be responsible for those problems on an exam or test.
- Many students appreciated the fact that the lab assignment did not involve unnecessary calculations and repetitive procedures that actually did not contribute to their learning
- All students at some part of their journaling emphasized on the hands on approach they received.

- All students expressed the benefit of being able to see a mathematical equation in the form of graph or the theoretical concepts beings presented visually.

> I think the lab is helping, but there is really no way to show it. I felt like understanding more of the material, but I don't feel like it shows much. In my mind I can see things and explain things better, but it doesn't really show on the test because of how things are structured and organized.
>
> *Greg*

- Almost all Students from ELEC 304 expressed that they understood the concept of the time domain and frequency domain better after performing the lab.
- A frequent comment was that "the lab ties everything together."
- The questions that were posed in the lab assignments were straight forward and easy to answer.
- All students mentioned that the lab increased the interest level in the course.
- The lab gave them a chance to find answers for the "what if" questions that were discussed in the class.
- Most of the students felt that it was because of the lab they were able to see how the models and equations applied to real life.
- Students readily accommodated to a nontraditional lab component
- There were no expressions of boredom or disinterest in any part of journaling

Chapter V

Quantitative Measures of Learning

Quantitative study

The quantitative study followed a model that included the use of control and treatment groups. Both the control and the treatment groups received instruction using traditional teaching methods. The control group received analytical homework problems, and the treatment group had a laboratory component that replaced a part of the homework problems. The deleted homework problems covered the same concepts that were covered by the laboratory.

Student's prior knowledge was measured by their performance on the pre-quizzes to both the control and the treatment groups prior to the laboratory experience.

ELEC 304 - **Fall 2002**

The control and treatment groups existed for a single homework assignment. 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 total amount of exposure to the lab.

Each lab assignment was based on the underlying mathematical concepts and was aimed to illustrate the usefulness of the concepts. Both the control and treatment groups received traditional classroom lectures over the concepts. Pre-quizzes were given in order to assess any baseline knowledge of the concepts. Post-quizzes were created very similar to the post quiz and were used to measure the difference in learning between the control

and treatment groups. A total of four laboratories were integrated into ELEC 304 over the fall semester covering the following concepts:

1. Frequency content of periodic signals, the Fourier series.
2. Properties of the Fourier transform.
3. Filtering of signals.
4. Frequency response of systems.

An example of this procedure is described:

ELEC 304 students were exposed to the analytical procedure of calculating the Fourier series. All students received regular classroom lectures on how periodic signals pass through linear filters. The Fourier series of a periodic signal is 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 that included the following problem[21].

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 is that the filter output is 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

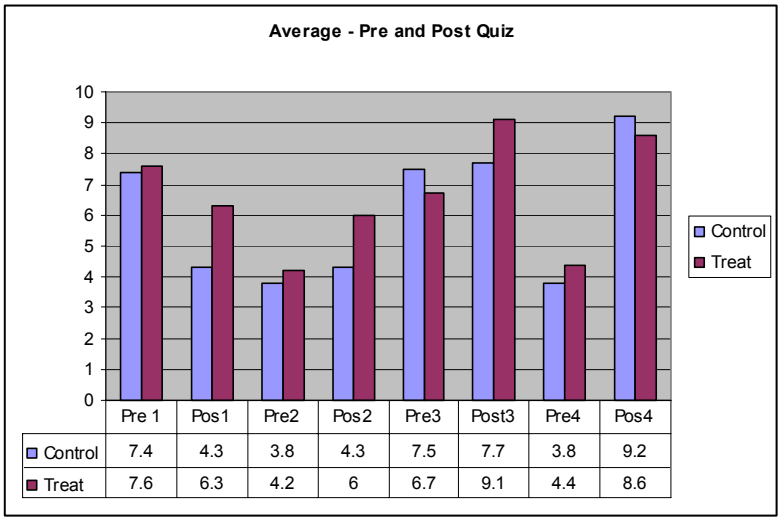
were then asked to adjust the cutoff frequency of the low-pass filter and observe the changes in the output signal. The students could see the effect in both the time and frequency domains simultaneously. The students were *not* asked to analytically calculate the Fourier series of the square wave. After completing the assignments, both the control and treatment groups were given the following post-quiz[21].

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.

Statistics from the Data

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 7. Quantitative results from ELEC 304 – Fall 2002

Results from observing the mean of the two groups 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[21].

Statistical analysis of data

The mean of the scores seem to indicate that the treatment group, the ones taking the laboratory assignments, performed better than the control group working off homework assignments. An acceptable method of measuring the significance is analysis of variance (ANOVA).

The attached table provides a summary of the means and standard deviation for tests 4, 5, 6 and 8, when the homework and lab assignments were provided to the control and treatment groups.

Test 4				
	Mean		St. Dev.	
	Ctrl	Trt	Ctrl	Trt
Pre	7.42	7.58	2.918	2.338
Post	4.38	6.29	2.601	2.758
N	24	24	24	24

Test 5				
	Mean		St. Dev.	
	Ctrl	Trt	Ctrl	Trt
Pre	3.83	4.19	2.995	3.53
Post	4.3	6.05	3.022	3.025
N	23	21	23	21

Test 6				
	Mean		St. Dev.	
	Ctrl	Trt	Ctrl	Trt
Pre	7.4	6.7	3.2	3.7
Post	7.7	9.1	2.1	1.6
N	18	19	18	19

Test 8				
	Mean		St. Dev.	
	Ctrl	Trt	Ctrl	Trt
Pre	3.83	4.42	2.572	2.317
Post	9.17	8.63	1.917	2.813
N	18	19	18	19

Based on analysis of Groups 4, 5, 6, and 8, the following observations ensue

- Post quiz numbers are higher in all cases except one, which is as expected.
- The mean in the post-quiz is markedly higher for the treatment group in all tests except test 8.

- In all cases, the mean for the post-quiz is not significantly different for the control group.
- The 95% confidence intervals of the two groups overlap raising questions about the significance of the difference between the means.

Using a 95% confidence interval, based on the t-test, the probabilities that the differences observed are indicative of the general population were:

Test	4	5	6	8
Pre-Quiz	<0.9	<0.9	<0.9	<0.9
Post-Quiz	0.985	0.94	0.98	<0.9

Tests 4 and 6 favor the treatment group, Test 5 is borderline, and test 8 does not show any significance. There are positive but inconclusive indications that the treatment assists in raising test performance.

Based on a single sample t-test with a 0.05 confidence interval, the difference was not statistically significant. The lack of significance in the quantitative data raised several issues about the study protocol. For example, were the five minute pre- and post-quizzes sufficient to measure the higher level learning expressed in the course objectives? Does a single lab assignment sufficiently correlate with a course objective to have a lasting effect, or are more sustained laboratory experiences required?

The quantitative protocol for the Spring 2003 semester is based on a pure treatment group and a control group.

ELEC 304 – Spring 2003

Control and treatment groups were maintained for the entire semester. The control group received the standard ELEC 304 curriculum with standard problem based homework assignments. The treatment group received a homework assignment consisting of a laboratory and a subset of the control group's problems. The deleted homework problems covered roughly the same concepts and material as the laboratory.

In order to measure differences in learning outcomes between the control and treatment group two exams were given. At the beginning of the course, all students where given a baseline exam to measure prior knowledge about material to be covered in the course. The baseline exam covered material spanning the entire semester and was not used to measure knowledge of prerequisite material. At the end of the course, all students were given the same comprehensive final examination. A typical student received a very low score on the baseline exam. The final exam was administered at the normal time (end of the semester) and was identical to the baseline exam. However the students were not aware of this and did not have access to the baseline exam at any point during the course. The difference in the performance between the two groups was computed to look for any statistical significance in grade between the two groups.

Statistics from the data

The results for ELEC 304 (spring 2003) are shown in Figure 2. Once again, the results suggest a difference in learning outcomes between the control and treatment groups. However, based on a single sample T-test with a 0.05 confidence interval, the difference was not statistically significant. The data shown in Figure 2 is for a control group with 17 students and a treatment group with 18 students.

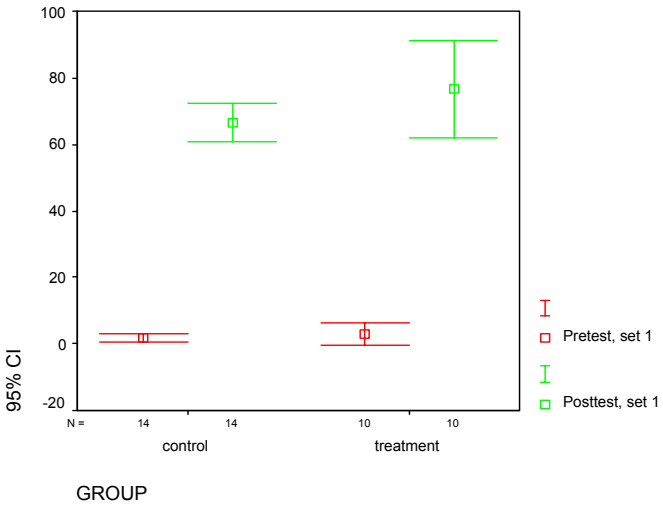


Figure 8. Quantitative results from ELEC 304 - Spring 2003

The same protocol used in ELEC 304 during the Spring 2003 semester was used in was used in ELEC 464/864 Digital Communications for the Spring 2003 semester. 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.

ELEC 464/864

The results of this study are shown in Figure 3. The data in Figure 3 is for a control group with 7 students and a treatment group with 5 students. The data from ELEC 464/864 is significantly diluted due to the mixture of graduate and undergraduate students and the ethnic diversity of the group.

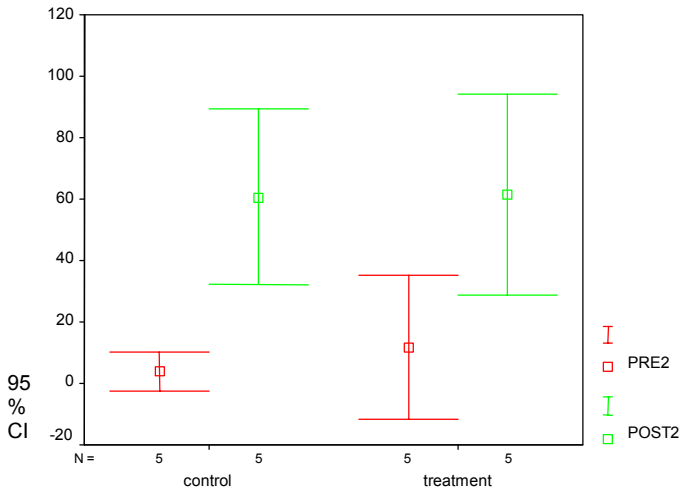


Figure 9. Quantitative results from ELEC 464/864

The high baseline score in the treatment group is due to the fact that two students in the group had undertaken a course similar to ELEC 464/864 at a different institution.

Chapter VI

Discussion

Student Perceptions of the Lab Experience

From the qualitative interviews, it was clear that students appreciated the lab set up. There were several references to the round the clock access to the lab, which made it easy for students to complete their assignments. Further, the absence of a restricted time limit to use the lab facilities was very much appreciated. Some students even mentioned going beyond the curriculum to experiment with the concepts. The interviews also brought to light that the lab also lowered the pressure of completing that task and allowed students to focus on the learning itself. The state of the art equipment facility was also appreciated by the students. Students reacted positively to the lab curriculum, and many indicated that they were looking forward to the incorporation of the lab component into the four-course sequence.

Impact on student learning

Almost students mentioned in the interviews that the lab helped them with clarification of course concepts. Many students responded increased confidence in their understanding of the course concepts. Students mentioned that some topics (like white noise ELEC 304) become clear only after seeing them in the lab. Thus the lab provided an opportunity for many students to address abstract concepts through concrete illustrations. Many students from ELEC 304 and ELEC 464/864 pointed out that the visual representation helped their long-term memory. Repetition of the concepts combined with hands on approach is a highly recommended teaching approach in science. Further, all the students expressed

that they enjoyed the lab component of the course and how it complimented the classroom lectures in their learning.

Other Impacts of the Lab on Students

Students enjoyed the utilitarian nature of the lab. They expressed the advantage of the lab in having an experience to work with equipment like the spectrum analyzer and oscilloscope in an undergraduate-level course. According to them it was getting the "real life" experience in the lab. This acted as a motivational factor in increasing their interest level in the course.

Limitations from the Qualitative data

The emerging themes in the qualitative section of the study suggested some inconsistencies between student performance and their perceptions of the impact of the laboratory on their performance. The quantitative and qualitative results have led to new questions.

- Do 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? [22]

Limitations from the Quantitative data

The quantitative data on student grades from both the semesters did not yield statistically significant results. 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[22].

The effect of the lab on student learning was compared against homework problems alone. But are they equivalent to be comparable? Do they contribute to student learning in the same manner? Is it possible to contrast the effects of the two? [22]

The students in all the three classes had diverse backgrounds. In ELEC 304 there were several students who were retaking the course. In ELEC 464/864 there were several international students who probably had earlier experience with the course material.

Benefits of Qualitative Study in Engineering Education

In engineering education, when quantitative results are not significant, qualitative results provide valuable insights into students' perceptions. The qualitative results give us indications as to which aspect of the lab the students felt beneficial. Bruning et al[23], in describing effective teaching strategies, suggest that students should be expected to reflect on their learning by using discussions and writing that promote deeper understanding. In typical engineering courses, the professor gets to understand students' perception on the course and his teaching practices through student feedback. But, when a journal component is involved, he or she can get feedback about their understanding of

the course concepts as the course proceeds. Further, it is also possible for the professor to understand the impact of different components of the course, like lab, homework, tests and exams. It is also possible to understand how these components relate to each other and to the course itself. Faculty comments from the interview were that they were convinced with the need to integrate the lab component into the course curriculum after hearing about the impact of the lab on student learning. The professor who taught ELEC 304 both the semesters often expressed that the excitement caused by the lab often spilled over into his lecture classes, where students were asking him more question as the semester progressed.

Curriculum Integration and Innovation

The faculties who taught ELEC 304 and ELEC 464/864 were impressed with the data generated from the interviews, and have integrated the lab component into the curriculum. Over Fall 2003 and Spring 2004 semesters, the systems and signals laboratory was a part of the three-course sequence in signals and systems.

The results of this study will be used to improve the overall learning experience of future UNL 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. As the EE Department at UNL has already undergone and passed Associate Board for Engineering and Technology (ABET) 2000 accreditation, this study will be incorporated into the assessment and feedback process required by ABET 2000[1].

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 was 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 wrote a journal after every lab assignment.

Chapter VII

Conclusions

The interviews and journals used to measure student attitudes and use of cognitive process involved with the lab experience indicated that lab was helpful in clarifying and reinforcing course concepts. The lab also increased the interest levels of students in the course.

The low number (N) of students in the signals and systems series of courses lowers the significance of the t-scores associated with student achievement. The academic improvement for students on an individual basis is an important finding. Face-to-face interviews yielded rich data, details, and unexpected themes. The interviews made it possible to analyze the affective as well as cognitive aspects of responses. The interviews also allowed us to obtain clarification of students responses thereby increasing the likelihood of useful responses. As the interviews for ELEC 304 was taking place in the fall semester it was possible for the researchers to identify the themes were framed. Their responses indicate that course concepts were clarified through their lab experiences.

A missing link was evident from the interviews conducted on all students. Though the students acknowledge the fact that the lab was helping them understand or clarify course concepts they did not perceive any improvement in their grade because of the lab. But the quantitative data shows that the student in the treatment performed better in the assessments after the lab experience. Hence the students believed that the lab assignments helped them understand the course concepts better but were not sure if their understanding led to better academic performance - better grades. As discussed earlier, this could be a misalignment between the course objectives, the assessment procedures,

and the lectures, or that the students have limited metacognitive awareness, or both. At this point, it is not clear what caused the missing link by which students were not able to see the connection between their heightened levels of understanding (because of the lab) and their performance in the course[22]. By checking the course objectives with what is taught and what is tested, the Engineering department could avoid a possible misalignment in the course structure.

Acknowledgment

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