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Anchoring student interest in electrical engineering experimental learning

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ANCHORING STUDENT INTEREST IN ELECTRICAL ENGINEERING EXPERIMENTAL LEARNING

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Abstract

The traditional approach to the laboratory component in the first electrical engineering (EE) or electrical engineering technology (EET) course has been based on students learning the use of basic electronic instrumentation, mainly a digital multimeter (DMM) and an Oscilloscope. Through his experience of more than 25 years teaching EET, the author has realized how difficult it is for students in these courses to be fully engaged during the whole term. In these laboratory experiences, students are typically required to do some calculations following the concepts from lectures, and then compare them to the results of simulations and direct measurements on a simple circuit. While this approach gives students the basic skills to use electronic instrumentation, the experimental work is, by design, self-contained, without challenging students to concepts beyond those described in those modules. Furthermore, these initial experiments do not show freshman students the real applications of electronic circuits in electrical engineering (technology).

To combat these limitations, the author has developed a set of exercises that are focused on increasing the engagement of students in their first laboratory course. These exercises also serve to anchor and amplify the initial interest of students in the field of electrical engineering (technology). These new exercises should not be understood as replacing the traditional work focused on developing appropriate and professional skills in the use of electronic instrumentation but to complement them. To this extent, both traditional and new experiments are interlaced through the term and thus exposing students to both approaches. By design, these experiments which are focused on electronic systems instead of electronic circuits, may leave students with several questions about the processes that take place during the experiment. These questions are used by the instructor to provide a roadmap of the future courses in their program of study which will be focused on these specific areas.

Initial assessments show students are satisfied with this approach compared to the traditional approach. While the current pandemic has forced a redesign of these experiences (such as students working alone instead of groups, maintaining physical distance, not sharing equipment, etc.), the results for the Fall 2020 term are consistent with those from previous terms.

Introduction

Experimental work in electrical engineering (EE) and electrical engineering technology (EET) serves a dual function: it reinforces the concepts being taught in lectures and teaches students how to use the different measurement instruments. They also coach students on how to develop good habits in the electrical engineering laboratory that will accompany them into their professional life. Furthermore, the interaction between instructor and students in the laboratory environment is more dynamic compared to lectures and helps to develop a fluid conversation between them [1]. A rigorous yet relaxed laboratory setup is a place in which students can make mistakes without the strong consequences that arise from similar errors in higher stakes assessments such as examination. Also, mistakes made in the lab also serves to avoid them in the future. Ideally, this experimental work should also encourage students to work beyond the minimal requirements for a given laboratory experiment and attempt new approaches on their own. Despite the amount of time that EE/EET students spend in the laboratory environment, the body of research on how this time affects their overall learning is very limited.

The traditional approach to the first experimental course in an EE/EET program begins with building basic circuits in a solderless breadboard and performing measurements of resistance, voltage and current on its different components. These are typically followed by building series circuits, parallel circuits and series-parallel circuits of varied complexity. The next step focuses on verifying the different theorems taught in the lectures such as Kirchoff's Voltage/Current Law, superposition, Thevenin/Norton equivalents, maximum power transfer, etc. This scaffolded approach helps with overcoming the initial difficulties from moving between the abstract concepts of a schematic to building actual physical circuits. In the author's observations, it is very common for students to make mistakes at the time of inserting components in the correct spots of the solderless breadboard. While these errors are initially abundant, they diminish after few weeks of experience. Moreover, these initial circuits help to level the playfield between students who had some exposure to basic instruments such as power sources and digital multimeters in high school or due to personal interest with those for which these are all new concepts [2].

While this approach provides a solid foundation for future work, the activities themselves can be perceived by the students as being tedious, repetitive and not challenging enough. This can be problematic for those first-semester students still unsure of their educational paths [3]. Moreover, by not providing a complete overview of the EE/EET realm they may contribute to those students who are not fully committed to the EE/EET program to drop out and instead to enroll in other programs with more engaging activities [4].

This paper shares the author's experiences in combining these basic laboratory experiments designed to instill good instrumentation and laboratory practices with additional experiments that gives students a broader view of the EE/EET professional careers. These are used to introduce a higher level of creativity and engagement which ultimately increases student interest in the field and persistence to degree students a broader view of the subject while introducing an increased level of creativity that is critical for student retention and success [5].

Traditional experimental work

As stated in the introduction, the purpose of these new experiments is not to substitute the traditional work in a freshman EE or EET course, but to complement it. One needs to find a balance between motivating students towards exploring new concepts that they will encounter in subsequent courses with developing good and sound measurement techniques. Table 1 depicts a traditional 15-week first EE/EET laboratory course along the initial emphasis for each experiment. While some of these can be repetitive, they nonetheless instill good skills at the time of building circuits.

Table 1: Traditional experiments in a freshman EE/EET course.

Week	**Lab Experiment**	**Goals for Lab Experiment**
1	Introduction to Electrical Lab	Safety considerations/guidelines Solderless breadboard connections Initial experience with DMM
2	Measure Resistance	Use breadboard correctly Troubleshoot connections breadboard Use DMM to measure R Verify tolerance of resistors
3	Measure Voltage	Build circuits on breadboard / troubleshoot Connect DMM to measure V correctly
4	Measure Current	Build circuits on breadboard/ troubleshoot Connect DMM to measure I correctly Internal DMM fuse and safety
5	Series Circuits	Verify concepts from lecture Build circuits with multiple components
6	Kirchoff’s Voltage Law & Introduction to Simulation	Apply KVL to series circuits Compare calculations, simulations and experimental results
7	Parallel Circuits	Verify concepts from lecture Build circuits with multiple components
8	Kirchoff’s Current Law	Apply KCL to series circuits Compare calculations, simulations and experimental results
9	Series-Parallel Circuits	Challenge to build more complex circuits Compare calculations, simulations and experimental results
10	Superposition	Verify concepts from lecture Compare calculations, simulations and experimental results
11	Thevenin/Norton Equivalent	Develop familiarity with calculations Compare V/I from two equivalent circuits
12	Loading Effects	Verify concepts from lecture Careful use of voltage divider

13	Maximum Power Transfer	Verify concepts from lecture Calculate and simulate power values
14	Introduction to Oscilloscope	Initial exposure to new instrument Initial exposure to AC signals
15	Capacitor Charge/Discharge	Verify concepts from lecture Different trigger modes in DSO to capture signals

New and High-impact experimental work

In order to increase the level of creativity needed to fully engage students in the EE/EET field since day one, the author has developed a series of additional activities and. Some of these activities can be easily incorporated in the already existing traditional experiments while some others will require their own dedicated time. It is important to clarify to the students that they will not fully understand all the parts and processes that are part of the experiments and their main goal is for the students to investigate what is happening. This is done on purpose to elicit their questions and familiarize them with thinking about different possibilities [6]. Table 2 summarizes these experiments -which will be described later- along where the author has placed them in the sequence of traditional experiments from Table 1. The author has chosen these experiments because of their low cost and general availability of parts and materials.

Table 2: Summary of additional, high-impact experiments or activities designed to engage freshman students .

Location	**Lab Experiment**	**Goals for Lab Experiment**
Initial	Microcontroller for Electromyograph system	Exposure to complete electronic system Link to future courses in academic program
With #3	Effects of power on resistors	Experience excess power on a component
After #4	Other power sources: solar cells	Measure V, I in alternative source Experience ‘real world conditions’
Anytime	Identify components from consumer printed circuit boards	Introduce ‘real world components’ Exposure to SMD devices I/O connections
After # 10	Visualizing the codes from a TV remote control	Introduction to optoelectronics
After # 13	Basic oscillator with a 555 timer	Basic use of LEDs in circuits Initial experience with integrated circuit Oscilloscope settings
Final	Software Defined Radio: FM radio and codes from a vehicle fob.	Modern technologies Link to future courses in academic program

Obviously, the introduction of these seven new experiments shown in Table 2 needs to coexist with those designed to teach basic experimental skills within the 15-week period for a semester used by most institutions. However, it is not difficult to either incorporate some of these activities into already existing laboratory experiments or to combine some of those already existing to free up time for the new ones. This is an area in which instructors should make their own decisions based on their experiences. The following paragraphs briefly describe in more detail those activities.

Microcontroller for Electromyograph.- This is the first experiment that freshman EE/EET students taught by the author encounter after a brief overview of the electrical engineering laboratory and a briefing on safety protocols. The main goal of this activity is for the students to experience a complete electronic system consisting of analog and digital electrical systems involving both hardware and software. Figure 1 shows a picture of the system that is based on a low-cost Arduino microcontroller and a low-cost EMG sensor. The instructor stresses to the students that although all these components and parts are new to them, they will acquire the knowledge to design a similar system by the end of their senior year. This is a system in which surface electrodes attached to the arms are used to record the electrical signals generated by flexing the muscles on the arms. This electrical signal known as 'electromyograph' or EMG is then digitized fed into a microcontroller that responds by moving a small servo motor. Students are also guided on visualizing the analog EMG signal on the oscilloscope with its parameters set up by the instructor. The instructor briefly describes the purpose of this instrument and mentions that a further experiment will explore the use of the different settings on the oscilloscope in more detail. While this activity is aimed to engage students in the discipline, it is also used to (1) map out how these different subsystems relate to the EE/EET courses in their academic program and (2) discuss the societal impact of electrical engineering in improving quality of life for individuals with certain disabilities. Instead of a traditional lab report, students are required to submit a short paper identifying courses in their curriculum that will cover the different parts used in the experiment as well as humanitarian benefits of electrical engineering in general [7].

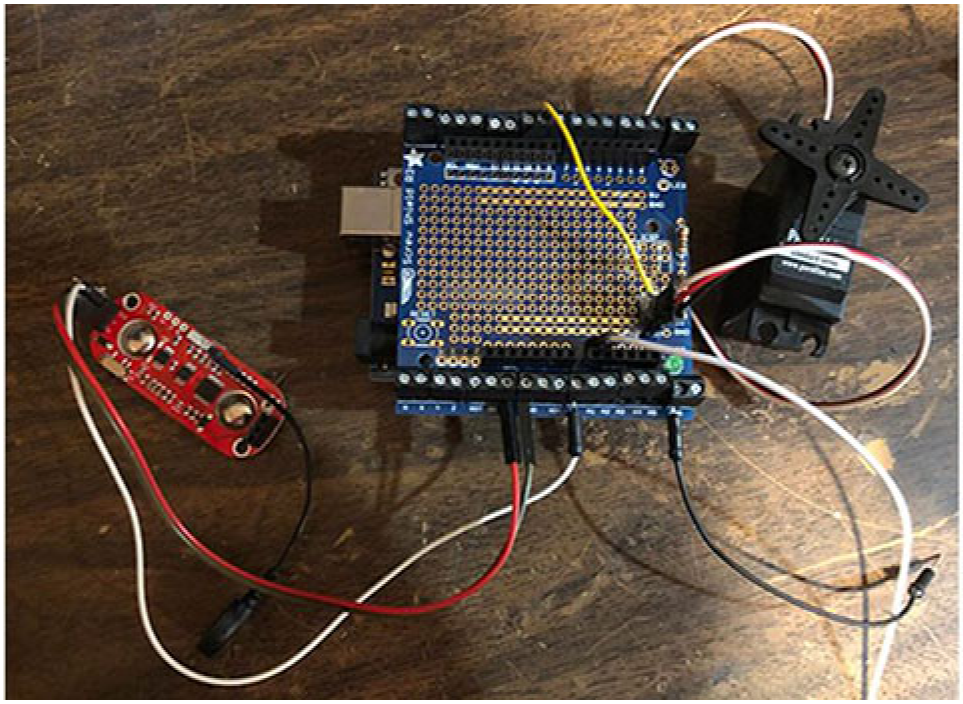

Figure 1: Low-cost microcontroller-based EMG system

Effects of power on resistors.- Introductory lectures on electrical engineering discuss power ratings of resistors as well as the use of high-power resistors in specialized applications. However, other than calculating power dissipation in homework assignments and exams, this is a concept that tends to be forgotten in the laboratory. To overcome this shortcoming, the author created a final activity in the experiment used to measure voltage in circuits by requiring the students create a simple voltage divider made of a 10 **Ω** power resistor and a 100 **Ω**, 1/8 W resistor. Students are then asked to slowly increase the voltage of the power source measuring the voltage across one of these resistors and estimating the temperature of the 100 **Ω** 1/8 W resistor using a contactless thermometer. Students are able to measure the increase in temperature of this resistor, visualize the discoloration associated to this increase in temperature and, if they continue with the experiment, the resistor burning. The instructor finishes reminding the students that if they ever smell a similar odor in a future circuit, they need to quickly shut down the power source. This is a 10-minute activity that has a positive impact on students as they experience a 'real world' failure in a controlled environment.

Other power sources: Solar cells.- This experiment takes place after students have learned how to measure voltage and current in basic resistive circuits. The students are asked to connect a single solar cell and then a combination of two cells in series and later in parallel, with each cell measuring approximately 30 cm^2. For each configuration, students are required to measure the voltage and the current flowing through a load for which they change its value. This experiment serves for the students as an introduction to alternative energy sources and to make the transition from the abstract concept given by the schematic to the correct connection of the solar cells, the load and the DMM. Because this experiment takes place outdoors it also serves to spark+ curiosity from students enrolled in other engineering majors. Furthermore, students are introduced to the challenges of making measurements in 'real world conditions' in which the passing of a cloud alters the recorded data which forces the students to make decisions on whether to continue with the measurements or start over. A drawback of this experiment is its weather dependency which causes that the instructor can never be sure if this experiment will run, especially when living in areas in which weather changes rapidly.

Identifying components from consumer Printed Circuit Boards (PCBs).- The author has run this activity during the lecture period by giving each student or group of students a PCB (pre-COVID) or a picture of the PCB (during COVID) salvaged from discarded consumer electronics. An example of such boards, focused on traditional 'through-the-hole' components in shown in Figure 2. Students are asked to identify as many components as they can and share these with the rest of the class. The instructor uses this time to discuss with the students how PCBs are created and populated, the differences between 'through-the-hole' and 'surface mount' components which generates a discussion on the differences between prototyping and creating PCBs for commercial purposes. The instructor also places a special emphasis on the different connectors that are on the PCB, a component that is often overlooked but it is critical for devices to work correctly.

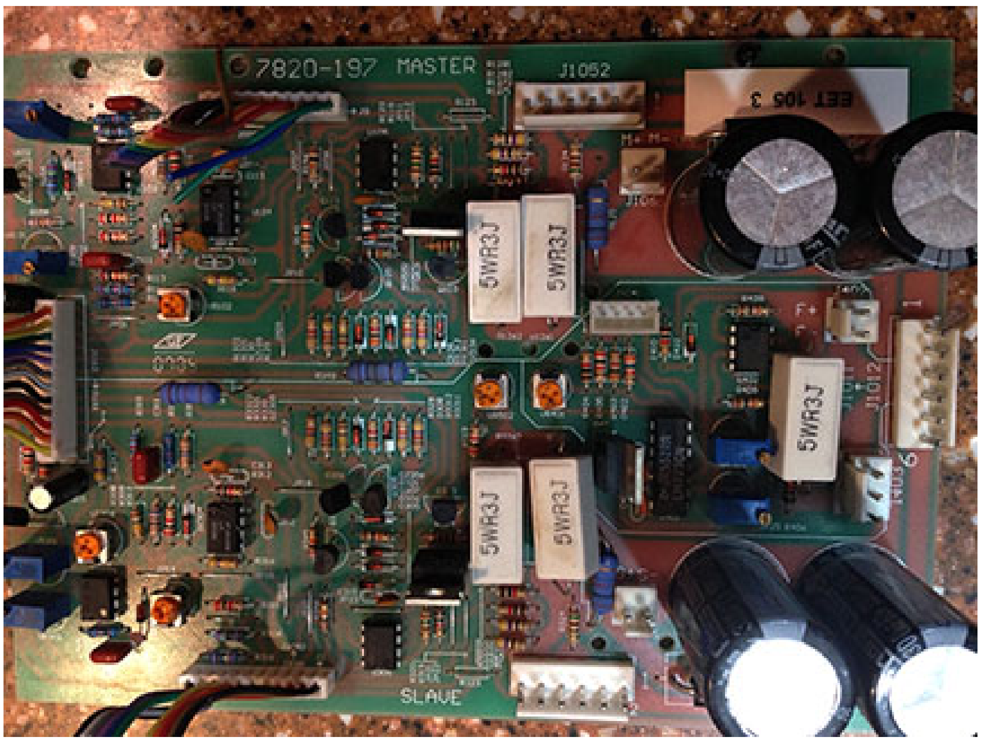

Figure 2: Commercial PCB used by students to identify components.

Visualizing the codes from a remote control.- This experiment serves to introduce concepts of optoelectronics and to help the students become even more familiar with the oscilloscope. The author has created a circuit based on an infrared (IR) photodiode that acts like the receiver for the remote control (there are also several kits available in the market). Students are asked to configure the oscilloscope to visualize the digital signals at the output of the receiver and identify similarities among the different codes generated by pushing the different keys in the remote control as shown in Figure 3. Students are also asked to modify the angle of incidence between transmitter and receiver that results on a code being generated which results on mapping out the allowable area for the remote control to work correctly. They are also asked to experiment on how the signals are affected by distance between transmitter and receiver, reflections, etc.

Figure 3: Codes generated by a TV remote control

Basic Oscillator with 555 timer.- Freshman EE/EET students typically do not have the opportunity to work with integrated circuits. This experiment aims to expose students to these devices from a user's perfective stating that in future courses they will learn how to design circuit with these integrated circuits. The experiment also serves to share with the students how ICs are identified by different manufacturers and for them to increase their skills on populating the solderless breadboard from a schematic, this time containing an integrated circuit. Two LEDs with different colors can be used to visualize the output of the 555 timer for which students can change its frequency with a potentiometer.

Introduction to Software Defined Radio.- Software Defined Radios (SDR) have created a revolution in the world of electronic communications using radio frequency. SDR substitutes the traditional hardware-based subsystems used in receivers with software, thus making the computer the workhorse in SDRs. This gives SDR extreme flexibility in reconfiguring them to detect different signals. This experiment gives students the opportunity to be exposed to a cutting edge technology from the user's point of view. More importantly perhaps is that the software displays the signals in the frequency domain which gives students access to an extremely inexpensive spectrum analyzer, an instrument that otherwise they would not be able to use in a freshman course. With a basic antenna as simple as a piece of wire, students can detect and decode FM radio or the RF signals generated by their vehicle fobs, garage door openers and similar common equipment.

Preliminary Assessment Results

The author has been developing and introducing some of the laboratory experiences described above for several years. It has not been until recently that he decided to formalize the process by developing a comprehensive assessment plan to evaluate student perceptions of this approach and their engagement in the program. This assessment protocol was approved by the Institutional

Review Board of Penn State as listed at the end of this paper. The first formal assessment occurred after the Fall 2019 term and was focused on comparing a subset of traditional and new experiments. A second focus of this assessment was to better understand student perceptions on the Microcontroller and EMG system. The author had planned to continue and expand the assessment during the Fall 2020 term. However, at that time, the COVID pandemic was in full swing. While the author was able to continue with in-person offering of these laboratories, there were restrictions put in place by Penn State to limit the spread of the virus. The restriction that had a major impact on the assessment process was that students had to work individually instead of in groups which prevented comparing results from these two terms as the conditions in which students had to work were vastly different, also considering maintaining a physical distance among them, universal masking and sanitizing equipment. Furthermore the length of the on-campus activities during the term was also reduced which did not allow for the full set of hands-on, experimental labs.

Within these limitations, it was possible to perform some limited assessment on the effect of the new laboratory experiences. Table 3 shows student comments after performing the initial Microcontroller and EMG system laboratory experience.

Table 3: Student comments after EMG system laboratory experience.

Student comments after experiment
I thought the lab was interesting and fun to do while at the same time teaching and familiarizing us with the different devices, hardware, and software that go into making a lab like this successful.
The most interesting part about this lab was watching the oscilloscope and software on the computer produce the voltage readings when we contracted and retracted our muscles.
I find it fascinating that our bodies produce electricity and we have the ability to measure the amount of electricity that is flowing through our bodies.
The most interesting part of this lab was the fact my muscles generate an electrical current that can be measured, manipulated in order to perform a task, even as simple as turning a servo motor.
I like that this experiment shows a useful technology that’s beneficial to many.
The electrodes were the most interesting part of this lab. If the muscle contraction controlled a fan or turned on a light this lab would be improved.
I think the ability for the impulses of your arm to move the plastic piece on the motor was the most interesting part of this lab.
The only thing I disliked about the lab was not being able to fully understand how the EMG works, it would be nice to get a full explanation of exactly what goes into the circuit board before having to use it.

> I liked being able to compare my electrical signals with those of my group to see how everyone's muscles are different. My signal was totally different from those of my group.

Overall students show a high degree of satisfaction after this first laboratory experience that attempts to engage them in the EE/EET field and is used to explore how the different topics are going to be covered in future courses in their curriculum.

Students were also asked to respond to a survey identifying (1) the two laboratory experiences which they found more; (2) the laboratory experiences that they believe would be more useful for their future studies in their academic program; and (3) the laboratory experiences they found most challenging. These results are shown in Table 4.

Table 4: Student perception on traditional and new laboratory experiences.

Most interesting lab experiences	
EMG System	24 %
Solar Cells	20 %
Optoelectronics	18 %
Simulation	11 %
Series-parallel	9 %
Measuring R,V,	7 %
AC Signals/DSO	7 %
555 Oscillator	4 %

Lab experiences most useful for future courses	
Series-Parallel	25 %
AC Signals /DSO	25 %
Simulation	22 %
Optoelectronics	17 %
555 Oscillator	11 %
Measuring R, V, I	0 %
EMG system	0 %
Solar Cells	0 %

Most challenging lab experiences	
555 Oscillator	30 %
Solar Cells	27 %
Series-Parallel	13 %
AC Signals/DSO	13 %
Optoelectronics	10 %
EMG System	3 %
Simulation	3 %
Measuring R,V.I	0 %

The results from Table 4 show that students display a strong interest in the new laboratory experiences as they provide them with an overall overview of the EE/EET field. It is also interesting to note that, despite this interest, students are also aware that being proficient in simulation, analysis of circuits and using the digital sampling oscilloscope (DSO) are concepts that will help them in future courses as shown in the middle column. The major challenges in the labs, which are centered in the experiences with Solar Cells and the 555 Timer are attributed to translating the abstract concept of a complex schematic to the physical population of components in the solderless breadboard.

Open-ended comments from the students indicate that the majority of them found the laboratory experiences enjoyable although about half of the students surveyed indicated that the laboratories focused on measuring resistance, voltage and current were 'boring'. More than 90 % of the students also indicated that they felt very confident in using the DMM, while about 70 % of them also indicated confidence in using the DSO. Perhaps a more telling aspect is that half of the students indicated interest in purchasing a DMM for their own use and a couple of them were also considering purchasing an oscilloscope for personal use.

Conclusion

This paper presented a set of laboratory experiments for an introductory course in an EE or EET program that are designed to increase student engagement which ultimately leads to persistence towards degree completion. These experiments were designed to show students different areas of their future chosen profession while accepting and acknowledging that students did not have yet the knowledge to fully understand the different processes that are taking place. This is also use useful to guide students through the different courses in their degree program that will over these specific areas in detail.

The preliminary assessment of these experiments, combined with the traditional approach indicate a high level of student satisfaction with the laboratory portion of the course. However the ongoing pandemic caused a disruption on how the experiments were performed (single student vs groups of 2-3 students for example and elimination of several in-person weeks) which does not allow for the continuous assessment of this work among consecutive semesters. While the development of these new, high-impact experiments has reached a steady state, future efforts in this area will be focused on the assessing their impact on student learning. This will be done by developing an assessment tool that can be used independently of the experiments being performed alone or in groups of students. Furthermore, the author also intends to collaborate with the instructor of the subsequent course to obtain direct data for assessing student performance in the electrical laboratory.

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