Massive Open Online Laboratories? Ongoing Work with Microelectronics Experiments Performed Outside of the Traditional Laboratory

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Abstract

With the advent of open source hardware and software, students are able to perform advanced microelectronic experiments outside of the laboratory setting using low-cost components and equipment. Offering experiments outside of a traditional lab accommodates distance-learning as well as large class sizes. Many authors have addressed comparisons of in-lab laboratories with ones completed virtually or remotely,[1,2] however much less has been studied regarding the use of actual, physical laboratories by students at home or in their dormitory rooms outside of the traditional laboratory.[3,4] To respond to and leverage technological advancements in portable test and measurement equipment, several student-accessible electronics hardware platforms were considered including the NI myDAQ, Arduino development board, TI LaunchPad, BitScope, Analog Discovery, and a Creative Soundblaster USB Audio System. Ultimately, an initial pilot study with 14 students was conducted in a summer microelectronics course using the NI myDAQ. This, along with high-quality instructional videos, allowed students to complete experiments on their own outside of the laboratory setting. In this study, two of the later course hardware exercises—multi-stage amplifier and op-amp amplifier—were offered to half of the class as labs to be completed outside of the traditional laboratory. Independent validation of the experiment using randomized, multi-stage testing was performed and its effectiveness queried using in-person laboratory observations, instructor discussions, a post-laboratory survey, and student laboratory report assessment. Recommendations for implementing out-of-lab student experiments include anticipating hardware failure, encouraging student collaboration, and providing live TA assistance. As a result of the pilot work, additional laboratory offerings using these recommendations as well as explored alternative hardware solutions are being pursued.

Motivation

Over the past five years, the Electrical and Computer Engineering program at Duke University has experienced significant growth in enrollment. This growth has presented new challenges not only in continuing to provide high quality instruction to more students, but also in scheduling laboratory sessions throughout the week with limited space and equipment. With the advent of open source hardware and software, the possibility of having students perform advanced microelectronic experiments outside of the traditional laboratory setting using low-cost components and equipment exists. Offering laboratories outside of a traditional laboratory setting accommodates distance-learning as well as large class sizes.

In prior work, there have been several studies by authors addressing comparisons of in-lab laboratories with ones completed virtually or remotely.[1,2] However much less has been studied regarding the use of actual, physical laboratories by students at home or in their dormitory rooms outside of the traditional laboratory. One study using in a digital circuits course used software simulation with an emphasis on debugging.[3] Another, more recently, reported on initial attempts with actual hardware-based laboratories completed outside of the traditional laboratory.[4]

In this work, to respond to enrollment and space challenges and to leverage technological advancements, several student-accessible electronics hardware platforms were considered for use with out-of-laboratory experiments. The platforms considered prior to the study included the following:

- NI myDAQ
- Arduino development board,
- TI LaunchPad
- BitScope
- Analog Discovery
- Creative Soundblaster USB Audio
- System.

The course chosen to implement this study was the sophomore level Microelectronic Devices and Circuits course. This course is a hands-on, laboratory driven introduction to microelectronic devices, sensors, and integrated circuits. In it students experiment with and verify the operation of semiconductor devices. They subsequently build circuits using these devices in topologies such as a multistage amplifier and an operational amplifier bandpass filter. These two laboratories were chosen to implement the pilot study using the out-of-lab laboratory hardware: the NI myDAQ.

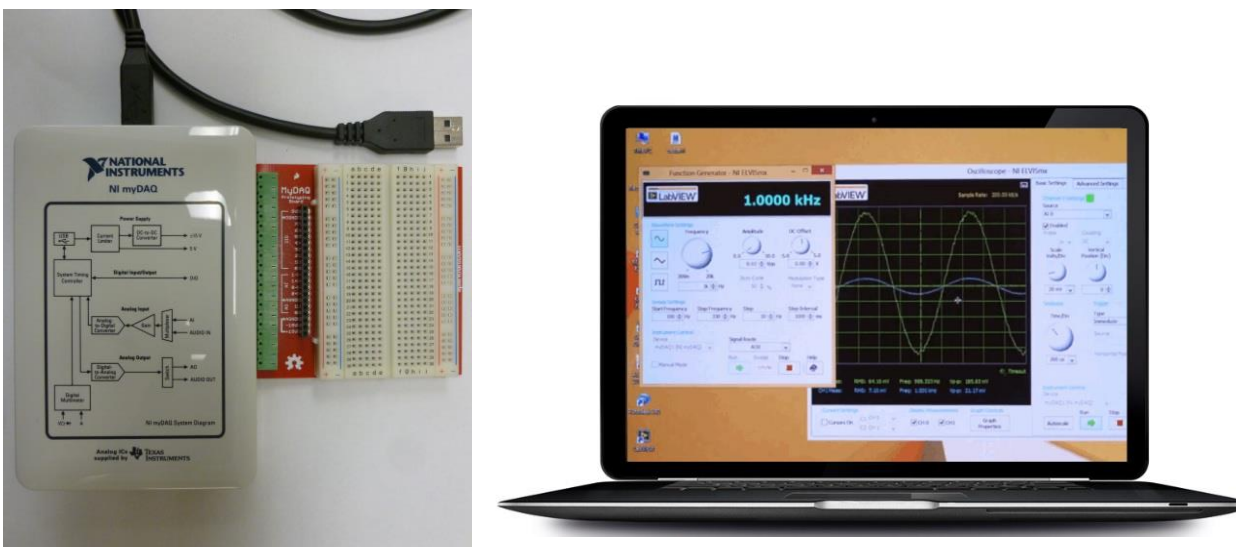

Figure 1. NI myDAQ hardware platform used for out-of-lab experiments (www.ni.com) (Left) and associated NI Elvis software interface (Right)

Methods

The initial pilot study consisted of 14 students and was conducted during the summer offering of a sophomore-level first course in microelectronic devices and circuits. The hardware used for out-of-lab laboratory experiments was the NI myDAQ. The myDAQ had important advantages when compared to the other platforms.

The NI myDAQ was chosen as the hardware platform for out-of-lab laboratories for several reasons. First, the National Instruments ELVISmx software package for the myDAQ meshed well with current laboratory exercises since students have already been exposed to NI LabVIEW software earlier in this course. Also, the myDAQ offers a more complete suite of test and measurement modules than the other options including a function generator, oscilloscope, signal analyzer, and a built in power supply.

In addition, high-quality instructional laboratory videos were developed to assist students as a teaching assistant would in a normal laboratory introduction. These videos were recorded professionally in the normal laboratory setting and featured a rehearsed walk-through of the laboratory including whiteboard diagrams and zoomed-in details of the circuits using the hardware itself. These videos were made available to students on the laboratory course website thus allowing students to complete experiments on their own outside of the laboratory setting.

In the study, two of the later course hardware exercises—multi-stage amplifier and op-amp amplifier—were offered to half the class as remote laboratories. The students then completed the lab that they had not done using standard bench-top equipment in a traditional laboratory setting the following week.

Independent validation of the experiment was performed and its effectiveness queried. The teaching team was very committed to evaluating the pilot project. The goal of the evaluation was to determine whether students experienced the same troubleshooting process using the NI myDAQ as they typically experienced during a class lab session using the same hardware. The evaluation was also intended to identify any challenges or potential problems prior to launching the project in future course offerings.

The data sources used in the evaluation included the following:

1. In-person observations of two classroom lab sessions–results of which are detailed throughout this study
2. Informal discussions with the lab personnel and teaching assistant–which provided background course philosophy and pedagogical objectives that are included as comments throughout this study
3. A survey given to students after they completed the NI myDAQ labs–the results of which are published here (**Tables 1–3**)
4. The lab reports completed by the students–for which analysis of expected versus measured results are given here and deviations from one another reported for in-lab versus out-of-lab groups (**Tables 4-5**)

The control group who performed the experiment in the laboratory with standard bench equipment utilized the Agilent E3631A and E3611A DC power supplies, the Agilent 34410A digital multi-meter, the Agilent 33220A function generator, and the Agilent DSO6014A oscilloscope. The group who used the NI myDAQ performed the laboratory experiment outside of laboratory and obtained their measurements using the National Instruments myDAQ (p. n. 195509F-01L) and NI ELVISmx 14.0 software instruments.

Teaching Team

The team who implemented and assessed this new initiative was multidisciplinary coming from both the Electrical and Computer Engineering (ECE) department as well as the Center for Instructional Technology (CIT) and Office of Information Technology (OIT) within the University. Duke supported this work internally through an Online Duke grant. The Online Duke initiative is designed to advance educational excellence by providing leadership and support to faculty and programs across the university in an effort to promote teaching innovation.

The ECE members consisted of the following individuals:

- 1 full-time ECE faculty member—course instructor
- 2 full-time laboratory personnel—lab pedagogy and facilities support
- 1 undergraduate teaching assistant—in-lab student support both physically and online

The complementary CIT and OIT members consisted of the following individuals:

- 1 education technology specialist
- 1 program evaluator
- 1 information technology analyst
- 1 video producer

Results

A total of 11 students completed the post-lab survey, 6 of whom completed the multi-stage amplifier lab and 5 of whom completed the op-amp amplifier lab using the NI myDAQ kit. The complete student survey is included in Appendix A. It should be mentioned here that early on in the first offering of the multi-stage amplifier lab, the exact type of potential problem we hoped to identify through the pilot study occurred: some of the manufacturer breadboards that students used to build the circuit were found to be defective and non-functional. As a result, students attempting to complete that laboratory using the NI myDAQ outside of the lab did not have a comparable remote laboratory experience as the students completing the same laboratory in lab. To remedy this situation, the students who had defective boards returned to the laboratory for a replacement board. They then completed the lab in the traditional lab setting, however they still used the myDAQ hardware with no remote TA assistance. Recommendations that appear at the end of this paper present suggestions that will help prevent similar problems in future course offerings.

Communication and Collaboration

In general, students completed the labs individually in this course. However, they were allowed to collaborate with one another about concepts and approaches to the lab. During in-class observations, it was apparent throughout the lab session duration that students were communicating frequently with each other and with the TA. We found that this was also true during the out-of-lab labs (**Table 1**). Just under half of the students completing each out-of-lab lab worked with another student outside of class to complete the assignment. Of those, one person collaborated on less than 25% of the lab while the other four students did more than half the lab with another student. The students also relied heavily on the TA; only 1 person said s/he did not get TA assistance for the NI myDAQ lab.

Troubleshooting

Just as was observed in class, the most common way that students approached troubleshooting was to visually compare their circuit to the diagram. Of the students reporting, 7 completed troubleshooting visually; 2 people used the multimeter; no one used the oscilloscope; and one student wrote that s/he "tried everything" (**Table 1**). A key objective of these labs is for students to encounter problems building the circuit and have to invoke circuit debugging techniques. All students except one indicated confusion about how to proceed at some point during the lab. This is evidence that the lab was meeting the objective and students were engaged in active troubleshooting.

There is evidence that the NI myDAQ labs took longer for students to complete than the in-class labs. Students using the remote hardware spent an average of 3 hours on the op-amp lab and almost 8 hours on the multi-stage amplifier lab, as opposed to the standard 2.5 hours allotted for in-class labs. While the students would not have spent 8 hours on the multi-stage lab if the breadboards received from the manufacturer had not been defective, they also likely would have sought assistance sooner if they had been trying to use faulty hardware during an in-class lab. When asked in the survey, 73% of all students felt that it took them longer to complete the lab outside of class than it would have taken them to do the same lab in class. Of the students who did the op-amp (no faulty equipment) lab, half said it took them longer using the NI myDAQ than it would have in class.

Table 1: Student Experiences with the MyDAQ Lab

General questions:	Yes	No
Worked with another student (not TA)	45%	55%
Got help from TA	82%	18%
Were you ever confused about next steps?	91%	9%
Would you build another circuit for fun?	64%	36%
Simulation questions:	Percentage of students	
Did simulation before lab	36%	
Did simulation during lab	9%	
Did simulation after lab	36%	
Did not do simulation	18%	

Student Backgrounds

The students all felt comfortable building circuits with instructions, and 64% felt "somewhat comfortable" doing so without instructions (Table 2). Of the 11 students reporting, 7 said they would build another circuit for fun. Some students had experience with this particular circuit prior to building it. Students were assigned the task of simulating the circuit using PSPICE software prior to working on the lab. Of these, 4 students completed this task as assigned, 1 did it during the lab, 4 did it after the lab, and 2 students did not do the simulation. Of the 4 students who did the simulation in advance, 3 were "very" or "somewhat comfortable" building circuits. The distribution of responses was the same for the 4 students who did the simulation after the lab.

Table 2: How Comfortable are You Building Circuits?

	Very comfortable	Somewhat comfortable	Somewhat uncomfortable	Very uncomfortable
With instructions	64%	36%	0%	0%
Without instructions	0%	64%	18%	18%

Student Feedback

Students were asked a series of questions about their experience with the NI myDAQ labs (Table 3). They had varying opinions about whether they liked being able to do the lab outside of the normal lab section time. When asked if they liked working outside of class, half had no opinion on the subject, one person agreed to liking the experience, and the rest "disagreed" or "strongly disagreed". The students in the op-amp lab all agreed that they knew how to get help if they needed it, but 2/3 of the students in the multi-stage lab said they did not know how to get help.

Almost all of the students (10 out of 11) agreed that it was a disadvantage not to have TA assistance when doing the lab on their own. Most students, 6 out of 11, also agreed that they would rather not do labs outside of the normal lab setting; the remaining four had no opinion on the subject.

When asked about the actual NI myDAQ equipment, opinions varied. Three students preferred the NI myDAQ to the lab equipment, four had no opinion, and four preferred the lab equipment. During our in-class observation, one student was seen using the NI myDAQ in the lab. When asked, the student said that the NI myDAQ allowed a screen shot of the oscilloscope display to be taken and that the function generator on the NI myDAQ was preferable.

Table 3: Student Feedback on the MyDAQ Lab Experience					
	Strongly agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
It took me longer to do the MyDAQ lab than it would have taken me to do the same lab in class	55%	18%	18%	9%	0%
I liked being able to do the MyDAQ lab outside of class	0%	18%	45%	27%	9%
I knew how to get help if I had problems during the MyDAQ lab	18%	45%	0%	18%	18%
It was a disadvantage not to have a TA during the lab	36%	55%	9%	0%	0%
I would rather not do labs outside of class	27%	27%	45%	0%	0%
I like using the MyDAQ better than using the lab equipment	9%	18%	36%	27%	9%

Laboratory Report Assessment

Based on the written results and analysis performed by students in the laboratories where the myDAQ hardware was used, evaluation of the control group (in lab) and the experimental group (out-of-lab) was carried out by comparing expected circuit parameters based on PSpice circuit simulations to empirically measured circuit parameter values. The measured circuit parameter values, then, were carried out with either the NI myDAQ kit available to the study group or the bench-top equipment available to the traditional in-lab group.

A comparison of the expected gain from the multi-stage amplifier (Common-Source, Common-Drain (CSCD) amplifier) circuit with that measured by the students using either remote or in-lab hardware was made. These results are summarized in Table 4. The number of students (n) completing this laboratory in-lab was 5 and those doing so remotely was 6. The data indicates that while the standard deviation amongst laboratory groups for this measurement was similar (~10.5), the percentage difference from the expected gain measurement was considerably greater for the experimental group (4% as compared to 59%, respectively). As was mentioned above, some of the manufacturer breadboards that students used to build the circuit were found to be defective and non-functional. As a result, students attempting to complete this laboratory using the NI myDAQ did not have a comparable remote laboratory experience as the students completing the same laboratory in lab. Most of the students who had defective boards ended up returning to the laboratory for troubleshooting with the TA and completed the lab in the traditional way there. However, the students did still complete the lab using the myDAQ hardware. Nonetheless, at least a few students did not obtain gain measurements that were as close to the expected value as those who used the standard in-lab hardware.

Table 4: Multi-stage Amplifier Gain Comparison (PSpice Simulated vs. Measured Results)		
	In-lab groups	Remote lab groups (MyDAQ)
Number of Student participants (n)	5	6
Multi-Stage Gain Measurement—Standard Deviation	11.7	10.1
Multi-Stage Gain Measurement—Percent Difference[1]	-3%	59%

[1]Negative percentage difference indicates that measured values are less than expected values.

Table 5: Op-amp Gain and Resonant Freq. Comparison (PSpice Simulated vs. Measured Results)		
	In-lab groups	Remote lab groups (MyDAQ)
Number of Student participants (n)	6	7
Non-Inverting Amp. Gain Measurement—Standard Deviation	1.5	0.3
Non-Inverting Amp. Gain Measurement—Percent Difference	31%	2%
Op-amp Bandpass Filter Resonant Freq. Meas.—Standard Dev.	6.0	6.0
Op-amp Bandpass Filter Resonant Freq. Meas.—Percent Diff.	-4%	-4%

For the operational amplifier non-inverting bandpass filter laboratory, a comparison of the expected gain and also the resonant frequency of the filter was made. Table 5 summarizes these results. The number of students (n) completing this laboratory in-lab was 5 and out-of-lab was 7. In this comparison, it was observed that the overall gain measurements of this circuit were less tightly clustered and further from expected for the in-lab control group (1.5 s.d. and 31% difference from expected) than those of the remote laboratory group (0.3 s.d. and only 2% difference from expected). The second metric, expected versus measured resonant frequency for the bandpass filter of the multi-stage amplifier showed the same results for both groups (6.0 s.d. and measured values -4% from expected).

One additional important note to be made is that at least one student in the above group chose to use the myDAQ hardware remotely for the op-amp laboratory even though he had already done so for the previous multi-stage amplifier lab. If nothing else, this single data point indicates that at least one student found the myDAQ remote lab experience to be favorable enough to use the hardware again by choice over the standard laboratory test and measurement equipment in-lab.

Recommendations & Future Work

Based on the above evaluation results, we have three recommended changes to consider implementing when the project is launched in subsequent course offerings.

1. Anticipate hardware failure—The NI myDAQ equipment should be tested immediately prior to being issued to students, and students should be told to contact a TA to test for hardware failure if their circuit is not functioning after 4 hours of troubleshooting.
2. Provide TA assistance—Use of videoconferencing to offer 1-2 optional live TA sessions when students can ask questions or submit pictures of their circuits for troubleshooting.
3. Encourage NI myDAQ lab meetings—Students should be encouraged to find places where they can meet in small groups to do the NI myDAQ labs in order to replicate the collaborative troubleshooting process observed in the lab.

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Appendix A: Student Laboratory Survey for in-lab vs. out-of-lab myDAQ laboratories

Thank you for agreeing to participate in research comparing traditional ECE labs with the MyDAQ labs. This survey will ask about your experiences completing the MyDAQ lab. Please think only about the lab you completed outside of class using the MyDAQ kit when you answer these questions. This survey will take no more than 10 minutes.

Your answers to this survey will not have any affect on your grade in this course. Dr. Brooke will never know the answers provided by any individual student. Dr. Brooke will not see any data from this survey until after grades have been issued in this course.

About how much of the time spent on the lab was with another student?

- Less than 25%
- 25% - 50%
- 51% - 75%
- More than 75%

Did you get help from the TA during the MyDAQ lab?

- Yes
- No

Did you do the simulation component before/during/after the lab?

- I did it before the lab
- I did it during the lab
- I did it after the lab
- I did not do it

How comfortable are you building circuits with instructions?

- Very comfortable
- Somewhat comfortable
- Somewhat uncomfortable
- Very uncomfortable

How comfortable are you building circuits without instructions?

- Very comfortable
- Somewhat comfortable
- Somewhat uncomfortable
- Very uncomfortable

How did you troubleshoot during the lab?

- I used the multimeter
- I used an oscilloscope
- I visually compared my circuit to the diagram
- I used another tool (write it below)

- I did not use any tools to troubleshoot

How did you know if the circuit was working as intended?

Did you have any problems with the lab hardware and, if so, how did you handle them?

Were you confused about how to proceed at any point?

- Yes
- No

Would you build another circuit for fun?

- Yes
- No

How much time did it take to complete the MyDAQ lab (excluding time spent writing the report)?

How long did it take to write the lab report?

Please indicate how much you agree or disagree with the following statements:

It took me longer to do the MyDAQ lab than it would have taken me to do the same lab in class	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I liked being able to do the MyDAQ lab outside of class	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I knew how to get help if I had problems during the MyDAQ lab	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
It was a disadvantage not to have a TA during the lab	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I would rather not do labs outside of class	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I like using the MyDAQ better than using the lab equipment	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree