Implementation and Effectiveness of the Integrated Signals and Systems Laboratory

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Introduction

Over the past three years, the Department of Electrical Engineering at the University of Nebraska, Lincoln (UNL) has implemented an Integrated Signals and Systems Laboratory (ISSL) in its undergraduate curriculum. The laboratory experience uses a common experimental platform, the Telecommunications Instructional Modeling System (TIMS), in 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 paper summarizes our experience with the ISSL in terms of implementation and utilization and its effect on student learning.

Laboratory Motivation and Implementation

The ISSL at UNL is integrated into four separate three credit hour courses that are taught at the junior and senior levels in the undergraduate curriculum. The laboratory experience is 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 systems 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 systems 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 motivation for the creation of the ISSL came from prior experience in trying to establish an undergraduate laboratory for ELEC 462 Communication Systems[1]. The laboratory experiments were based on the typical block diagram of a communications system, which students implemented block-by-block 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 and increased student motivation. Second, much of the time and effort spent in the laboratory was expended trying to make the circuits function and not on exploring the concepts. The latter 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 came from the desire to improve student retention of theoretical concepts from course to course. Faculty in the Department of Electrical Engineering observed that students entering advanced senior level courses did not retain fundamental knowledge from prerequisite courses. On the other hand, students taking these courses commented that ELEC 304 and ELEC 305 seemed 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 the four course sequence would improve retention from course to course.

The purpose of the ISSL is to connect theoretical and mathematical concepts of signals and systems with the "real world". It was concluded that a successful laboratory experience required an experimental platform that avoided the traditional implementation pitfalls of a circuit-based laboratory without becoming a "black box" laboratory that turns students into passive observers rather than active discoverers. In addition, the experimental platform had to be flexible enough to be used throughout the course sequence. The platform chosen is the Telecommunications Instructional Modeling System or TIMS.

The TIMS platform consists of a basic system unit and card modules that implement components of analog and digital communications systems as well as amplification, filtering and interfacing to external test and measurement equipment. 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 expected to be substantially longer than other platforms. Additional information about the TIMS equipment may be found at www.qpsk.com. 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 computer that enables real time screen captures and electronic laboratory notebook and report preparation. The ISSL has four complete laboratory stations.

ELEC 304 is a required course in both the electrical engineering (EE) and computer engineering (CE) undergraduate curricula. ELEC 305 is a required course for EE undergraduates, but optional for CE undergraduates. ELEC 462 and 464 are senior technical elective courses and are taken by approximately one fourth of the senior class of electrical engineering students. Each fall semester ELEC 304, ELEC 305 and ELEC 462 are taught and each spring semester ELEC 304, ELEC 305 and ELEC 464 are taught. Thus, in each semester three classes with an approximate total enrollment of 120 students use the ISSL. In order to accommodate such a large number of students, students are given twenty-four hour access to the laboratory and faculty coordinate due dates using a web based calendar. This approach has been very successful with virtually no complaints from students concerning equipment availability.

The TIMS equipment has a companion laboratory manual with many experiments for analog and digital communication systems. For ELEC 462 and ELEC 464 it was necessary to adapt these to our curriculum and course objectives. We have currently written four laboratories for ELEC 462 and five laboratories for ELEC 464. In the case of ELEC 304 and ELEC 305[2] it was necessary to develop completely new laboratories. We have currently written five laboratories for ELEC 304 and four laboratories for ELEC 305. All of these laboratories will be available for download at the ISSL web site by the time of the publication.

Laboratory Impact on Students: Qualitative Data

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.

A mixed methodology[3,4] study that included both quantitative and qualitative techniques was used to assess the impact of the lab[1]. The quantitative data from this study[5] indicated increased student outcomes in each course as a result of the laboratory experience. In addition, students who had used the laboratory in ELEC 304 and/or ELEC 305 scored higher than a control group of students who had not used the laboratory in either course on a prerequisite exam given to students entering ELEC 462. We now present the results of the qualitative portion of the study.

The qualitative portion of the study was designed to measure student perceptions regarding the effectiveness of the TIMS lab experience and the data produced, at first exciting and ultimately curious results. The qualitative study was based on interviewing randomly selected students for each course that had used the laboratory. The over-arching focus was to determine the effectiveness of the signals and systems lab with respect to performance and retention of material throughout the course sequence. The data provided answers to these two questions and also produced interesting unanticipated results about student meta-cognitive development.

The qualitative interview questions were:

1. Are there course concepts that have been clarified by the TIMS laboratory experience?
2. What is your perception of the time spent versus understanding gained?
3. Did the laboratory influence your dedication to the course?
4. Did the laboratory experience help you understand the utility of the course materials?
5. Did your laboratory experience give you a real or perceived advantage in the course?
6. Did the lab help you retain material throughout the course sequence?

The qualitative results are discussed on three axes: one, the positive impact of the laboratory experience on student performance; two, a positive but less distinct impact on content retention throughout the course sequence; and three, issues of meta-cognitive awareness that either indicates a cognitive developmental gap between younger undergraduates and non-traditional older students or a need to effect purposeful instructional and curricular changes.

First, the qualitative results indicate positive results regarding concept clarification and motivation. Twenty-eight of the thirty students interviewed in the first course, ELEC 304, stated that the lab experience helped with course concept clarification and twenty-five students cited increased motivation or interest towards the course because of the labs. This fact is more interesting because from this group of thirty students, including those who were able to identify specific concepts that were clearer due to the lab, only six stated that they believed that the lab helped their academic performance in the course, i.e., a higher course grade. A representative response to question 1 above is (here and in subsequent quotes the underlines are added):

> Yes, I think that working in the frequency domain using a spectrum analyzer is something that helped me a lot; just because what we do in class a lot is sketch the diagrams that the frequency domain and the frequency response signal. But <u>seeing</u> the real sign and real frequency response I think helped a lot. If nothing else, just to get a <u>real world</u> sense of how we actually use the equipment, so I think so.

Many student responses reflected a common notion about “real world” and “seeing” indicating that the concrete applications inherent in the lab lessons helped clarify abstract course concepts. Another student stated that it was “interesting to <u>see in real life</u> what actually happens when you low-pass-filter something”. Overall, the students consistently stated that the lab helped them understand course concepts. Moreover, quantitative results based upon their summative assessments (grades) reinforced the fact that they were indeed benefiting academically from the labs whether they realized it or not[3].

Students in the upper level electrical engineering courses, ELEC 462 and ELEC 464, reported that the lab experience helped them clarify concepts, as well. However, their comments in response to questions about course concepts were, generally, about retention. When asked if the lab helped them clarify concepts they would, at first, identify notions that were easier to <u>see</u>, as with the lower level students, but then reform their answers to state how the lab helped them retain and remember concepts from ELEC 304 and ELEC 305. The student example stated below is typical of how the upper level students responded. Again, the student was asked if the lab helped them clarify course concepts.

> Um, well, if you don’t actually <u>see</u> what you’re doing, I think, if you don’t <u>see</u> what you’re doing, after a class, you just kind of forget and it doesn’t really stick with you because a lot of number crunching and stuff like that just kind of …you find in your <u>short memory</u> and you don’t really get that much out of it as much as if you <u>actually see</u> it then <u>when you go back to something you at least have a reference</u> of what you…it’s in your head, a <u>mental picture</u>.

The notion that retention was linked to the lab had yet to be suggested to students as it was one of the last questions asked. This may mean that students learned how better to use the lab over time or that the retention requires more time to effectively measure. The third area discussed in this paper, meta-cognitive awareness, may be influential with the upper level students as well; these students may be maturing as they progress through the program and are learning how better to self-regulate their learning process. This may make it easier for them to understand the connection between the lab and their overall learning processes.

The second area of interest is the retention of concepts throughout the course series. Our study hoped to determine the impact of the TIMS laboratory experience and find out if it helps students maintain conceptual understandings from ELEC 304 to ELEC 305 and then to the senior course sequence ELEC 462 and ELEC 464. While the lower level students were not able to specifically identify the TIMS lab experience as the primary reason for retention of course materials, many concepts form ELEC 304 were cited as well established and students remembered them from the earlier course experiences. The students were unable to clearly delineate between concepts that were learned in the ELEC 304 lab or understandings that were reinforced through multiple experiences such as the lab, the homework assignments, or the lectures. However, of the seventeen students interviewed from ELEC 462 and ELEC 464 all were able to generally identify concepts that were reinforced in earlier lab experiences. Here is another student response to a direct question about concept retention and the TIMS laboratory experience.

> I think so. To be honest, I hadn't done anything in the lab really for outside of senior design project, I hadn't done anything in a lab course since I took 307 so it was nice to have that experience again, because <u>you lose sight</u> of that, you know, it eventually comes back to you.

Third, the data indicated that issues of cognitive awareness might imply either a developmental gap between younger undergraduates and non-traditional older students or the need to effect purposeful instructional and curricular changes based upon when the students took the lab. Initial data analysis found that in the thirty interviews of ELEC 304 students, responses indicated the students' ability to identify the positive attributes of the lab, but only two of thirty indicated that they thought that the lab experiences provided them with a real or perceived advantage in the course in terms of a higher grade. The students were not aware of treatment group test scores but were certainly aware of their own work and yet only two of the thirty respondents were able to see the lab as a summative advantage.

Originally, we believed that developmental issues, in particular, the ability of students to regulate and monitor their own thinking and learning, a process known generally as meta-cognition, were the cause of the differences. We believed that the two students who were able to identity the lab as directly impacting their academic performance could do so because they were older, non-traditional students with an advanced developmental status. These issues are briefly discussed below but may not be the only influential factor due to information coded from the most recent group of six ELEC 464 students. Of the six ELEC 464 students, four were able to see a connection between the lab and their grades yet none of these were older or non-traditional.

This may mean that something other than a student's developmental stage is as influential as the lab, such as where they are in the "experiential learning cycle" as suggested by David Kolb in his *Model of the Learning Cycle*[6]. Kolb believes that there is a four-stage process of experiencing, reflecting, conceptualizing, and planning that students enter at various times during the learning process and that students make small incremental improvements within such a cycle, which may mean that each student will be at a different level of understanding at the time of inquiry. It may also mean that students rely on their own learning preferences when determining what teaching and learning techniques are most beneficial and that the curriculum may need to purposefully include all the of learning cycle stages and address preferences.

This, however, does not mean that developmental meta-cognitive stages can no longer be considered an important part of the study results, only that we will need to redesign future studies to accurately gauge why students have difficulty identifying how the lab experience assists them academically. We are interested in knowing if the lab curriculum needs to be properly placed in the "Cycle of Learning" as Kolb suggests or as Schoenfeld[7] states about meta-cognition, "How well you keep track of what you are doing when you are solving problems, and how well (if at all) you use the input from such observations to guide your problem solving actions is an important cognitive management process, (meta-cognition), that cannot be proved or discounted as salient in this study."

Again, during analysis of the qualitative data for the first three semesters, we noticed that only two of thirty ELEC 304 students interviewed were aware of the advantages afforded them by participation in the lab. Looking at the demographics of those students revealed that they were older and non-traditional undergraduate engineering students. The most articulate respondent was clear about the advantage the lab provided and he was able to articulate how his learning was impacted, which we believe indicates a higher level of meta-cognitive awareness:

> It definitely helped me undo my old way of thinking like a technician. When I started the course, I guess I came in with the attitude that I can see how this works because of what I know about how RC circuits work . . .. Once I came in here and started doing frequency domain, since it was more hands-on, I guess it gave me validity. That's what the lab gave me, a reason for using the transfer function; it's much easier to see what's going on with a transfer function now that I can see it in real life instead of on a piece of paper.

He went on to discuss the advantage that this type of experience gave him regarding his overall performance in the course, which was not stated by younger, traditional undergraduate students:

> Oh, I'm sure. Definitely, if my attitude changes towards, (pause) and I actually do prefer this method rather than doing it the old way, or at least what I thought was the old way . . . It definitely, instead of more, it puts my mind to thinking about how does this work from a transfer function and how does this work from the RC point of view?

This student also identified increased interest in the course, increased motivation toward the lectures, and a generalized appreciation of course materials that he expressed as helping with his academic performance. For example, he stated, " I definitely appreciated the material more. I would say I studied more. It definitely increased level of grades from the first to the second tests". Again, we were and are still interested in why certain student demographic characteristics were either able to identify this advantage or not respectively. What are the developmental factors that determine the meta-cognitive abilities of undergraduate engineering students and what are the characteristics of the engineering curriculum that may exacerbate student developmental differences? Now we must also consider, in light of the latest data, what are the curricular and instructional factors that may also be influential in the teaching and learning process.

Conclusions

The Integrated Signals and Systems Laboratory has been established at the University of Nebraska, Lincoln over the past three years. The ISSL is now regularly used in three separate courses each semester with an approximate total enrollment of 120 students. Quantitative and qualitative data suggest that the laboratory has been successful in increasing student outcomes in each course and in improving prerequisite retention from course to course. In addition, the qualitative data suggests that meta-cognitive or developmental issues may be important when designing undergraduate laboratories.

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