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Development of On-Line Lecture and Preparation Resources for Electrical Engineering Laboratory Courses

Dr. Susan C. Schneider, Marquette University

Susan Schneider is an Associate Professor in the Department of Electrical and Computer Engineering at Marquette University, Milwaukee, WI. She is also the Director of Undergraduate Laboratories for the Electrical Engineering program. Dr. Schneider is a member of ASEE, the IEEE, Sigma Xi and Eta Kappa Nu.

Dr. James E. Richie, Marquette University

James Richie received his Ph.D. degree from the University of Pennsylvania in 1988. He is presently associate professor and associate chair of the Department of Electrical and Computer Engineering at Marquette University. Dr. Richie is a member of ASEE, IEEE, Sigma Xi, Tau Beta Pi and Eta Kappa Nu.

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Abstract –

The goal of this project is to convert five electrical engineering undergraduate teaching laboratories at our university to a hybrid teaching format to increase student satisfaction with the laboratory experience and promote deeper learning. The face-to-face lectures previously used to prepare students for the associated subsequent laboratory session are being replaced with on-line lecture modules to review the theory for the experiments. In addition, on-line quizzes and/or exercises to confirm student understanding of the laboratory theory are being created; formerly such content mastery was probed using preparation review questions requiring handwritten responses. Application modules consisting of either narrated slide presentations or short videos showing the hands-on aspects of electrical engineering laboratory procedures such as building circuits and properly operating the test and measurement equipment are also being created so that the students know what they should be looking for during their experimental work.

The first set of on-line course materials for a sophomore level circuits laboratory was deployed during the 2011 – 2012 academic year with two more junior level laboratories converted in each of the subsequent academic years. Assessment data from surveys, course procedures, and student laboratory preparation is compared to the student performance on similar laboratories administered in the previously used traditional face-to-face lecture format. In addition, these same instruments are used for formative assessment of the on-line features to better tailor the modules to the needs of the students.

In this paper, three things will be described. First, the common on-line structure developed for the five laboratories within our university's course management system will be presented. Second, examples of materials including lectures, quizzes and videos developed for several of the laboratories will be shown. Finally, the formative and summative assessment instruments will be described including how the results of these assessments inform the continuing development of the on-line materials.

Introduction –

The overall goal of this project is to convert five electrical engineering undergraduate laboratories to a hybrid format to increase student satisfaction with the laboratory experience and promote deeper learning. The existing lecture/laboratory structure is being modified by placing the lecture materials used to review the theory for the experiments on the course site within the university course management systems, Desire to Learn (D2L). On-line quizzes and/or exercises are incorporated to check content mastery. Additional videos or slide presentations showing the hands-on aspects of electrical engineering laboratory procedures, such as building circuits and properly operating the test and measurement equipment, as well as showing examples of what expected outputs should look like are being created to provide examples for the students during their own laboratory work so they are making their measurements on properly working circuits. The time that is freed up by moving the review of theoretical concepts and equipment use from the formal lecture period is now available for deeper discussions of the meaning and relevance of the data the students acquire in the laboratory.

A significant body of literature is available in engineering education journals and conference proceedings addressing the issues of modernizing teaching laboratories to take advantage of new and emerging educational technologies. Many of these papers can be categorized as either (1) projects incorporating multimedia elements to create on-line materials to facilitate the delivery of theory instruction while retaining a significant "hands-on" component,[1-13] or (2) projects in which virtual or remotely operated laboratories suitable for distance or totally on-line education are created in which the hand-on experience is replaced by simulations or a set of data generated by others using the equipment.[14-19] Our revision of the EECE laboratories falls into the first category and has significant aspects of the flipped or inverted classroom experience.[20 – 24]

There are two primary goals for this project:
(1) Increase student satisfaction with their undergraduate engineering laboratory experience in their major.
(2) Modernize the delivery of theory review and equipment usage associated with the electrical engineering laboratories using on-line materials to create hybrid versions of these courses.

It is (was) anticipated that accomplishment of the first goal - to increase student satisfaction with respect to their laboratory experience - can be facilitated by achieving the second goal - replacing the traditional lecture with a modern multimedia array of materials which bring a fresh perspective to the conceptual, analytical, and procedural aspects of each laboratory assignment. The flexibility of multimedia allows for demonstration of lab technique via video, creation of sample data sets to practice laboratory data analysis technique, and competency quizzes to insure the student has mastered each level before moving to the next.

Laboratory Course Format -
The department offers five laboratory classes for engineering students; one or more of these classes is required for majors in three different programs, Electrical Engineering (EE), Computer Engineering (CompE) and Biomedical Engineering – Bioelectronics Option, and – Biocomputing Option (BioE or BioC, respectively) as shown in Table 1. Each of these courses follows a similar format. In the traditional format for these courses, there is a weekly one hour lecture which introduces or reviews concepts for the upcoming laboratory. The goal of the lecture component is to teach the students good engineering practice regarding lab work, including pre-lab preparation, lab procedures, and post-lab practices. The objectives for the lecture are to (a) review/explain needed concepts; (b) demonstrate the required analysis or design techniques; and (c) introduce or reinforce appropriate lab or equipment procedures. The students then complete a pre-laboratory assignment in which they are directed to review materials and document the answers to questions related to their review in their laboratory notebook. Each laboratory (session) typically requires that the students perform multiple (2 to 5) experiments, so students prepare for each experiment by designing and/or simulating circuits to predict expected performance and document those results in their laboratory notebook. They also document the necessary experimental procedures and data tables for these experiments in their laboratory note books for use during the laboratory session. The students then complete this set of experiments in a two- or three-hour laboratory session, followed by post-laboratory work in which they critically review the data acquired to complete the laboratory. The laboratory notebook is graded three times for each laboratory to check student work for the pre-lab, the data and notes from the laboratory session and the post-laboratory work.

Table 1: List of undergraduate teaching labs			
Course Title	Required of	Format	Semester, typical enrollment
Circuits Laboratory 1	EE, CompE, BioE	1 Cr; 1 hr lec; 2 hrs lab	Fall, 55-80
Circuits Laboratory 2	EE, CompE; BioE	1 Cr; 1 hr lec; 2 hrs lab	Spring, 55-80
Digital Electronics Laboratory	EE, CompE; BioE, BioC	2 Cr; 1 hr lec; 3 hrs lab	Fall; 55 - 85
Electrical Instrumentation Laboratory	EE	2 Cr; 1 hr lec; 3 hrs lab	Spring; 25-40
Analog Electronics Laboratory	EE	2 Cr; 1 hr lec; 3 hrs lab	Fall; 25-40

These laboratory classes are atypical of those in many electrical engineering programs – our laboratory courses are stand-alone classes and are not embedded within a course devoted primarily to the development of the student's theoretical background in a subject. Our formal laboratory classes are sequenced so that often the majority of the relevant theory has been previously presented in a concurrent or prerequisite class.

This timing of our lab classes with respect to the theory courses presents both "opportunities and challenges[11]." These opportunities and challenges both contribute to student satisfaction with their laboratory courses. The opportunities occur because laboratory experiments can be crafted that draw upon the whole of the preceding theory class leading to significant projects which allow students to synthesize the material as a whole rather than just draw upon material covered in the immediate two weeks, a pattern which is typical of laboratories embedded within another course. The challenge which arises is that some students may need substantial review of the theoretical underpinnings of the experiments because of the time lag between presentation of the theory and its use in significant multi-faceted experiments. In addition, most students need to have the "whole" pointed out to them so they can see how all the parts they learned previously contribute to the experiment they are to perform. Indeed, one often repeated comment on course evaluations is "the lecture is a waste of time - the material covered in lecture has been covered in (a previous course) already." And, as might be expected, the opposing comment – "need more review in lecture" – appears in the same proportion. This review, however, is not directed towards taking an exam – it is often broad ranging, bringing multiple topics into play to carry out the design or the experiments to be completed as well as their significance.

When the lecture materials are provided as on-line materials, students are able to proceed through them at their own pace. This on-line review can be accomplished by each student in the amount of time that the student actually needs rather than requiring all students to sit in lecture. By breaking the lecture materials into three main components - conceptual, analytical, and procedural components - each component may have questions that the student must successfully answer before continuing with the laboratory assignment. In addition, on-line lecture materials eliminate the need for the teaching assistants to attend the lectures for the laboratory classes, increasing the flexibility for scheduling teaching assistants as well as ensuring that the TAs are familiar with the experimental theory.

Another common student comment is – “I couldn’t figure out how to operate (the equipment) and the TA didn’t give me any/enough help”. The time constraints and volume of material to be covered in the traditional lecture/lab model is not amenable to the illustration of lab procedures and equipment operation in lecture. While such demonstrations can and are done in the laboratory, with one TA for 6-8 teams of 2 students, the students can still spend a bit of time waiting their turn for help with equipment and/or troubleshooting. On-line modules to illustrate the use of equipment can be viewed before the laboratory as part of the preparation and available during the laboratory for review on-demand. These tools modules are also valuable for TA training, particularly for those TAs from overseas who have not had access to the types of equipment used in our laboratories.

We still meet with the students regularly during the assigned classroom lecture time. These times are used to answer student questions, review data from previous experiments to discuss the quality of the data they are acquiring and what may have contributed to bad data and how to properly address such issues. We can also devote more time to discussions and practice on presenting their technical work in the form of technical reports, memos, and white papers. In-class time is also used to help students run their preparation simulations and learn to properly interpret the results rather than just printing the plots. We can also foster student curiosity by helping them to develop and implement “what-if” scenarios both in lecture and in the laboratory.

Development of the On-line Lecture Modules -
During the 2010 spring semester, the three faculty members serving as the course coordinators for the laboratory courses worked with two course designers from the university’s Center for Teaching and Learning to establish a common look and feel for the instructional modules and learn how to actually create the on-line materials. Each of the instructors, one of whom has subsequently retired, has been associated with one or more of the laboratories for several years and has extensive lecture notes and experience with the content and management of laboratory classes.

The primary result of the discussions with the course designers was a generic outline for the content of the on-line lectures as shown in Table 2. This outline represents the combined experience of the instructors used to establish the gestalt of the online lectures based upon <u>all</u> the types of lecture experiences that had been provided over the years to students in the traditional format for these courses. Three main sections are identified – (1) the section in which the “Overview, Objectives and Purpose” for each weekly laboratory session is given, followed by (2) the “Background” section in which the theory behind the experiments is reviewed, the specific application details for an experiment are given, and information on any additional tools needed to accomplish the experiment are provided and finally, (3) the “Practice” section in which the specific preparation work for the experiments to be accomplished in the laboratory is detailed, and the post laboratory data analysis and review work is described. In the background section, depending upon the particular work to be done in the weekly laboratory session, there may be from zero to as many as needed of each of the subsections (for example, 2 theory modules, 3 application modules, no tools module).

Table 2: Laboratory Online Content Outline		
Main Sections	Subsections	Comments
Overview, Objectives and Purpose	(none)	
Background	Theory Application Tools Preparation Quiz	As needed for a particular laboratory
Practice (*)	Preparation Laboratory Post Lab Reflections	

After the student has worked through all the background modules, they take the preparation quiz. The purpose of the preparation quiz associated with each laboratory is – frankly – to ensure that the student has viewed the online modules in a timely manner and, at least, begun the remaining experimental preparation work. These quizzes are completed by each student individually and are based on the readings, lectures, and preparation work expected for each laboratory. The open note quizzes vary from 10 to 20 questions and are timed for completion within 1 hour of initiation of the quiz – most are structured for automated grading. The quizzes are available until midnight of the day prior to the lecture or laboratory meeting (depending on the instructor) and may be taken up to two times with the best grade used. The (statistical) results of these quizzes can be used to facilitate discussion in the lectures.

The other result from the preparation work was related to the production of the on-line materials. Because each instructor is personally responsible for creating all of the online lecture modules for their own courses and each has a different preferred operating system, the choice was made to create the online lectures in the form of narrated slide presentations using those tools with which the instructor was most familiar. The overarching requirement is simply that the students be able to easily view the materials from within the D2L framework.

The online materials are posted on the course D2L site – one module for each laboratory. Individual topic lectures (i.e., Theory, Application 1, etc.) are typically 5 to 8 minutes long, with no single topic lecture exceeding 15 minutes in duration. The total time to view all on-line lectures once for a single laboratory ranges between 45 and 60 minutes similar to the fifty minute face-to-face lecture. With the online format, however, students are at liberty to replay any topic as many times as they wish[24] or to skim swiftly, unlike the traditional lecture.

Assessment of Project Goals -
The measurable outcomes for the project are (1) increased student satisfaction, and (2) development of on-line lecture and preparation materials for five hybrid laboratory courses. For the second goal, to date three of the five laboratory classes are fully converted to the hybrid format: Circuits Laboratory 1, Digital Electronics Laboratory and Instrumentation Laboratory; Circuits Laboratory 2 has online modules for almost half of the laboratories with the others on hold to accommodate upcoming changes in the electrical engineering curriculum. Since the conversion process began, the overall structure of the Analog Electronics Laboratory has changed to a set of three open-ended design projects chosen by each student team which are

quite varied in topic and scope. This format is not as amenable to modularization as the others; however, several applications modules are in development to support the more common student project work observed in this course over the last two offerings.

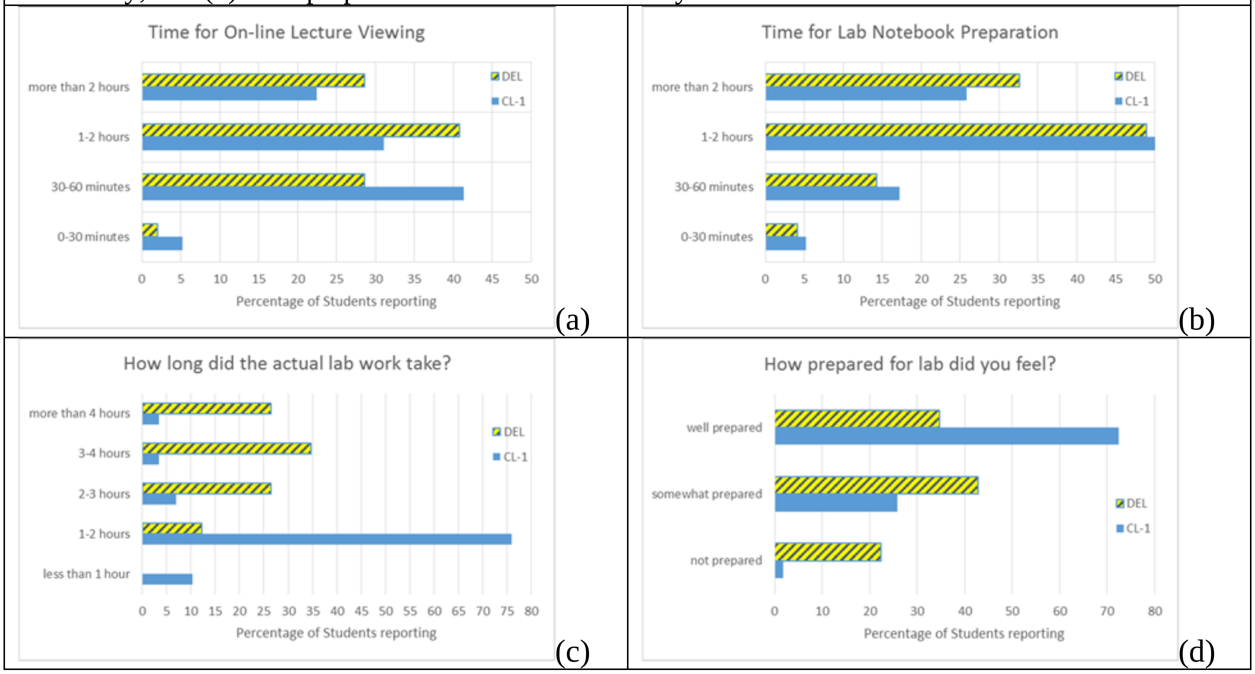
Metrics used to monitor student satisfaction include (1) time to complete preparation work – (a) time needed to view the on-line materials, (b) the time needed to prepare the laboratory notebook with designs and simulations in advance of the laboratory session and (c) time to complete the hands on experiments; (2) satisfaction with the overall time expended for the course; and (3) satisfaction with the amount of learning they accomplished in the course. Student achievement (instructor satisfaction) was monitored by the instructors through review of the post laboratory analysis report for one or more of the laboratories in the course.

A twenty question end-of-semester survey was administered in both Circuits Laboratory 1 and Digital Electronics Laboratory in fall 2013 posted on the respective course D2L sites. In this survey, students were asked to report how much time "on average" they devoted to the several aspects of the laboratory as well as their perceptions of satisfaction with their preparation and overall learning in the course. In fall 2013, there were 76 students enrolled in Circuit Laboratory 1, 76% of whom participated in the survey; in Digital Electronics the survey participation rate was 92% of the 53 enrolled students. To encourage participation, students who completed the survey were given full credit for their lowest quiz grade in the class.

Figure 1 shows the survey results for time spent viewing the on-line materials (figure 1a); average time it took them to complete the preparation of their laboratory notebook including designs and simulations as well as experimental procedures and data tables (figure 1b); how long – on average – they thought it took to complete all hands-on work assigned for each laboratory session (figure 1c), as well as how prepared they felt going into the laboratory session (figure 1d). In these, and all subsequent figures, the legend "CL-1" stands for Circuits Laboratory 1; similarly, "DEL" denotes Digital Electronics Laboratory.

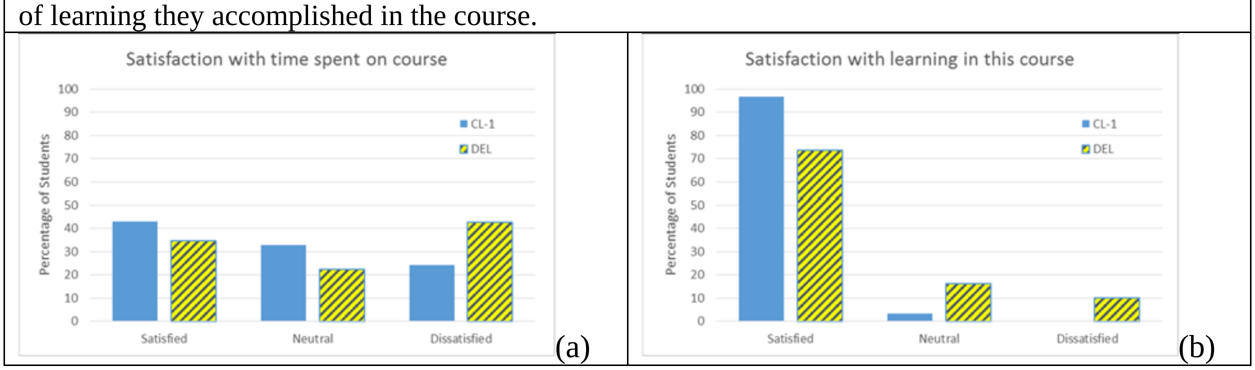
These figures show that – on average – students in the sophomore level Circuits Laboratory 1 spend between 2 and 4 hours preparing for the laboratory; this amount of time is in line with the one credit assigned to this course. In addition, the CL-1 students are generally able to complete their hands-on experimental work within the associated 2 hour laboratory session. The junior level Digital Electronics Laboratory is a 2 credit course and yet, students course report about the same amount of preparation effort as the CL-1 students. Only 35% of the DEL students report that they complete all their experimental work within the associated three hour lab session which is also about the same number of students who report feeling well prepared for the laboratory.

Figure 1: Survey results on student perception of average time spent on (a) viewing the on-line lectures, (b) preparing their lab notebooks, (c) carrying out the experiments associated with each laboratory, and (d) their preparedness for each laboratory.



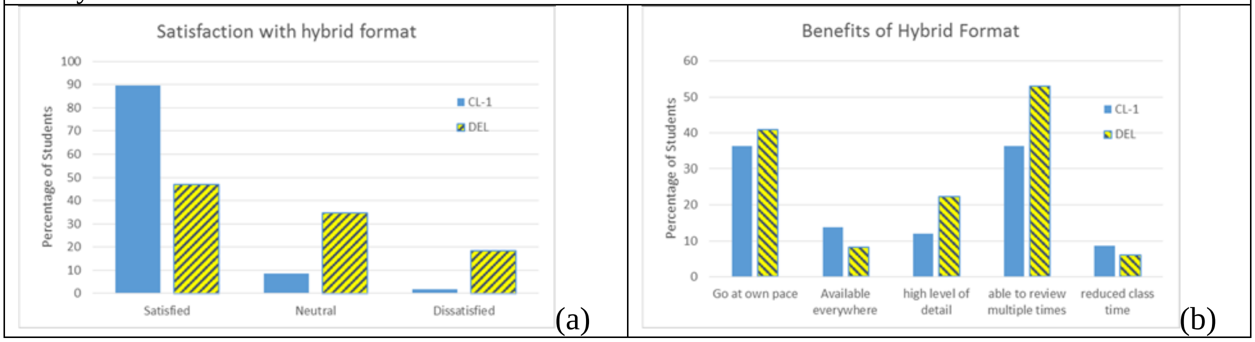
Student satisfaction with the (total) time involved with the laboratory course as well as with the amount of learning they accomplished was also assessed. These results are shown in figure 2. The majority of students are quite satisfied with their learning in these courses (fig. 2b), but fewer of them are content with how much time it took them to accomplish this learning (fig. 2a).

Figure 2: Survey results on student satisfaction with (a) total time spent on course and (b) the amount of learning they accomplished in the course.



Students were also asked to describe their level of satisfaction with the hybrid format of the course. The sophomores in CL-1 report much higher satisfaction with the hybrid format than the juniors in DEL as seen in figure 3a. On the survey, students were asked to list what personal benefits they perceived resulting from the hybrid format. When the responses were analyzed, the most often cited benefits from both groups were the same and the students in both courses noted these benefits in about the same proportions, as seen in figure 3b.

Figure 3: Survey results on (a) student satisfaction with the hybrid format and (b) perceived benefits of the hybrid format.



In Circuits Laboratory 1, student achievement was monitored by the instructor through review of the post laboratory analysis report for one of the laboratories in which the students were to design, build and test an operational amplifier signal conditioning circuit. The online lecture modules showed how to design a similar signal conditioning circuit. As can be seen in table 3, the percentage of student teams with successful (working) designs is steadily increasing even though the online materials have not changed during this period.

Table 3: Circuit Laboratory 1 – Student Achievement (Signal Conditioning Laboratory)

	Percentage of working circuits	Number of student teams (majority of 2 person teams)
Fall 2011	50%	28
Fall 2012	61%	28
Fall 2013	69%	39

In the Digital Electronics Laboratory, student achievement was monitored in a similar manner for a two week laboratory experience in which the students designed, built and tested a simple open loop motor control using a microcontroller with associated external motor drive circuitry and sensor to monitor motor rpm. During the first week, students individually built and tested the motor drive circuit and the frequency measurement application each with the microcontroller in order to understand both parts of the external hardware. In the second week, they combined these two concepts to change the speed of the motor using a potentiometer while simultaneously measuring the rpm. In spring 2013, the lecture for this laboratory was presented during the weekly 50 minute lecture period. In fall 2013, online lectures were used. While the percentage of student teams able to get the motor drive circuitry and the frequency measurement to work separately did not change from the traditional to the hybrid versions of this laboratory, there was a slight increase in the number of student teams who were able to successfully demonstrate the integrated project.

Another assessment done in the Digital Electronics Laboratory course was to see if the addition of a modest number of on-line materials can enable students to extend their learning beyond the material formally covered. In fall 2013, a laboratory with several experiments to learn about microcontroller interrupts was added; prior to this semester students used interrupts by duplicating application note projects. In DEL, a multi-week final project chosen by the student team is done – the requirement for this project is that they must incorporate a microcontroller into their project and their project must involve interaction with the external world through sensors and/or actuators. The code for the final reports for the Spring 2013 and Fall 2013 semesters was examined to observe the level to which student projects using interrupts did so through rote use of code from existing application notes or if the team had written more sophisticated interrupt service routines. These results are shown in table 5. Before the online modules were available, only 12% of the students moved beyond rote usage; with the online modules, over 48% of the student teams had clearly moved beyond the simple experiments from the interrupt laboratory. In addition, more teams in total used interrupts in their final projects in the fall semester compared to the previous semester.

Table 4: Digital Electronics Laboratory – Student Achievement (Motor Control Laboratory)

	Percentage of working circuits			Num.student teams (2 person)
	Frequency Measurement	Motor Control	Successful integration	
Spring 2013	68%	80%	24%	25
Fall 2013	68%	80%	32%	25

Table 5: Digital Electronics Laboratory – Extended learning (Final Project – use of interrupts)

	Percentage of student projects showing		Number of student teams (2 person)
	Rote use of interrupts	Extended use of interrupts	
Spring 2013	44%	12%	25
Fall 2013	20%	48%	25

Discussion of Results -

If the sole goal of creating the hybrid format for these laboratories is to increase self-reported student satisfaction, then the data show mixed results. Circuits Laboratory 1 students seem more satisfied than those students in the Digital Electronics Laboratory course with both the time they devote to the lab course as well as the amount of learning accomplished. There are sufficient differences between the two courses, however, to preclude direct comparison. The first difference is the switch from a 1 credit course (CL-1) in the sophomore year to a 2 credit level course (DEL) in the junior year; students may not immediately recognize that an increase in effort (preparation, in particular) should also occur. The second difference is that in CL-1 the relevant theory for the laboratories has been covered in another class (Electric Circuits 1) while after the first two laboratories in DEL, the remaining laboratories cover totally <u>new</u> material not previously covered in a regular class. Another notable difference is that students in CL-1 must use the equipment in the teaching laboratories to complete their work while DEL students can complete much of the work for many of the laboratories at home using the required low-cost microcontroller evaluation/development kit ($35) and associated free development software. The DEL students then needed only report to the lab to demonstrate their working applications. Anecdotally, the DEL instructor observed that for the majority of the laboratories, one third to one half of the student teams had left their 3 hour lab session within the first 2 hours. The teaching assistants reported that, in their opinion, the teams remaining had <u>not</u> properly completed the preparation work for the laboratory in line with the self-reported values shown in figure 1d for satisfaction with preparation.

With respect to enhanced student learning as a result of the hybridization of these laboratory courses, the results are very encouraging, particularly the results from the final project in DEL which show students extending their base knowledge in a content area after just a fairly modest introduction to the subject via online lectures.

The teaching assistants reported that their own viewing of the online materials allowed them to be more helpful to the students in the lab. They also reported that they found they could often refer students having difficulty to the specific online module in which the answer to their question resided, which in turn allowed them more time for some of the more challenging problems which (always) arise in the laboratory sessions. This was true for both the veteran and new teaching assistants for the course.

Observations and future work -
The act of converting the laboratories from traditional lecture/lab format to on-line lecture/lab format can be time consuming. The instructors report that for each lab producing the narrated slide presentations from existing lecture slides and assignment documents (i.e., the on-line lectures), creating the preparation quizzes and posting the materials (the first time) takes about 15-30 hours. Completely new laboratories without already existing materials take about 50% longer to develop. However, once developed – the on-line materials are easily ported from one course site to another and, if desired, rearranged in a new order. Moreover, once the bulk of the laboratory materials for a course have been developed, the time burden to replace an existing lab with a different one is not as onerous; 20 hours or so for one new lab compared to 200-300 hours for a course with 10-12 labs in the semester. The on-line materials are on a three-year refresh cycle to revise existing materials that we continue to use.

Beneficially, the individual lecture modules are easily shared among the laboratory courses; for example, the tools module which shows how to use the oscilloscope to obtain an FFT is being used in two different lab courses, also, the laboratory modules associated with learning how to use Multisim™ developed for CL-1 are posted in the review sections of multiple other courses.

Based on formative assessment questions asked of students in Spring 2013, the generic outline for the laboratory online content has been modified, replacing the entire “Practice” section of the outline (Table 2) with an assignment document to condense the tasks to be accomplished for the set of experiments for each laboratory from multiple slides in a presentation to a 1 or 2 sheet document per student suggestion. This assignment document is posted at the start of each laboratory module.

The work to extend the online conversion to the remaining two electrical engineering undergraduate laboratories continues. In spring 2014, the second offering of the Instrumentation Laboratory (IL) in the on-line format will occur and the end-of-semester survey will be conducted again to compare the results with those reported here. One hypothesis that we put forth is that since IL is the second 2 credit laboratory course, students may understand the need for more preparation early in the semester and may report higher levels of satisfaction with respect to time devoted and learning accomplished.

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