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Developing Portable Lab Kits for a Foundational Circuits Class

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Developing a Portable Laboratory Kit for a Foundational Circuits Course

Abstract

Increasing online and distance education has become a significant interest in engineering education today. As these venues for learning have become increasingly feasible and popular, one aspect of engineering education resists the transition online: the laboratory experience. A traditional engineering teaching laboratory (lab) requires a significant amount of equipment, materials, and personnel in order to operate, and so the experience is therefore restricted to a specific time and space. To address this, labs have been developed to allow remote access to local equipment so that students can conduct experiments through an interface over the internet. While this is a valuable resource, it reduces hands-on interaction and still requires maintenance, troubleshooting, and space at the host site.

However, new technology in circuit analysis has made it possible to assemble the basic equipment needed in an electronics lab station in a small kit for less than $350. On this scale, it becomes possible to create portable lab kits that individual students could use to perform lab experiments on their own time outside of the physical lab.

This paper describes a pilot test of a portable lab format based on the Analog Discovery USB oscilloscope and multi-function instrument made by Digilent®. The format was developed and tested in an introductory circuits course covering the analog analysis of electrical circuits under alternating current (AC) and direct current (DC), and a brief introduction to digital circuits. The course includes three hours of lecture per week and a three-hour lab every other week that explores concepts and applications related to lecture topics.

The development process is documented, including adaptations to lab exercises necessitated by the limitations of the Analog Discovery. Also, student feedback was collected throughout the pilot testing process, and general themes and ideas are presented here. As anticipated, students struggle to become familiar with the Analog Discovery system, but benefit from the flexibility offered by the portable lab. Finally, recommendations for future implementations are given based on lessons learned along the way.

Background

In the modern era of instantaneous information and communication through the internet, online education has become a significant area of growth and research in the education community. Many see online education as a key to providing quality education to a broader population in a broader range of places. In data collected by the Babson Survey Research Group it was found that two-thirds of chief academic officers at surveyed universities believed that online education was critical to their school's long-term strategy [1], [2].

The increase of formal online education has also spread to engineering [3], although to a lesser extent than other disciplines. The lag in bringing online education to engineering is primarily attributed to the traditionally interactive and hands-on nature of engineering laboratory (lab) experiences [4], [5]. According to Bourne et al., "laboratories are notably difficult to provide online because of the traditional desire for the direct operation of instruments [4]." Though another line of discourse and research investigates the appropriate role of lab experiences in engineering education [6], lab work has been established as a cornerstone of engineering curriculum and practice that that will continue to be important to the field.

In order to bridge the gap between the removed nature of online education and the hands-on nature of lab work, many universities have developed remote lab systems that allow distance access to university lab equipment [3], [7], [8], [9], [10]. Other universities have developed simulations, or virtual labs, to allow students to complete or practice lab work fully online, without access to any equipment [11], [12], [13], although this practices is less common.

Although the remote or virtual lab environment is a valuable tool, the primary critique of this method is that it does not allow students direct interaction with the instruments and test objects [14]. This paper describes an approach to an electrical circuits lab that provides the flexibility of a virtual lab and the direct interaction of a physical lab by providing students with portable lab kits that include all the necessary equipment to perform lab activities anytime and anywhere from their own computer.

Portable lab implementation

In this paper, we discuss the process of implementing a portable lab format in a basic circuits course taught at a traditional large-sized university in the western United States. The course serves approximately 150 students per semester from non-electrical engineering disciplines (primarily mechanical, biological, and civil). The 3-credit class includes 3 hours of lecture per week as well as a 3-hour lab every other week. Topics include DC and AC analysis of RLC circuits, and a brief introduction to digital circuits.

The lab space used for this class has a capacity of 32 students, so students are split into six lab sections that meet at different time slots during the week. During lab sessions, students work in pairs to complete step-by-step lab activities that demonstrate course principles and relevant applications. In the lab room, each of the 16 lab stations include a triple-output +/- 25V power supply, a bench digital multimeter, a function generator, a two-channel oscilloscope, a breadboard, and a set of circuit components. An undergraduate Teaching Assistant (TA) oversees each lab section in order to provide guidance and answer questions throughout the period.

Over the course of the semester, there are seven lab sessions that are aligned to lecture content. Table 1 outlines the concepts and activities included in each of these sessions. Most lab sessions require students to analyze given circuits and then build and measure circuit parameters to verify their analysis technique. Most labs also include either a design or application component that requires students to design their own circuit to meet given specifications or to perform a given function.

In previous course offerings, class notes, video lectures, and additional video examples were generated and posted on the course website for students. During one class offering, these materials were used to transform the course into a hybrid class in which students watched

Table 1: Lab activities for each lab session

Lab session	Week of class	Lab content
1	3rd week	Introduction to lab equipment Verification of Ohm's law Understanding sources of error
2	5th week	Power consumption of fan at various speeds and sizes Comparison of series and parallel structures Equivalent resistance of series/parallel circuits
3	7th week	Comparing Thevenin equivalent circuits Verification of Superposition Theorem Taking measurements with a Wheatstone bridge design
4	9th week	Transient behavior of capacitors Steady state behavior of inductors Constructing a capacitive touch sensor to control an LED
5	10th week	Introduction to signal generator and oscilloscope Measuring frequency response of resistors, inductors, and capacitors Experimental introduction to an RLC filter
6	13th week	Determine type and value of unknown RLC components Introduction and experimentation with audio filtering
7	15th (last) week	Building a two-digit counter based on senor input using digital chips

lectures online and physically attended lab activities. Although this format was not continued, it has provided resources to make this engineering course accessible online to a broad audience not limited to a physical location. However, to migrate this course to a fully online format the hands-on lab exercises must also be adapted to be accessible outside of the physical classroom.

The development of a portable lab format allowed students to complete lab exercises outside of the time and place constraints of the traditional lab. These portable labs included lab guides and all the required tools and components within a small box (portable lab kit) that students could take home with them. While students performed the lab experiments, they documented their results and analysis in the provided lab guide file. Students then submitted the completed lab guide online through the university learning management system, where graders could access the file, give feedback, and assign a grade.

Our kits were built around the Analog Discovery (AD) tool [15], developed by Digilent, which includes most of the functionality of the multimeters, function generators, and oscilloscopes used in the lab contained in a small USB device. The device plugs into a host computer through a USB cable on one end, and to breadboard sockets on the other through an array of wires, in order to serve as an interface between the circuit and the analysis software on the host computer. A picture of the AD can be seen in Figure 1. The Waveforms software [16], is used to read AD input and serves as the user interface for all the individual tools and functionalities of the AD.

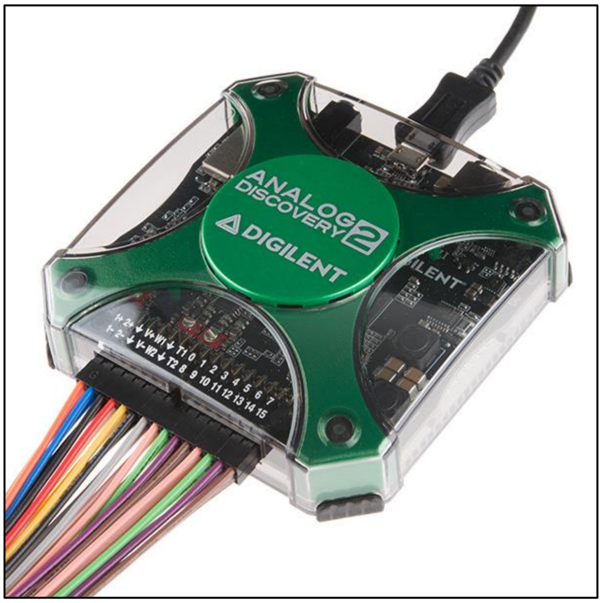

Figure 1. The Analog Discovery 2, by Digilent®. Image credit: SparkFun Electronics

Each portable lab kit consisted of an AD, a breadboard, and a set of circuit components matching those in the lab. Later on, an inexpensive handheld meter, a small battery pack, and some additional wires were added to simplify using the kits. For a full list of components that were included in the kits, and an approximate cost breakdown, see Appendix A.

Since the goal of this project was to make our traditional lab activities available in a more flexible setting, lab instructions were minimally adapted rather than redesigned to accommodate the constraints of the AD. These adaptations primarily involved adjusting circuit parameters and measurement techniques to match the abilities of the AD without changing any lab content.

The most significant limitation of the AD was the power supply. Since it draws all of its power from a standard USB port, it cannot exceed 5V and supplies very limited current. To accommodate this, circuits that specified a supply greater than 5V were modified to specify 5V instead. Most lab activities involved such simple circuits that the current limitations were not an issue, however in lab two the AD could not supply the 1-2 amps pulled by the fan motor, and in some cases in lab seven could not drive all of the digital hardware. For lab two, the fan was replaced with a small USB powered fan that had a much smaller motor and drew less current. By lab seven, we added a battery pack to the kits that could power the circuit separately from the AD and provide a higher current. Within the 5V limitation, the AD was able to mimic the multiple outputs of the power supplies in lab since it can supply voltage through a +5V and -5V power lines, as well as through the two separate channels of the waveform generator.

The other limitation of the AD is its lack of an ohmmeter or ammeter. We first tried to adapt the lab instructions to accommodate by adding current sensing resistors into circuits in which current was to be measured, and assuming resistors were equal to their nominal values. However, after the first two labs, this was found to be unsatisfactory, and we developed a new solution discussed below.

Since this was a pilot test of the portable lab concept, students were welcomed to take advantage of the portable lab format on a voluntary basis but otherwise participated in the traditional face-to-face lab format. This meant that most students, who had already scheduled their lab sections, only used the portable lab format when an unexpected one-time scheduling conflict arose with their regular lab section. A few students also took advantage of the portable lab format when they wanted to postpone lab work in order to study for earlier deadlines, or when they were sick and not able to attend classes.

Outcomes

Overall, this pilot test was a successful proof-of-concept implementation of the portable lab idea, although it illuminated many issues with the process that still need improvement. Over the course of the seven lab sessions, the portable lab format was used a total of 19 times by 15 different students. As students completed labs using the portable kit, informal feedback was collected through a brief survey. Students were asked about the amount of time spent on the lab, significant issues that came up, and overall perceptions of the portable lab experience. Though this feedback is not reported here as data, it was used to iteratively improve the portable lab process throughout the semester and has informed the following discussion.

The first few lab sessions became a testing ground for the technical details of the portable lab kits. Although the AD effectively replaced the entire lab station, its technical limitations required careful consideration. Though we had originally intended to add current sensing resistors to several circuits in order to measure current via voltage, we found that current measurements based on the nominal value of the sensing resistor were not sufficiently accurate. In response to this, we added small handheld multimeters to the lab kits in order to measure either resistance or current directly. This reduced the adaptations that needed to be made for the AD and made minimal impact on the cost or portability of the kits. Once these were added to the kits, many students also found it more intuitive to measure voltage with the external meter rather than using the AD voltmeter.

The experience level and confidence of students heavily affected the success of the portable lab experience. For students who felt comfortable with the equipment and setup, the flexibility and individuality of the lab was very beneficial. One student expressed that completing the lab on his own pushed him to learn the processes better, acknowledging that although helpful, having a lab partner and TA available could become a crutch. Multiple students also appreciated the chance to take their time and tinker and learn without slowing down their lab partner or feeling pressure to complete the lab and leave.

On the other hand, students who were uncertain about the equipment or how to set up very simple circuits struggled to complete the lab in such an unguided setting. For example, several students became stuck trying to connect the AD power supply or the waveform generator as the source for their circuits. These issues that caused students the most trouble were often small misunderstandings that consumed long periods of time but could have been quickly corrected by a lab assistant if available. To address these kinds of issues, students were encouraged to promptly ask questions by email when they were unsure of how to proceed. Though not as instantaneous as a physically present instructor, prompt email exchanges helped to reduce the amount of time students spent confused and frustrated.

Despite the challenges of not having the support of a TA and lab partner, most students who used the portable lab were able to successfully build and correctly test all circuits in the lab activities and reported completing the work in 2.5 to 3.5 hours, which is comparable to the time required in the physical lab setting. Though not definitive proof, this comparison suggests that the portable and traditional labs provided comparable learning experiences.

Recommendations

This pilot test demonstrated the viability of a portable lab approach to a traditional circuits lab, and highlighted several important considerations for future implementations. On the technical side, we found that although the AD seemed to be the complete package, it was helpful to include a small external multimeter and power supply. These additions made the overall process much smoother and expanded the set of possible experiments.

Although this project primarily ported existing labs to the AD platform, there is also significant potential to take advantage of the additional functionality of the AD beyond the basic lab equipment to add new lab activities within the portable lab format. For example, the scripting functionality and I/O pins could be used to add a significant programming element, or the spectrum analyzer or logic analyzer could allow students to visualize the behavior of their circuits from a different perspective. For example, since ADs were also available in the regular lab, a new lab activity was developed to take advantage of the scripting feature. A script was provided that coordinated the waveform generator and oscilloscope to measure capacitance and allowed students to build a capacitive touch sensor. By combining the AD’s capabilities, this activity was able to introduce students to an interesting everyday application of the course material.

From a pedagogical perspective, it was found to be important for students to have, and to feel like they have, sufficient resources to learn the lab procedures and accomplish the work. To achieve this, resources should include detailed instructions and/or video tutorials that are customized to the particular lab activities involved. Since tools like the AD have functionalities that can be extended far beyond an introductory lab, generically available tutorials may confuse or overwhelm students with unnecessary details. A customized tutorial can instead focus students on the elements of the tool they will use the most and demonstrate the tool in a relevant context.

In addition to explanatory resources, students should have a means to quickly contact an instructor or assistant who can answer questions in a reasonable period of time. Not only does this help students who become stuck on simple misunderstandings, but it also assures students that though they are working alone, help is available and they do not need to give up if they encounter difficulties. A consistent protocol in which students always include a picture of their circuit, a screen capture of the software running, and a description of what they have already tried, along with their question will also help the instructor provide useful feedback.

In summary, we found that using the AD to replicate standard lab equipment successfully allowed students to complete basic lab work with electrical circuits outside of the physical lab room. This flexibility was simply a convenience for our students but could be leveraged to allow the course to be offered in more places and formats, possibly including a fully online format. This type of unsupervised lab work requires that students have access to more resources to introduce them to the lab equipment and processes but can also provide significant learning opportunities.

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Appendix A – Portable Lab Kit Contents

Item	**Approximate cost**	**Notes**
Analog Discovery	$260	The older Analog Discovery was used instead of the newer Analog Discovery 2, since sufficient quantities were already available in the lab.
Breadboard	$15	A 1360 contact point was used, although a smaller board would suffice.
Handheld multimeter	$10	
Wire jumper kit	$5	
Alligator clip wires	$5	
Resistors, photoresistor, potentiometer, inductors and capacitors	$5	Approximately 20 resistors, 1 potentiometer, 1 photoresistor, 3 capacitors, and 1 inductor of various standard values were included
LEDs	$5	Several standard LEDs and two 7-segment displays were included
Digital chips	$20	A 7404, a 7408, and two 74143 chips were used in the Lab 7 project
IR proximity sensor	$10	Used in the Lab 7 project
5V battery pack	$5	In this pilot, a 3-AA battery holder was used to provide 4.5V, which was sufficient for the lab activities, although a better solution that provided 5V would be preferred.
USB powered 2-speed fan	$10	Used only for Lab 2. Could be any type of variable load.
Total	**$350**	