AC 2010-1209: NEW DIRECTIONS IN ENGINEERING EDUCATION: THE DEVELOPMENT OF A VIRTUAL LAB COURSE IN ELECTRONIC CIRCUITS AT MICHIGAN TECHNOLOGICAL UNIVERSITY

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New directions in engineering education:
The development of a virtual lab course in electronic circuits.

Abstract – The development of virtual education satisfying the needs of engineering education is getting increased attention in the current era of Web and virtual technologies. In this paper, we present the rationale, implementation and formative evaluation of a virtual lab environment for an electronic circuits course. The system, which is under development, has been designed as a supplement to a traditional course, providing an option to on-campus students. It is also intended overcome the barriers that non-traditional students, holding regular jobs and geographically separated from campus, face. The distance education option provides remote laboratory experiences, using a graphic interface that is equivalent to a real laboratory that traditional students experience.

Introduction

Michigan Technological University began offering its Circuits and Instrumentation course for non-Electrical Engineering majors to distance education students as an opportunity for automotive industry employees to begin to retool for inevitable changes in their industry. Eventually offerings expanded to support the Electrical and Computer Engineering Departments Power Engineering certificate program as well as co-op and learn abroad programs. One of the distinguishing elements of education is the lab experience [3]. There is a growing interest in using the Internet to provide students with remote access physical laboratory apparatus [1, 2, 5, 6]. However, the adoption of the Internet to deliver to deliver and implement laboratory experiences has been slowed down by concerns about quality of instruction [3, 4]. Engineering educators face new challenges to design effective learning experiences for the next generation of engineers, using the emerging technologies [2, 6]. The problem for the Circuits and Instrumentation course at Michigan Tech was that it had a significant lab component that was increasingly difficult and expensive to deliver. The challenge was to develop, implement and in some manner validate a circuits laboratory that represents the pedagogic equivalent of a hands-on laboratory. This paper represents our effort. The Michigan Tech Distance Lab system enables distance-learning students to perform electrical engineering lab experiments over the internet. These experiments involve using actual circuits, and actual measurement tools. It is not a simulation. This system is enabled by National Instruments LabVIEW and Electronic Laboratory Virtual Instruments Suite (NIELVIS). The NIELVIS provides several measurement tools, as well as a breadboard on which to build the circuit. With LabVIEW running with its internal web server enabled, and NIELVIS providing an interface between the actual circuit components and LabVIEW, the students are able to measure various electrical quantities of the circuit as if they were in the lab.

Methods

The paper reports on two pilot studies. In the first study, a small group of automotive industry employees took the full Circuits and Instrumentation course at a distance, with lectures and labs, and final examinations conducted online. The focus of this paper is on the laboratory component only. The study was conducted with one experimental group, with no control group.

In the second study, a small sample of students (the experimental group), took the online laboratory option of the course. The students were volunteers drawn from a larger class that had regular labs. The two groups attended the same lectures, the only differences being in the type of lab experience. At the conclusion of the virtual lab experience both groups had a brief, 45 minute, orientation session where they came into the laboratory to be introduced to the actual equipment that is used in the course. At the end of the semester, they came into the lab to take a final lab examination using regular equipment. The arrangements for the final laboratory examinations were identical for both the experimental group and the regular group.

At the end of their courses, cohort 1 and cohort 2 students completed a survey on their experiences of the course. The students taking the regular class were not surveyed. The focus of the survey was to solicit feedback from the students, and to evaluate how well the online laboratory experience motivated them to learn. To evaluate course motivation, a modified Keller scale [7] was used. The Keller scale measures motivation on four dimension of: 1) relevance, that is the extent to which the students perceived the course to be relevant to their interests; 2) confidence, that is the extent to which the students were confident about their work; 3) attention, that is the extent to which the course experience engaged their attention; and finally 4) satisfaction, that is the extent to which the students were satisfied by their course taking experience.

The students responded to a set of 6 Keller-type prompts. The prompts, categorized into the four dimensions of the Keller model were:

Confidence

1. As I have gone through the LABS I have felt confident that I knew what I was supposed to learn and do.
2. The LABS have helped to build my confidence in learning EE concepts

Satisfaction

2. Completing the LABS has given me a feeling of accomplishment

Relevance

1. The LABS are relevant to my future work as an engineer
2. The skills and knowledge that I have gained fro the LABS are worth the time and effort I have put into it.

Attention

4. The labs have stimulated my desire to learn more

The students were also invited to respond to open ended questions about their experiences.

In addition to the survey data the overall performance of cohort two on the lab component of the course is compared to that of the regular class. Since the sample of the group was small, no statistical inferences are drawn. The comparison is based on descriptive statistics only.

Design and Implementation of the Course

Theory of Operation

System overview

The distance student enters the Distance Lab website via a PC computer and a broadband Internet connection. When the student has accessed the system, a webpage on the selected LabVIEW server is opened inside the Lab page on the Distance Lab website. This page displays the embedded LabVIEW VI's (virtual instruments). There are currently five NIELVIS systems in operation. Each experiment has circuit components whose resistance, inductance, capacitance values have been premeasured and recorded for use by the students in comparative studies between simulations performed off line and the distance Lab experiments.

Theory of Operation

Figure 1. Operation flow chart

Lab Timeslots

Students select time slots to engage the current experiment from the lab web site. Labs are broken into two one-hour sessions. At the appointed time the student logs into and authenticates to engage the lab. A teaching assistant (TA) is available by both email and instant messenger for consultation or assistance. Students can also use the lab during the open lab times, but they do not expect the TA to be instantly available for help. The TA should be in close proximity with the LabVIEW servers in case something crashes.

One shortcoming of the distance lab methodology is that the students do not have the ability to directly manipulate the components and construct the circuits. The TA must do so using pre-measured components. We are currently equipping the lab with web cams and encouraging the TAs to make themselves available via Skype.

When the students first log on to the Distance Lab web site they have the opportunity to select the server that they will use. In Figure 2 below is a screen capture of what the TA sees at the entry page for the distance lab. In this figure all servers are set up for students to perform the second half of Lab 3, Nodal Analysis.

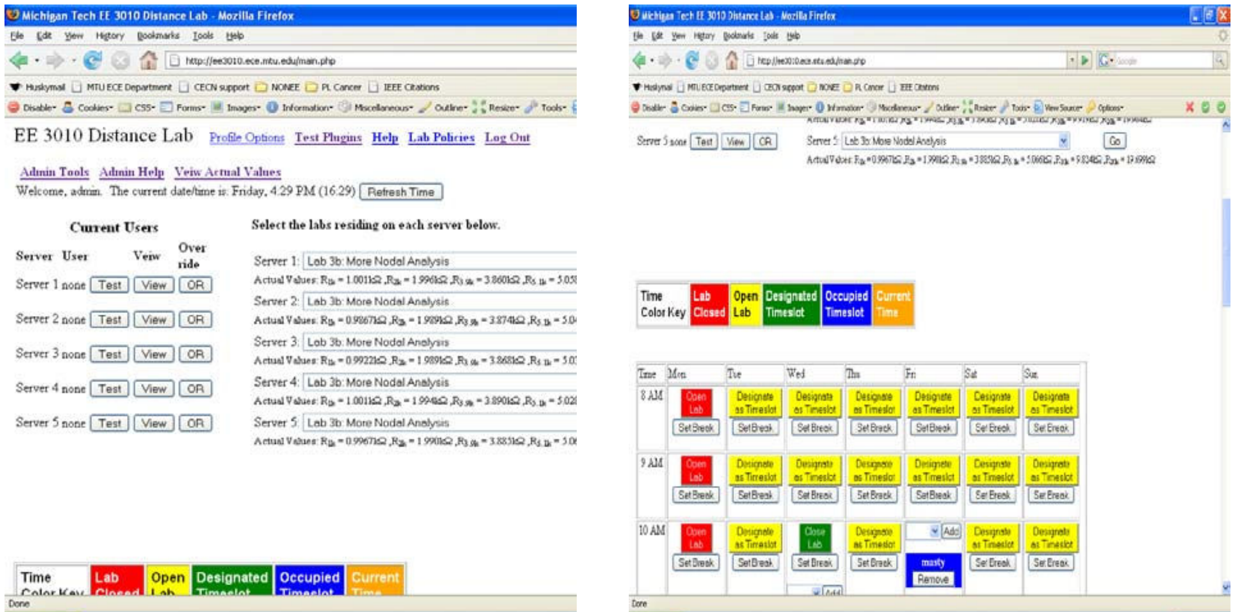


Figure 2. Setting up the servers and Time slots; what the TA sees

In order to provide maximum flexibility to the students, who proceed through the labs at different rates, the servers are independently configurable. The TA servicing the lab can easily have each server set up for a different experiment in response to individual student requests.

The lab experiments currently offered over the 14-week semester are:

- Week 1: Students and TA set up for the lab
- Week 2: Lab Zero: Introduction to ECE
- Week 3: Lab 1: Multimeter Measurements on Resistive Circuits
- Week 4: Lab 2: Simulation of DC Resistive Circuits
- Week 5: Lab 3: Nodal Analysis
- Week 6: Makeup Lab
- Week 7: Lab 4: Thevenin Equivalent Circuits
- Week 8: Lab 5: Digital Oscilloscope Familiarity
- Week 9: Lab 6: Measurement of Transient Signals
- Week 10: Makeup Lab
- Week 11: Lab 7: AC Magnitude and Phase
- Week 12: Lab 8: Frequency Response to Passive Filters.
- Week 13: Lab 9: Introduction to LabVIEW
- Week 14: Makeup Lab

We describe the initial lab, Lab Zero, and elements of the Measurement of Transient Signals Lab to provide an orientation to the technical aspects of the lab course.

Lab Zero: Introduction to ECE

Lab zero is a virtual lab, intended to introduce students to basic electronic test equipment and components. In part one of the lab we introduce the test and measurement equipment. In part two, the student is exposed to photographs of electronic components and shown the schematic representation of the components. Although the student does not have the opportunity to physically handle the components, he or she will have the opportunity to see them and get a sense of physical size shape and coloring so that when confronted with the actual components there will be some basis for recognition and the ability to make physical connections to a breadboard or other circuit construction mechanism. The circuit for each lab is constructed on breadboards for the NIELVIS system. Modifications are in the works to replace these bread boarded systems with printed circuit boards to make quick set up easy for the TAs.

What the student sees

When students log in to the remote lab website they will encounter an entry page that allows them to sign up for a time slot to complete the current experiments. With five physical systems available, there are usually multiple labs running simultaneously. The lab that students who are on pace with the class is specifically identified. The text is hyperlinked to the lab instructions for that experiment.

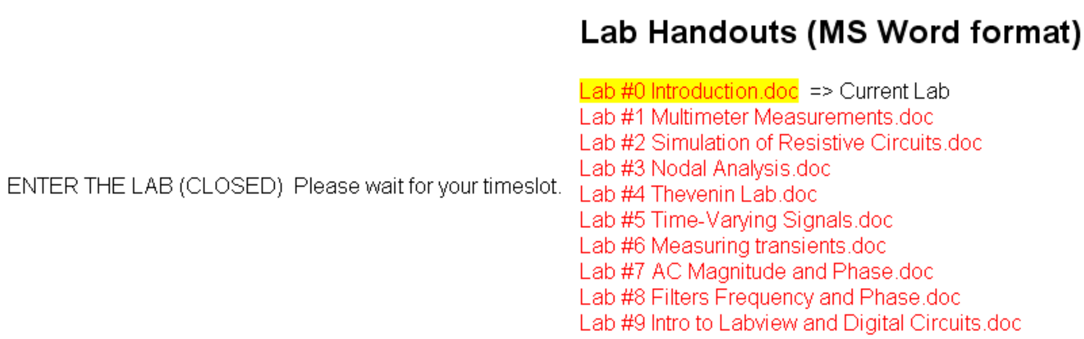
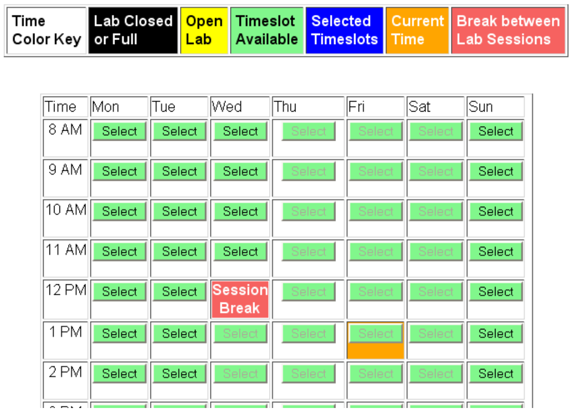


Figure 4: Remote lab entry page

The student also has the opportunity to select a time slot to perform the work during the week. The opportunities are preset by the lab TA as shown in Figure 2.



Time Color Key	Lab Closed or Full	Open Lab	Timeslot Available	Selected Timeslots	Current Time	Break between Lab Sessions

Time	Mon	Tue	Wed	Thu	Fri	Sat	Sun
8 AM	Select	Select	Select	Select	Select	Select	Select
9 AM	Select	Select	Select	Select	Select	Select	Select
10 AM	Select	Select	Select	Select	Select	Select	Select
11 AM	Select	Select	Select	Select	Select	Select	Select
12 PM	Select	Select	Session Break	Select	Select	Select	Select
1 PM	Select	Select	Select	Select	Select	Select	Select
2 PM	Select	Select	Select	Select	Select	Select	Select

Figure 5: Student Time Slot selection panel

When the time the student has selected arrives, he or she is allowed to "enter" the lab and perform the experiment. In part one of Lab Zero, the students are introduced to the basics of multimeter voltage and current measurements. They are not required to actually make the connections for the meter. However, they are shown how the meter must be connected in order to make both current and voltage measurements, and are required to operate the meter by selecting the appropriate meter function and the appropriate range of measurements. This operation is similar to most common multimeters and prepares them to operate and make the actual measurements when confronted with actual equipment. Figure 6 is an extract from the student instructions for Lab Zero and shows the test instruments the students will operate during the upcoming semester.

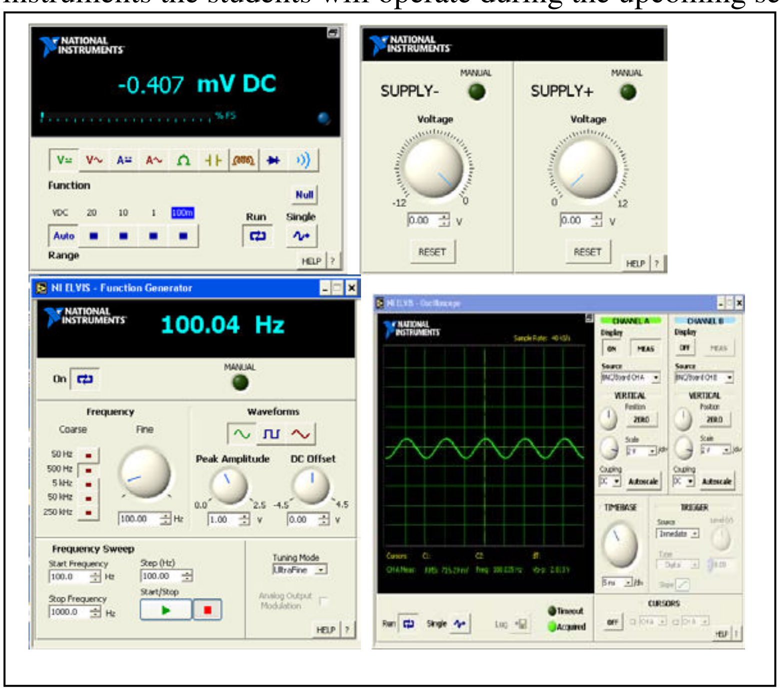


Figure 6. Lab Zero Virtual instruments

The students familiarize themselves with the operation of virtual instruments by adjusting the power supply and reading the reported voltage on the volt meter and adjusting the range settings on the voltmeter to record the changing measurements.

In Part B of the lab they have the opportunity to change the settings on the multimeter to make current measurements. An extract is shown below in Figure 7.

> Adjust the power supply voltage, and note the corresponding change in the voltage measured by the multimeter.
>
> Set the voltage to 0.05 V, and set the range to 100mV. The "range" specifies the maximum value that the multimeter can handle. It also specifies the precision of the multimeter; the lower the range, the higher the precision. Switch between the four numeric ranges and note how the voltage changes. Record the measured voltage for each range in the table below.

Range	**Measured Voltage**
100 mV	
1V	

> Now, switch the range back to 100mV, and set the power supply + voltage to 0.5V. You will receive an error message. Set the range to 1V, and you will receive a voltage reading. You should set the range of a multimeter to the smallest value that is greater than the value that you are measuring. If in doubt, start with the highest range, and work your way down. Modern digital multimeters (DMM) have an Auto-range selection. This will cause the meter to automatically choose the range, depending on the value of the quantity that you are measuring. Now, set the range back to auto, and the Supply + voltage to 0V.
> The power supply has been wired to a resistor of unknown value, as shown in Figure 3.

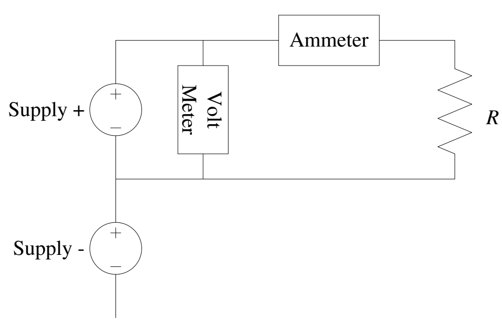


Figure 3: Multimeter Setup

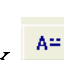
> We will now use the DMM to measure the current through this resistor. Click  to measure DC current. This will enable the Ammeter in the circuit of Figure 3. Null the meter, then set the Supply + voltage to 6V.

Figure 7. Extract from Lab Zero instructions

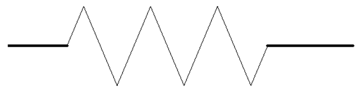
In Part two of Lab Zero the students see photographs of electronic components and their schematic representations to familiarize them with real-world devices.

Part 2: Component Identification

Pay close attention to the schematic diagrams. Since this is a remote course, we will be doing a lot of simulations using Multisim.

Resistors

Carbon Resistor



Real **Schematic**

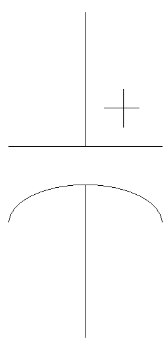
This is the most commonly used of all resistors, especially for low-power applications.

Wire-wound resistor, also known as a power resistor

Real **Schematic**

Resistors like this are used in situations where the resistor needs to handle high power.

Electrolytic Capacitor



Real **Schematic**

Electrolytic capacitors are *polarized*, they must be inserted into a circuit in the proper connections, (not backwards). The lead marked (-) (the shorter lead) must be connected

Figure 8. Electronic Component Orientation from Lab Zero

After the students understand the operation of the function generator and are able to use the oscilloscope to display the time varying signals, they are exposed to the problem of measuring and then eliminating the bounce in electrical switches in the Measuring Transient Signals Lab.

1. The circuit in Figure 1 is constructed in the Distance Lab. The [internal] power supply is used for the +5V source of the circuit. Log into the Distance Lab, and enter the lab. The switch in the Virtual Instrument is triggering an actual switch on the NI-ELVIS board.

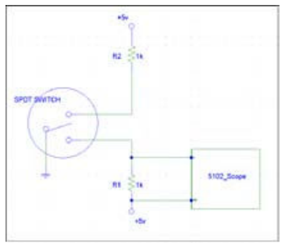
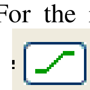


Figure 1: Switch circuit

2. Channel A of the scope is connected across R1 in the circuit. Adjust the volts/division and the horizontal time scale to get a good view of the signal.

3. The "Trigger" sub-panel on the oscilloscope, shown in Figure 2, is what you will be using to adjust the edge slope, source, and trigger level. For the resistor you're measuring across, it would be a good idea to use rising edge slope. . This is because we don't want the waveform to be displayed until the trigger conditions are met, set the source to CH A. Finally, pick an appropriate voltage level at which you want the scope to display the signal, and adjust it using the "Level" control.

4. After you've set the trigger conditions, run a "Single" acquisition. Start the Virtual Instruments by clicking "Run" . (Make sure that the button is pushed in.)

5. Push the "Single" button on the Run Control sub panel. This allows for a single measurement that will be taken when the oscilloscope senses an input that crosses the trigger threshold.

6. Hit the switch in the VI. This should create a picture on the oscilloscope of the voltage across the resistor. The voltage should have a lot of bounce to it, such as in Figure 3.

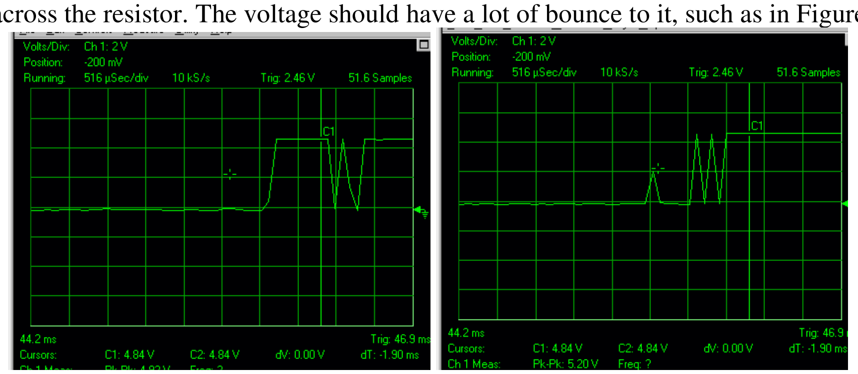


Figure 9. Extract from Measurement of Transient Signal Lab Instructions

Figure 10 below shows the virtual instrument that the student will manipulate to set the controls appropriately to observe the transient switch voltage displayed by the circuit shown in Figure 8. Each of the controls are functional and must be set correctly, in a fashion similar to almost all "real" oscilloscopes found on test benches, in order to observe the transient behavior. Correctly setting the 'scope requires the student to understand the mathematics behind the behavior and then translate that understanding into terms appropriate to the tool. The time constant of the circuit must be determined in order to correctly set the time base of the tool. The steady state voltage must be determined in order to correctly set the vertical scale, and appreciation of the scale of the transients informs the settings for the trigger and threshold controls.

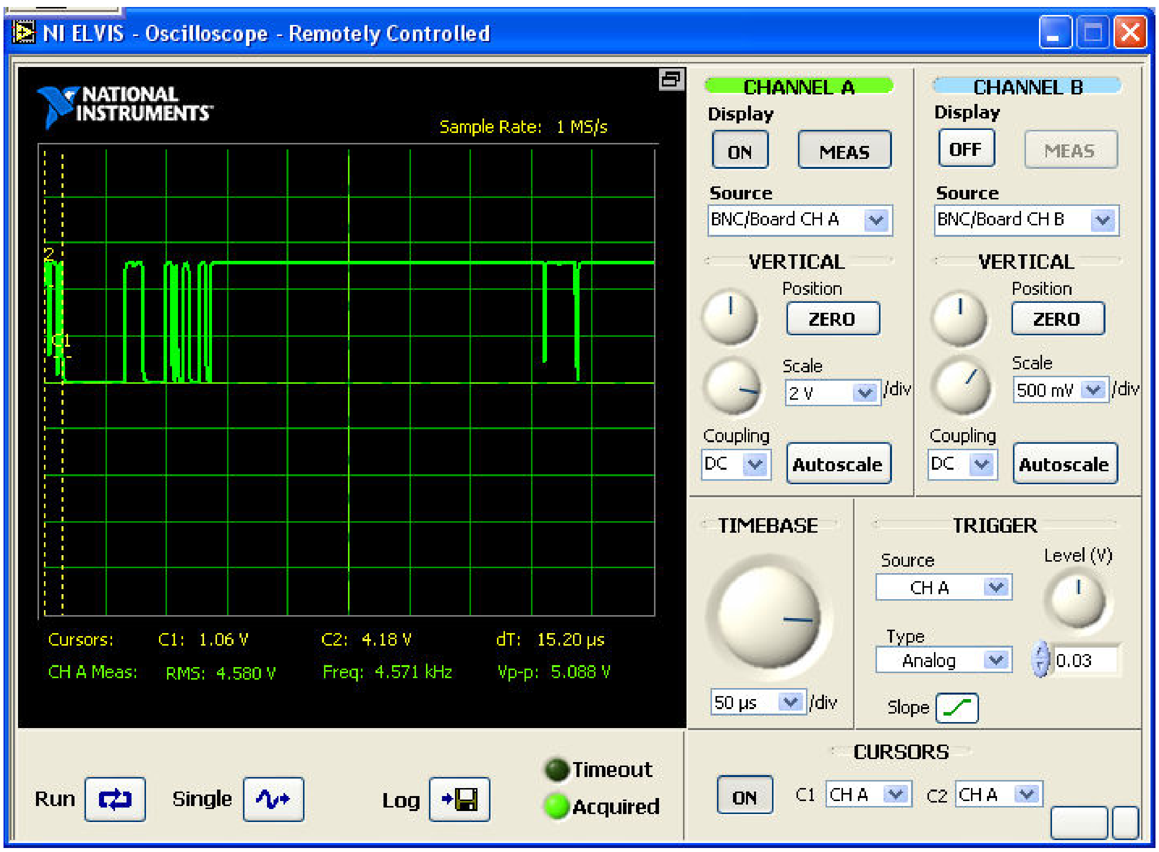


Figure 10. What the student sees when correctly executing the transient measurement lab.

Results

The results for the two groups are presented next. While both groups completed their lab work online, the first cohort was different in that they were learning from a remote site. Because of these differences, the groups are discussed separately. Some general comparisons will be made about the two groups.

Cohort 1

Cohort 1 was made up of 12 students studying at a remote site. Of the 12, five were Mechanical Engineers, 6 were Electrical Engineers, and 1 indicated the category 'other.' Eight of the students were male and 4 were female. Ten of students responded to the course survey.

The six survey prompts based on the Keller model of course motivation are presented in table 1 together with frequencies of response. The frequencies indicate the number of times a rating was given by the group. The mean rating is also given, which is obtained by summing the total raw score for a prompt, and dividing it by the sample size of 10.

Table 1: Summary of Students responses for cohort 1, with the numbers indicating frequencies for each option selected.

Survey Item	**Number of students responding** On a scale of 1-5 Not true =1, Very true =5					**Mean rating for all respondents**
	Not true	Slightly true	Moderately true	Mostly true	Very true	
1. As I have gone through the LABS I have felt confident that I knew what I was supposed to learn and do.	2	0	2	5	1	3.30
2. Completing the LABS has given me a feeling of accomplishment	1	2	3	2	2	3.20
3. The LABS are relevant to my future work as an engineer	4	0	2	2	2	2.80
4. The labs have stimulated my desire to learn more	2	3	2	1	2	2.80
5. The LABS have helped to build my confidence in learning EE concepts	1	3	1	3	2	3.20
6. The skills and knowledge that I have gained fro the LABS are worth the time and effort I have put into it.	1	4	1	1	3	3.10

The data summaries indicate a course motivation within the moderate range, centering around 3.0 on a 5 point scale. To facilitate analysis, the data are also grouped in the categories of the Keller dimensions, that is 1) *relevance*, that is the extent to which the students perceived the course to be relevant to their interests; 2) *confidence,* that is the extent to which the students were confident about their work; 3) *attention,* that is the extent to which the course experience engaged their attention; and finally 4) *satisfaction,* that is the extent to which the students were satisfied by their course taking experience. The average ratings are indicated below, organized by category.

Attention getting

- The labs have stimulated my desire to learn more. The overall rating for this element was a 2.80

Perceived relevance of course

- The skills and knowledge that I have gained fro the LABS are worth the time and effort I have put into it. The overall rating for this item was 3.10
- The LABS are relevant to my future work as an engineer. The overall rating was 2.80

Confidence of student in taking course

- As I have gone through the LABS I have felt confident that I knew what I was supposed to learn and do overall. The overall rating for this item was 3.30
- The LABS have helped to build my confidence in learning EE concepts. The overall rating for this item was 3.20

The satisfaction items on the questionnaire were:

- Completing the LABS has given me a feeling of accomplishment. The overall rating for this item was 3.20

The data are indicative of a marginally lower rating on the capacity of the course experience to engage interest, and on the relevance of the course to perceived interests and needs. Future surveys will use a survey with an expanded number of items for each category in order improve on the reliability of the findings. However the trend of a comparatively low rating on relevance is consistent with the finding from cohort 2, suggesting that this aspect merits further investigation.

Cohort 2

A total of 9 students took the online lab class, while attending regular lectures. Six of the 9 returned a survey on their course experience. Of the 6, 4 were males, and 2 were females. Two had taken an online course before, and 4 had not. The students were asked to indicate as many as three reasons why they opted for the course. A good schedule fit was indicated by 5 of the respondents, flexibility of the online option was indicated by all 6 students, and comfort with the online environment was indicated twice. Flexibility and schedule fit were the dominant reasons. The students were asked if they had any regrets for signing onto the distance online option, and if they at any time wished they could have taken the regular option. Four said that they had not regrets, and 2 indicated that they wished they had taken the regular lab class

As noted above, the students took the final exam using regular laboratory equipment. They were asked if they had experienced difficulties using the physical equipment. Four students said they had experienced difficulties, 2 said that they had not experienced difficulties.

The 6 survey prompts that were used for cohort 1 were used to gain a measure of student course motivation. The data are summarized in table 2. The frequencies indicate the number of times a rating was given by the group. The mean rating is also given.

Table 2: Summary of Students responses for cohort 2, with the numbers indicating frequencies for each option selected.

Survey Item	**Number of students responding** On a scale of 1-5 Not true =1, Very true =5					**Mean rating for all respondents**
	Not true	Slightly true	Moderately true	Mostly true	Very true	
1. As I have gone through the LABS I have felt confident that I knew what I was supposed to learn and do.		1	1	3	1	3.7
2. Completing the LABS has given me a feeling of accomplishment		1	2	2	1	3.5
3. The LABS are relevant to my future work as an engineer	1	1	2	1		2.2
4. The labs have stimulated my desire to learn more	2	1	1	1	2	3.5
5. The LABS have helped to build my confidence in learning EE concepts	1	1	1	1	2	3.3
6. The skills and knowledge that I have gained fro the LABS are worth the time and effort I have put into it.	1		1	3	1	3.5
7. Based on my experience, online labs provide an effective learning experience for students			1	4	1	4.0

The data summaries indicate a course motivation within the moderate range, centering around 3.3 on a 5 point scale. Item 7 provided the student an opportunity to evaluate their overall experience with the virtual labs. The students provided a rating to the question prompt: “Based on my experience, online labs provide an effective learning experience for students.” The average rating on for this item was a 4.0 which is strong on a 5 point scale.

As for cohort 1, the data were grouped in the categories of the Keller dimensions of *relevance*, *confidence, attention, satisfaction.* The average ratings are indicated below, organized by category.

Attention getting

- The labs have stimulated my desire to learn more. The overall rating for this element was 3.5

Perceived relevance of course

- The skills and knowledge that I have gained fro the LABS are worth the time and effort I have put into it. The overall rating for this element was 3.5
- The LABS are relevant to my future work as an engineer. The overall rating for this element was 2.2

Confidence of students in taking course

- As I have gone through the LABS I have felt confident that I knew what I was supposed to learn and do overall. The overall rating for this element was 3.7
- The LABS have helped to build my confidence in learning EE concepts. The overall rating for this element was 3.3

Satisfaction with course experience

- Completing the LABS has given me a feeling of accomplishment. The overall rating for this element was 3.5

The mean rating for ‘relevance to future engineering work’ were notably low (2.2). This is consistent with the results for cohort 1. The ratings were higher when respondents were asked if learning the experience was worth their time and effort (3.5). The data suggests that more work be done to help students to relate the lab work to their anticipated future work as engineers.

Assessments of lab performance

In addition to the survey, laboratory performance data was obtained for cohort 2, as well as the regular class. The regular class had 199 students and the virtual lab class had 9 students. The laboratory performance of the two groups has been compared by computing mean scores for each of the groups. No tests of statistical significance have been attempted because of the small size of the experimental group. The data are summarized in table 3.

Table 3: Performance data, comparing the experimental group and the regular group on laboratory performance over the semester

	Experimental Group	Regular Group
Sum of semester scores	2484.84	54050.90
Number of subjects	9	199
Mean score	276.09	271.61
Standard Deviation	52.20	46.65

The descriptive statistics indicated average performances on lab that are comparable between the regular lab group and the experimental. This suggests that the students performed at the same level. More data will be needed to confirm this trend. However the data were consistent through the course.

From the written responses, it was clear that some of the students did not realize how the lab would be conducted and what they were signing up for. However, they were able to adapt. One student wrote:

At the very beginning when I did not know how to do the labs. I hadn't realized that I would have to remote connect and do the labs. That was the most confusing part, but after that I was glad that I switched.

A second student wrote:

I did wish I would have stayed in the regular lab in the beginning because at first I did not know or understand how to use the distance lab, but after a while I understood and got the hang of it.

The students commented favorably the on campus version of Lab Zero. One student wrote: "*I was able to correlate the virtual instruments to the physical ones and how it all works.*"

On the whole, students felt that they would have been more comfortable with the final exam if they had more opportunities to work with the physical equipment. Among the comments made were the following:

> *I did not understand how to use a bread board for the lab practical, because of this I did not have the chance to finish. I think had I known I could have finished because I know how to use all the other equipment.*

> *I had some minor difficulties with what some of the equipment settings meant and the certain buttons to use but I understood how to do everything, for some reason I could not get the current measurements to work out even though I'm pretty sure I was doing them correctly.*

Conclusion

The results of the work at Michigan Tech are encouraging. They are based on small samples and the findings are formative. The results for cohort 2 indicate a more positive response, when compared to cohort 1. It is difficult to account for the differences precisely because there are several differences between the groups. Cohort 1 was made up of working persons, while cohort 2 was made up of students. Cohort 1 had the entire course online, while cohort 2 only had the lab component online. Finally the cohort 1 group did not have the option to opt out of the online course, while cohort 2 was made up of volunteers.

Additional studies will be carried out with more stringent experimental design criteria, including surveys for both experimental and control groups. The feedback will be continuously incorporated into the course design in order to optimize delivery of instruction, and increase options for students on campus as well as those learning at remote sites.

References

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