The Challenges of Teaching Engineering Labs Online

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Abstract

The paper presents the Engineering Department's development and the pilot delivery of an online laboratory experience to support the electrical and computer engineering online delivery of a previously on campus course, "EE110: Introduction to Engineering". The most significant challenges in support of students in the construction, debug, and measurement of circuit parameters include the following: (1) replacing face-to-face interaction with both the instructor and other students in a group setting for debugging or troubleshooting circuits and (2) effective ways to promote student cooperation in helping one another. The paper describes the design of online labs for this course and selection of equipment. A pilot class has been delivered on campus with the materials generated as a simulation of an online course. Learning outcomes between the pilot class and the face-to-face class are compared. This paper discusses challenges and successes of teaching online labs, based on the recent experience and feedback from student surveys of the course. In conclusion, online laboratory activities need to be carefully structured to provide an effective learning experiences with a benefit similar to the classroom.

Keywords

engineering lab, online flipped lab, online laboratory experiments, flipped classroom, introduction to engineering

Introduction

Faculty members in the Colorado Technical University College of Engineering started to develop online courses since April of 2015. Because the undergraduate degrees in electrical engineering and computer engineering at CTU are ABET-accredited, the online courses that need to be developed have to meet ABET standards as well. In addition, the courses must meet the same learning outcomes whether delivered online or traditional face-to-face instruction. This paper presents faculty experiences in developing and conducting engineering laboratory experiences to be completed remotely for an online course. The project attempts to convert a face-to-face course entitled, "Introduction to Engineering" for online delivery by using existing technology tools from e-learning education, or from internet marketing. The most challenging part of the project concerns the replacement of the interactive demonstration, dialog, and immediate feedback for the student working with the equipment on campus with online support for the interaction with the equipment. In traditional labs taught on campus in laboratory setting, the instructor has the opportunity to observe students performing experiments. In this setting, the instructor can easily help students understand the process of debugging or troubleshooting circuits. Also, students usually work in teams helping each other fix circuit issues during lab sessions. Consequently, there is a significant amount of immediate feedback from the instructor and other students when troubleshooting circuits. Further special effort needs to be invested in fostering student cooperation in an online environment. It is important to ensure that the learning outcomes in online lab collaboration are comparable to campus based-laboratory experiences.

“Introduction to Engineering” is a first engineering course for electrical and computer engineering students. The campus-based course includes both lecture and lab sessions. The course introduced basic analog and digital circuits. All four full-time engineering faculty were involved in developing this course because it includes labs with different topics, such as analog circuits, digital circuits, simulation, and hands-on soldering and kits assembly as well as very basic communications theory. In addition, all faculty members wanted to gain experience in the creation of content for online delivery. As the challenges related to teaching online labs are addressed for this first course, then future development of additional electrical and computer engineering courses will become much smoother for online delivery.

EE110 is a four credits course having a length of 11 weeks (or one quarter). A required course for both electrical and computer engineering students, it is a prerequisite course for EE221, Circuit Analysis I. The development of EE110 online content was divided by four full-time engineering professors, each professor created specific sections of the course. In this way, professors can help each other learn about software tools to build engaging content. At one time, the engineering faculty became familiar with the process of online course development and its delivery of instruction. This paper concentrates on the laboratory content with the schedule shown in Table 1. The introductory course has nine Labs. The initial lab assignment manual provided step-by-step procedure of the experiments with screenshots of the circuits set-ups and the measurements results. Short videos for some labs were developed for explanation and demonstration the lab procedure. Subsequent laboratory assignments had supporting videos, screenshots, and pictures, as appropriate. This paper describes some of the key lab experiments during the design and development of ‘Introduction to Engineering’ labs for online delivery. The lab materials include manuals with images, photos and short introductory videos.

Week #	Lab Assignments
Week01	Circuits Laboratory Introduction
Week03	Digital I/O Circuits
Week04	Basic Gates Verification
Week05	Digital Simplification
Week06	Ohms Law
Week07	Complex Circuit Analysis
Week08	RC Circuits Multisim Simulation
Week09	Function Generator Assembly
Week10	Function Generator Testing

Table 1. EE110 Lab Schedule

To ensure the quality of the course, the transition to an online course involved the following six stages as shown in Table 2[1]. The paper also describes the selection of equipment and software for online equipment and lab kits. National Instruments’ (NI) myDAQ was selected to be the basis for the lab equipment for the course since the myDAQ package includes several software-based instruments, such as a signal generator, an oscilloscope and a multi-meter. The advantages and limitations of myDAQ are discussed along with additional affordable equipment for the student as recommended. The importance of one-hour synchronous chat session dedicated to lab work is also described. A pilot class was delivered as a simulation of an online course before being fully operational as an online course. The pilot class used all of the developed online course material and methods to simulate the online teaching. This paper compares the learning outcomes resulting from instruction for online labs and face-to-face labs. The challenges of teaching online labs, along with the feedback from student surveys of the course are also presented. Based on the results, effectively teaching engineering labs online is possible but with challenges that needs to be carefully considered. Suggestions for overcoming these challenges of online teaching of labs are discussed at the end of this paper.

Pre Design Stage (April -June, 2015)	**Set up schedule and assign design work to the four full time professors; make decision on development tools and lab equipment.**
Design Stage (July-September, 2015)	**Four professors corporate to development the online EE110 based on the schedule.**
Pre-Pilot Course Delivery(October-December, 2015)	**Testing the online course material by using the material in the delivery of EE110 face-to-face course. Trying to catch the errors and typos in the material, and improve the quality of the material.**
Pilot Delivery (Januray-March, 2016)	**Simulate the online environment for face-to-face students; receive feedback and evaluation of the course for continuous improvement of the course.**
Hybrid Delivery (July-September, 2015)	**Continue simulate the online environment. Students come to class three hours each week instead of five hours for the pilot class**
Online Delivery (October-December, 2016)	**Fully online delivery of EE110.**

Table 2. EE110 Design and Delivery Stages[1]

Summary of Approaches to Online Lab Teaching

In general, there are three ways to teach online Engineering Labs. They are the “virtual lab”, the “remote lab”, and “lab with portable kits”. In the “virtual lab”, the experiment is mimicked by using simulation software, such as LabVIEW, MATLAB, and Multisim. This method provides a simulation of a real circuit. But students still need to assemble and work an actual circuit. The teaching of the “remote lab” emulates a traditional lab, allowing students to set up and control an experiment in a remote client mode. In that way, students can gain experience similarly done at a traditional lab. But usually the equipment setup and maintenance cost and manpower needed to invest in a remote system is relatively high. “Lab with portable kits” means each student has a small, inexpensive lab kits which provides functions such as a digital multi-meter, oscilloscope, function generator, and power supply.

Berry[2] presented a paper comparing the online and on-campus version of teaching a sophomore-level introductory course in DC and AC circuits. The course included active hands-on lab components. National Instruments’ myDAQ was used as the lab equipment for this course. Online students were required to submit lab memos that included the purpose, procedure, the results, and screenshots from the myDAQ and Multisim of the lab experiment. To assess student outcomes, ‘Lab Practical Exams’ were used in the course as well. Astatke[3] mentioned that Mobile Studio IOBoard developed by Rensselaer Polytechnic Institute is used in their Electrical and Computer Engineering (ECE) labs for their online sophomore level electrical engineering courses. Zhai[4] compared three distance experiment forms: virtual experiment, remote control experiment, and video demonstration experiment. Since the cost of remote control form is too high, they combined virtual experiment (simulation) and video demo in their Electrical Online Lab.

By comparing the three ways of online lab teaching, the cost of implementation, and reviewing the experiences from other universities, the engineering department chose "lab with portable lab kits" for the online course development. The next two sections describe the myDAQ hardware and additional equipment needed to conduct the lab experiments.

Selection of National Instrument's myDAQ Hardware

Normally, a traditional circuit analysis lab needs equipment such as DC variable power supplies, function generators, multi-meters, and oscilloscopes. The faculty explored kits having these functions. The department compared the main specifications of equipment NI Elvis II and NI myDAQ. The comparison between these pieces of hardware from National Instruments is listed in Table 3.

ELVIS II has much better performance, but is more expensive than myDAQ, the price of ELVIS II is more than 10 times of myDAQ. The ELVIS II has a variable power supply, and can provide maximum output current up to 500mA, but myDAQ has a maximum output current limited to 2mA. Both ELVIS II and myDAQ hardware have virtual instruments for '+/-15V' power supply, digital multi-meter, function generator and oscilloscope. The Elvis II system has a few more virtual instruments than myDAQ. It was decided that these ELVIS instruments are 'nice-to-have" features but are not necessary for the purposes of our engineering curriculum". On the other hand, myDAQ has a Level Output, which could be used as a variable power supply. The physical size of ELVIS II is much bigger and much heavier. After the purchase of a few ELVIS systems it was decided that the faculty can use the ELVIS virtual instruments for demonstration purposes in more advanced courses. However, the NI myDAQ is found to be an affordable and acceptable choice based on the cost and functional comparison found in Table 3.

Main Laboratory Specifications\ Instrument	NI ELVIS II	NI MyDAQ
Analog Input	8 differential or 16 single ended channels	2 differential or 1 stereo audio input channels
Analog Output	2 channels Maximum output current 5mA	2 channels Maximum output current 2mA
Digital I/O	24 DIO	8 DIO
Digital Multi-meter Functions	DC Voltage, AC Voltage, DC current, AC current, resistance, diode, capacitance, inductance	DC Voltage, AC Voltage, DC current, AC current, resistance, diode
AC Voltage Frequency Range	up to 20 kHz	up to 2 kHz
Power Supplies	Maximum output current of +/-15V supply is 500mA; Maximum output current of 5V supply is 2A; Maximum output current of Variable Supply (0 to +/-12V is 500mA)	Maximum output current of +/-15V supply is 32 mA; Maximum output current of 5V supply is 100 mA; Maximum output current of Level Output (0 to +/-10V is 2 mA)
Physical	Dimensions: 34.3 x 28.0 x 7.6 cm Weight: 1.9 kg	Dimensions: 13.6 x 8.8 x 2.4 cm Weight: 0.164 kg
Price	$ 2,455 (http://sine.ni.com/nips/cds/view/p/lang/en/nid/205425)	$179 (http://www.studica.com/National-Instruments-students-ni-labview-MyDAQ/ni-MyDAQ.html)

Table 3. NI Elvis II and NI MyDAQ Comparison. [5, 6]

The price of myDAQ makes it a reasonable investment for the laboratory experiences, especially when the system will be used in more advanced classes in analog electronic circuits, digital circuits and other engineering courses with minor additions to the system ($25 - $50).

MyDAQ limitations and Additional Equipment

Since the myDAQ has only one digital multi-meter, students can use it as a voltage meter or current meter, but not both at the same time. For some of EE110's lab experiments, it is necessary to measure both current and voltage at the same time. Consequently, two meters are needed: one to measure current and another to measure voltage. In other words, one additional digital multi-meter is needed for the students.

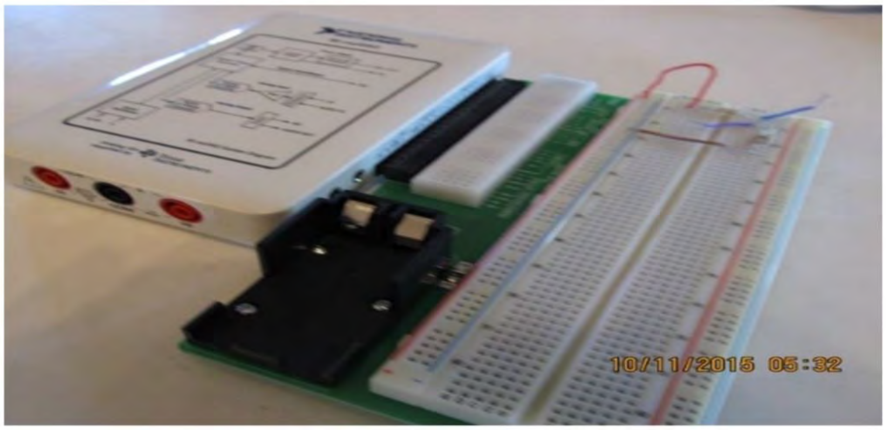

Figure 1. myProtoBoard attach to myDAQ

The **myProtoBoard** accessory board, shown in Figure 1, was selected to connect the **NI myDAQ** hardware. The myProtoBoard allows for easy use and to provide breadboard space to set up a variety of circuits. Students also need to have a component kit to do a number of lab experiments in the course. The ELENCO COMPONENT KIT, CK-1000 was selected since it provided various resistors, capacitors, semiconductors, LEDs, inductors and wires.

Based on the specification of NI myDAQ, labs from the on campus delivery of EE110 needed to be adjusted to meet be used with the new equipment. One limitation of myDAQ is the maximum output current is only 2mA. As an example of this limitation, one circuit is the Ohm's Law lab shown in Figure 2. The current of the circuit is 2.12mA. The lab requires student to vary the voltage source 1V up to 10V to demonstrate Ohms law. If V1 is changed to 10V, current will be 21.2mA. Since myDAQ analog output cannot provide current larger than 2 mA, V1 will just drop to a voltage much lower than 10 V. Consequently, students will be confused with the results they see. So labs need to be adjusted by considering this limitation.

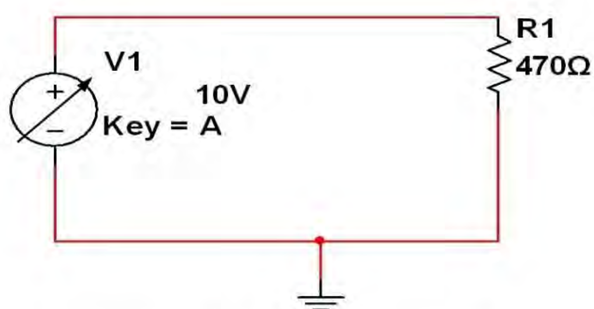

Figure 2. Resistor Circuit

In summary, the additional equipment and components kit are listed in Table 4. Total cost for the myDAQ hardware and items listed in Table 4 is approximately $420.

Given the identification of affordable laboratory equipment, the next section describes lab experiments, the course delivery and its implementation.

Name	Vendor	Price
myProtoBoard	www.studica.com	$44.99
Basic Parts Kit for NI MyDAQ	www.studica.com	$59.95
Amprobe AM-250 Industrial Digital Multi-meter	www.amazon.com	$79.85
60W Soldering Iron Kit TasiHome SOLREP 2000	www.amazon.com	$15.51
1MHz Function Generator Kit by Elenco, Model: FG500K	http://www.elenco.com	$38.25

Table 4. Additional Lab Equipment for EE110 course

Design of Lab Projects

The lab session in the "EE110 Introduction to Engineering" course includes both synchronous and asynchronous sessions. Each student is required: (1) to watch short videos related to the labs, (2) to read lab manuals and (3) complete each lab step-by-step at their own pace. Each week, a one-hour online synchronous chat session will be held dedicated to addressing student questions arising from the assigned lab experiments. In addition, the required chat sessions are recorded for students who cannot attend the live chat sessions. At the end of each lab chat session, there will be assigned graded problems the students need to submit related to the lab. This approach encourages students to attend the chat session, and benefit from the experience of the instructor and other students.

Usually students are required to follow three steps when conducting lab experiments in a campus setting as shown in Table 5. All of the steps are important in supporting student learning. Students completing labs online are expected to complete the same steps, resulting in the same student learning outcomes and meeting course objectives.

Step 1	**Hand calculation and design based on theorem.**
Step 2	Simulate the circuit based on the hand calculated design; compare the result from hand calculation.
Step 3	Build the circuit on breadboard, and test the circuit, and compare the result from simulation and hand calculation.

Table 5. Steps in Lab.

Although the course has the nine labs, the paper will not describe all the labs in detail due to paper space limitations. The section provides further details on selected labs. The first lab "Circuits Laboratory Introduction" was designed to help students become familiar with the hardware and software associated with myDAQ. Since students in this class usually do not have previous experience with electronics lab, the introduction started with myProtoBoard as shown in Figure 3. The myProtoBoard is easily connected to myDAQ to measure electrical variables using the myDAQ software instruments. Figure 4 illustrates the use of Labview software instruments from National Instruments (NI) to obtain the DC Level output coming from the myDAQ hardware. Figure 5 shows the measurement of DC current using the myDAQ and Labview's virtual multi-meter. The next two labs include basic digital logic and circuits. The digital logic labs complement analog circuits described next in terms of the RC circuit.

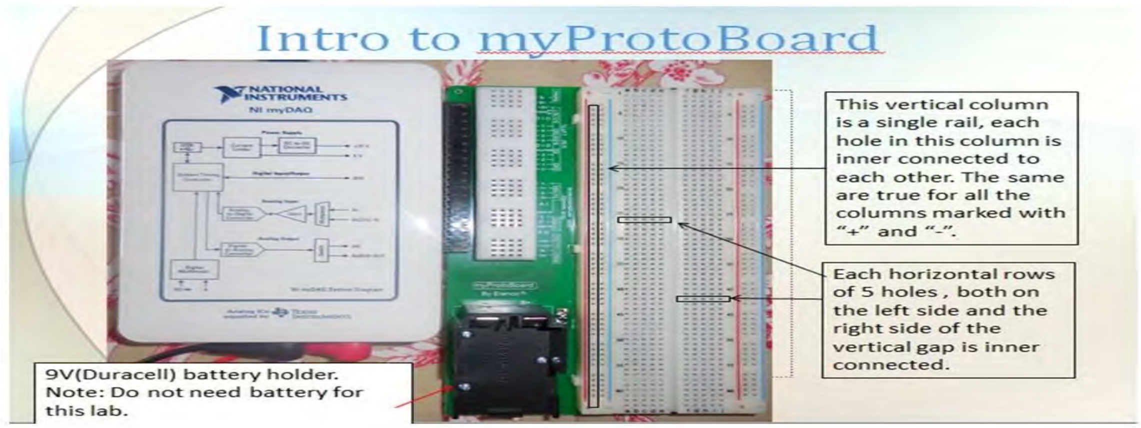

Figure 3. Introduction to myProtoBoard

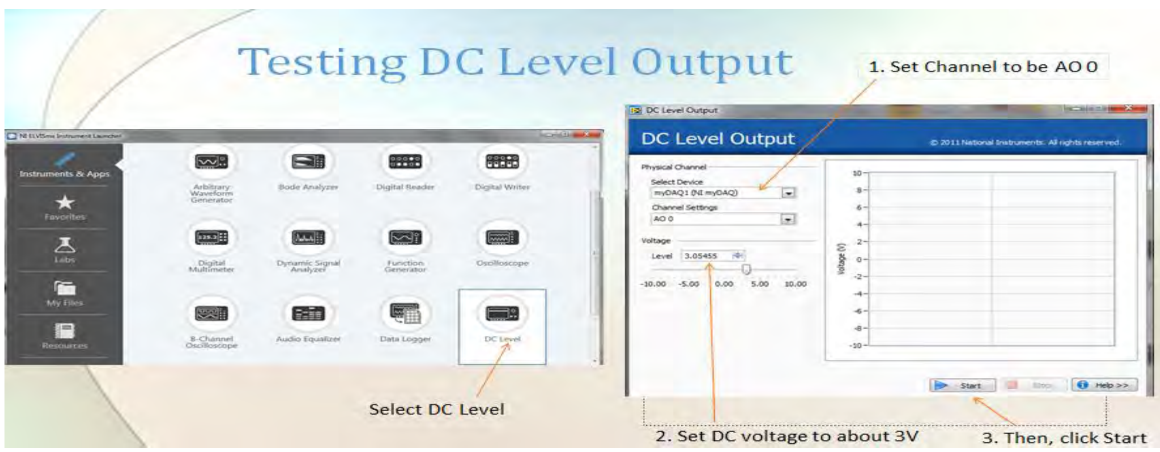

Figure 4. Testing DC Level Output

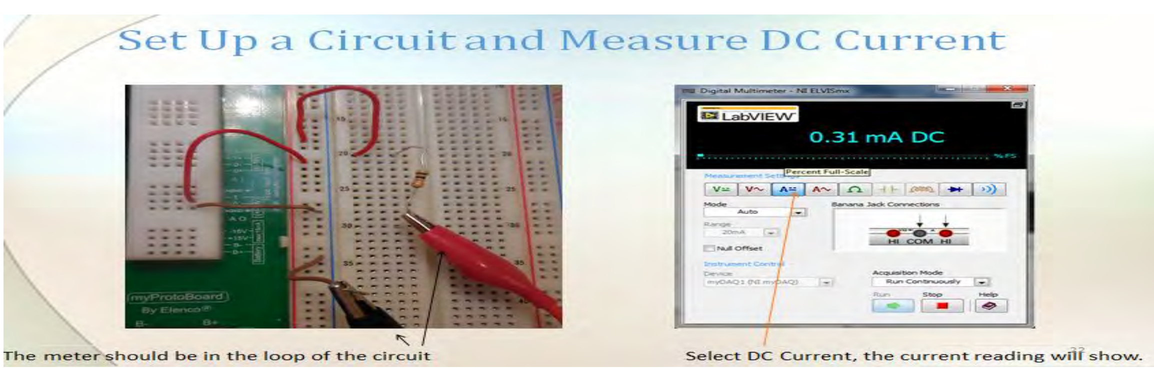

Figure 5. Measure DC Current.

The lab experiment for Week08 is an RC circuit using Multisim. Multisim is a circuit analysis tool similar to PSPICE with embedded software instruments such as an oscilloscope and multi-meter. Students learn to use Multisim to simulate the RC circuit in Figure 6 and learn how to use an oscilloscope.

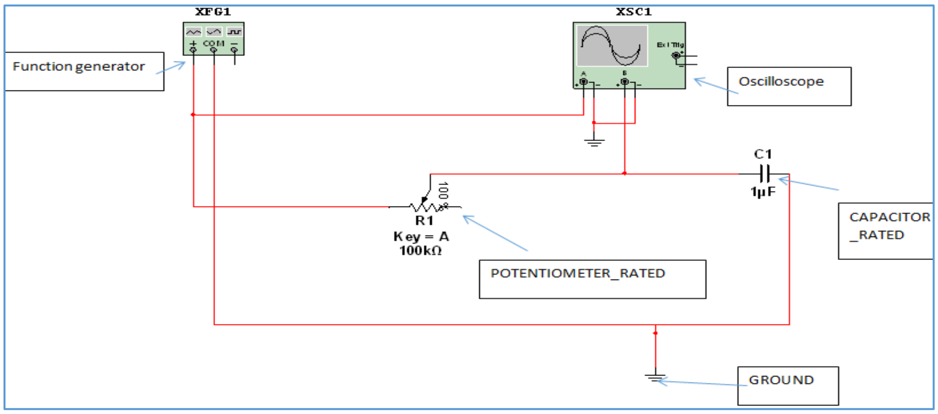

Figure 6. RC Circuit Simulation

In support of this lab, a short video "A Tutorial and Multisim Simulation on the RC Time Constant" was created to help enhance the student learning opportunity. The link of this video is uploaded to department's YouTube channel, STEM Videos for the Flipped Classroom with the following link: https://www.youtube.com/watch?v=t7ZJhzAx9JE.

To provide a memorable and practical lab experience for the student, a capstone experiment involves building a fully operational function generator from a kit. As shown earlier in Table 1, the last two labs are dedicated to the assembly and testing of a function generator during weeks 9 and 10. Students need to solder, assemble and test the ELENCO Function Generator Kit.

When considering labs involved with soldering, the engineering department was concerned about safety. The engineering faculty debated whether or not to include such labs in the online delivery. But CTU's engineering students do need the skills of soldering, circuit assembly, and integration of various circuit functions required for their capstone courses. In addition, building a functional piece of equipment further triggers student interest in engineering and provides motivation to pursue and complete their degree programs.

Pilot Stage for Introduction to Engineering Course

The engineering faculty completed the first three stages of development shown earlier in Table 2. The pre-pilot stage was taught during Fall 2015. The pre-pilot class tested the online lab experiments, but still used the traditional lab equipment in the classroom and the components stored in the lab cabinet.

Professor Guo taught the pilot course in Winter 2016. In the pilot stage, the online teaching environment attempted to simulate the online environment. The flipped method for lab instruction was applied to the "Introduction to Engineering" lab. In this pilot lab, the students used the myDAQ and supporting equipment described earlier, with the exception of the secondary power supply, and digital meter. Before starting the labs, students watched videos and read lab manuals for themselves and no lecture was provided by Professor Guo. As students begin doing the lab assignment, they can ask questions and also seek help during the simulated chat session during class.

However, there were some important differences between the piloted lab and the ‘real’ online lab. The instructor has a chance to see students’ circuits set up and can help students debug and troubleshoot the circuit in the piloted labs. In addition, students still need to interact with each other and collaborate in the lab.

Students Response and Feedback about the Pilot Course

At the end of the 2016 Winter Quarter, the Department Chair and Dean of College of Engineering held a Pilot Focus meeting that served as an end-of-course feedback. The course instructor was not present in the meeting in order to promote open discussion with the students. Students in the piloted class were interviewed about the effectiveness of the course. Eleven students registered for the class at the beginning of the quarter where one student dropped class during the middle of the quarter. Four out of the ten students in the class attended that meeting. The notes in Table 6 below summarize the student feedback.

From the summarized interview notes in the Pilot Focus meeting, students appeared satisfied with the videos, PowerPoint slides sets, assigned reading material and problem sets overall. The students thought that the myDAQ equipment and software instruments are very effective for lab experiments. Students also mentioned that the maximum allowed analog current must be considered in the lab design.

Students also expressed their concern of the effectiveness of the labs when they are fully delivered online. The department addressed this reasonable concern by stressing the importance of online and attendance of synchronous chat sessions when both instructor and students are together online at the same time to address questions raised by the students. However, more short videos may be needed to support students in learning all of the elements of the labs. In addition, troubleshooting tips need to be written for debugging each lab. Additional documents to be created include a troubleshooting procedure and checklist for students to follow before requesting help from the instructor during the online session. For example, here are steps that the students need to consider before coming to the chat session: (1) did the student follow the troubleshooting checklist? (2) did the student check with their lab partner for correct wiring of the circuit, including proper connections with power or perform the checklist with their partner? and (3) did the student post their questions on the discussion board and check for answers from other students experiencing the same issue?

1. Errors in the course are distracting said one student; but the student consensus was that the errors are very few in this course.
2. **The MyDAQ-based lab equipment is very effective** notwithstanding the issues of which we were aware such as insufficient drive current from the MyDAQ internal power supply and the need for an external digital multi-meter to complement the internal one so that both voltage and current may be measured simultaneously. One student said that he noted a distracting lag between his commanding a function and the realization of that command.
3. Videos and slide sets are well done and useful. There is a good balance between paper and online content.
4. The problem assignments are well done and useful.
5. One student said that the course is very intense. Snow days should not be allowed. You fall behind.
6. **They wondered if online labs would be as effective as those done in class live and in person.** There is a lot of person-person interaction in solving the problems with the labs. Kathy noted that if students will attempt the labs ahead of time and bring their issues to the chats, it should work well.
7. In response to one question as to whether they believed there might be a bias in industry against engineers who obtained their degrees online, they opined that there should not be but probably is. But they also said they are not yet engineers, do not work in those circles, and therefore do not know.

Table 6. Summarized notes in the Pilot Focus Meeting[7]

Comparison of Students Learning Outcomes in Face-to-Face Course and Pilot Course

Figure 7 compares accumulated lab grades of the ten remaining students for the pilot course to the lab grades from previous campus-based course taught by the same instructor. From the histograms, campus based lab students have higher grades than the grades from piloted course simulating the online delivery. After comparing the grades with attendance rate shown in the histograms on Figures 7 and 8, there exists a correlation between grades and attendance rate. Three students who failed the labs in the piloted course attended only 61.9%, 52.4 % and 19.1% of the classes. All the students in the face-to-face course attended 68% or more of all the classes. Students who failed the labs in the piloted-class missed many lab chats session during the 11 weeks. This preliminary data shows the importance of attending the Question-and-Answer (Q&A) chat sessions when it comes to lab experiments.

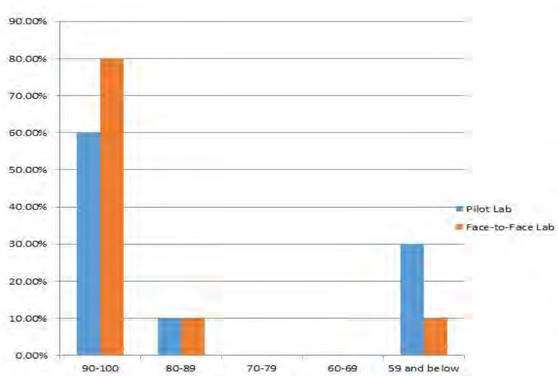

Figure 7. Pilot and Face-to-Face Lab Grades Histograms

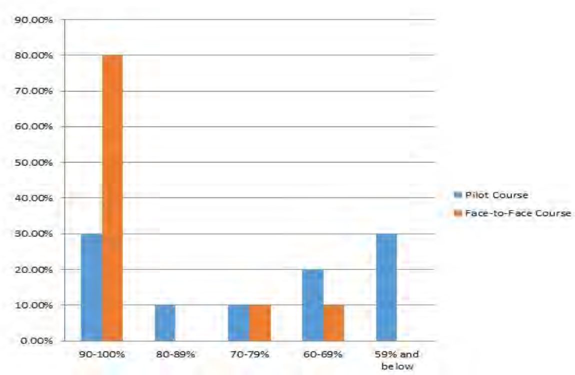

Figure 8. Attendance Histograms of Pilot and Face-to-Face Course[7]

Challenges to Teaching EE and CE Engineering Labs Online

One challenge when it comes to laboratory experiments is "Teamwork", as indicated in the ABET student outcomes an ability to function on multidisciplinary teams."[7] Engineers need to work with people having different background and personalities. In the campus-based "Introduction to Engineering" lab, students usually work in small teams (two students in one team). In that way, students can start to learn how to work in a team, even though it is a small team. Students cooperate and help each other build and debug circuits. Students must communicate in various ways and help their partner. However, for the online environment, promoting teamwork becomes harder.

Another challenge for online lab is lack of instructor's immediate support in debugging student circuits. When students do lab work and test circuits on campus, instructors can observe how the student performs an experiment, how students help each other find errors in the circuits and offer further guidance in their debugging efforts. However, for an online environment, it is difficult for instructor to observe the process of building the circuits, and offering immediate feedback. The instructor is presented with the "completed" circuit, when s students upload a picture or video about their lab experiment, but circuit components and wires are not easy for the instructor to see. For example, a connection may not be actually connected even though it appears connected. When circuits are connected incorrectly, then safety should be of concern as well.

Safety is always the number one important thing while working in a laboratory environment. Even in the electronics lab with experiments involving relatively low voltages and currents, usually equal or less than 15V, the faculty frequently sees and smells 'smoke' coming from student circuits during the lab sessions. Students often don't pay attention to the low power ratings of a resister or students place the polarized capacitor in the wrong direction. In addition, students occasionally touch the tip of the hot soldering iron by accident. In an online environment, it becomes difficult if not impossible for an instructor to observe the safety of the student. Address the safety concerns of the student remains a critical issue.

Conclusions and Recommendations

The preliminary results for the piloted lab course, "EE110 Introduction to Engineering", show that teaching engineering labs is very challenging when delivered online. But, if done appropriately, teaching online engineering labs could be successful. Several suggestions for online labs are listed below:

- One-hour synchronous chat session each week must be assigned to lab discussion
    - Students need to do lab first and follow troubleshooting procedures
    - Bring their questions and concerns to the chat session
- Need to record chat sessions from lessons learned by other students
- Students who could not attend the synchronous chat session must submit questions before the chat, and must view the recorded chats. Instructors need to keep remind students that they must attend the lab chat sessions.
- Need to provide debugging tips for each lab to help students troubleshoot the circuits
    - Develop and provide a troubleshooting checklist and other relevant resources

  - Before coming to chat session, students need to follow a troubleshooting checklist
- Safety issues need to be addressed in each lab
  - Student need protection tools, for example, goggles
  - Develop a safety checklist including best practices when soldering and assembling circuits
- Must consider the limitations of myDAQ hardware when developing lab exercises
  - For example, the maximum analog output current is only 2mA
  - The "-" input of Oscilloscope is floating
- Require students to upload the pre-lab and the screenshot of circuit implementation
- Use online collaboration tools such as "google hangout" to promote communication among the students while fostering teamwork and team discussion
- Students must record a short 5-10 minute video demonstration for one of the last 5 labs
  - This helps verify and validate student understanding
  - Instructor selects which labs to record

Overall, the full-time engineering faculty at CTU gained valuable understanding and insights when developing laboratory assignments for online delivery. These lessons learned will prove useful when moving toward full operation of delivering engineering labs for all courses in an online environment.

References

1 Guo, J., John Santiago, "Flipped Classroom method in Teaching "Introduction to Engineering" Course online", Abstract is accepted by 2016 ASEE Rocky Mountain Section Conference, Sept., 2016.

2 Berry, Carlotta A, "Teaching and Electrical Circuits Course Online", Proceedings of the 2015 American Society of Engineering Education (ASEE) Conference and Exposition, Seattle, WA, June 14 - 17 2015.

3 Y. Astatke, J. Ladeji-Osias C. J. Scott, "Developing and Teaching Sophomore Level Electrical Engineering Courses Completely Online", Journal of Online Education, Vol. 2, No. 2, 2011.

4 Zhai, Z, Y Wang, and Li Liu, "Design of Electrical Online Laboratory and E-learning", IERI Procedia Volume 2, 2012, Pages 325–330. Retrieved from: http://www.sciencedirect.com/science/article/pii/S2212667812001049

5 NI ELVIS II Series Specifications - National Instruments. Retrieved from: http://www.ni.com/pdf/manuals/372590b.pdf

6 NI MyDAQ Specifications- National Instruments. Retrieved from: http://www.ni.com/pdf/manuals/373061f.pdf

7 CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS, ABET, 2014. Retrieved from: http://www.abet.org/wp-content/uploads/2015/05/E001-15-16-EAC-Criteria-03-10-15.pdf

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Kathy Kasley earned her BS in Mathematics from Ursinus College, a Master's Degree in Mathematics at Villanova University, a Master's Degree in Electrical Engineering from the University of Colorado in Colorado Springs, and her Ph.D. in Electrical Engineering from the University of Colorado. Dr. Kasley is a Professional Engineer, and has a Consultant-Evaluator for the Higher Learning Commission of the North Central Association of School and Universities for over 15 years. Dr. Kasley has taught mathematics and Engineering at high school, and at the university level for over 25 years. She has served as an instructor, academic advisor, ADA student counselor, and dean or chair of Engineering.

John Santiago, Professor of Electrical and System Engineering

Professor John Santiago teaches courses in electrical, computer and systems engineering after retiring from the USAF with 26 years of service in 2003. He began teaching at CTU the following year. His interests includes: interactive multimedia for e-books, interactive video learning, and 3D/2D animation. Professor Santiago recently published a book entitled, "Circuit Analysis for Dummies" in 2013 after being discovered on YouTube. Professor Santiago received several teaching awards from the United States Air Force Academy and CTU. Last year, he was awarded CTU's Faculty of the Year for Teaching Innovations. Professor Santiago has been a 12-time invited speaker for celebrating Asian-Pacific American Heritage Month.