Electrical Engineering Core Course Laboratory Creation for Non-STEM Majors

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Abstract – **Practical laboratory exercises improve student understanding and motivation for learning abstract engineering concepts. The Department of Electrical and Computer Engineering at the United States Naval Academy (USNA), a four-year undergraduate institution, is tasked with teaching all students a course in electrical circuits and power. The course aimed at non-STEM majors includes a weekly two hour laboratory period to assist in drawing out these abstract concepts. The instructors for an Electrical Engineering circuits and power course for non-STEM majors jointly developed and troubleshot a series of five real-world, laboratory experiments. These experiments are intended to demonstrate real world skills and applications of the abstract concepts covered during the class.**

Index Terms – non-STEM instruction, Electrical Engineering, STEM experiments, Real World Skills and applications.

INTRODUCTION AND MOTIVATION

The United States Naval Academy (USNA) is an accredited, four-year, undergraduate institution. The academic program is focused on science, technology, engineering, and mathematics (STEM) information such that all of the students who graduate from USNA receive a Bachelor of Science (B.S.) degree. The intent of this program is to provide our nation with an officer corps for our Navy and Marine Corps that is technically proficient. However, USNA has a number of majors that are in non-STEM curricula including Arabic, Chinese, English, History, and Political Science. In order to satisfy the requirements for a B.S. degree, these students take courses in many STEM areas as a part of their core curriculum.

One of the courses in the core curriculum is EE301, Electrical Fundamentals and Applications. This course introduces AC and DC circuit theory and power systems. The topics covered include steady state and first-order transient voltage, current, and power; impedance matching; filters; transformers; motors; generators; and three-phase power distribution. Laboratory exercises are included in this course to improve student understanding of the concepts. The original exercises for the class had been in use for at least a decade and adjustment of the presentation and topics covered was required in order to reengage student interest.

DEVELOPMENT OF NEW EXERCISES

The existing laboratory exercises covered diverse topics in a series of 21 exercises set to run in a particular order. The exercises match up with the lecture portion of the course to reinforce the topics already presented. The list of topics covered in those labs are as follows:

- Introduction to the Laboratory Bench
- DC Kirchhoff's Voltage Law
- DC Voltage Divider Rule and Reference Voltage
- DC Kirchhoff's Current Law
- DC Series and Parallel Circuits
- DC Nodal Analysis
- DC Maximum Power Transfer
- Introduction to Oscilloscopes and Function Generators
- Capacitor Transients
- Impedance
- Series AC Circuits
- AC Series and Parallel Circuits
- AC Power
- AC Thevenin Equivalent Circuits
- AC Maximum Power
- Power Factor Correction
- Filters
- Transformers and Reflected Impedance
- Introduction to DC rotating machines
- Introduction to Three Phase AC Loads
- Three Phase AC Generator

A number of labs were replaced with new laboratory exercises. The topics chosen for these new exercises were MintyBoost Kit: A Battery Powered USB Charger, Coil Gun Capacitor Transients, Home Switch Wiring, AC Power Meters, and DC Skateboard Machine. These labs would replace the time dedicated to the DC Series and Parallel Circuits, DC Nodal Analysis, Capacitor Transients, Impedance, and the AC Maximum Power laboratory exercises. These exercises were chosen for replacement either because the new labs covered these topics or the material covered in these labs could be merged into other existing exercises. With the topics chosen for the new exercises and the exercises they would replace identified, the new exercises were developed.

I. MintyBoost Kit: A Battery Powered USB Charger

The intent of this laboratory exercise is to give EE301 students an opportunity to build an example of a useful circuit that can be used to charge their cell phones and also reinforce circuit concepts. This laboratory exercise uses the Adafruit MintyBoost Kit, an open-source hardware charger. During this exercise, many students are exposed to a printed circuit board (PCB) and soldering for the first time. The students assemble a battery powered USB charger that uses two 1.5 V batteries in series to produce a 5 V output in the small space of an Altoids gum or mint tin. Students learn the importance of ensuring they insert the correct sized resistor into the PCB in the appropriate location. Student understanding of the consequences of an unwanted short circuit is reinforced as they learn the skills involved when cutting the leads as components are mechanically and electrically attached to the PCB and soldered in place. For a successful charger, the attached components board must fit in the available Altoids mint tin. Several of the components must be installed in the correct orientation for proper operation (diodes and integrated circuit) or to ensure they are not damaged during normal operation (capacitors). Upon completion of the circuit, the students install two AA batteries and measure the output of the circuit to ensure the 5 V required by the USB specification is met. Students then have the opportunity to try charging their phones, cameras, or music devices. Pictures of a completed kit are included in Figures I, II, and III.

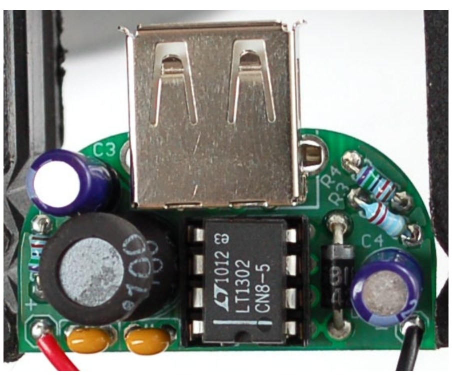

FIGURE I
COMPLETED MINTY BOOST KIT PRINTED CIRCUIT BOARD FRONT [1]

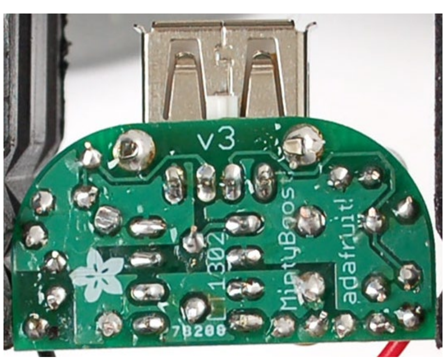

FIGURE II
COMPLETED MINTY BOOST KIT PRINTED CIRCUIT BOARD BACK [2]

FIGURE III
COMPLETED MINTY BOOST KIT [3]

Upon completion of the assembly, the students are asked a number of questions. These include questions about the input and output voltage, the lifetime of batteries installed in the circuit, the power provided by the circuit, a cost calculation for that power, and why the integrated circuit is installed on a socket. The exercise is also used as an opportunity to show that power conversion circuits are in use today that permit the variation of DC voltages through highly efficient methods. Students have responded positively to the lab and there was even a report of one student using the completed kit to charge their cell phone during the extended power outages in Puerto Rico following Hurricane Maria in September 2017.

II. Coil Gun Capacitor Transients

The intent of this laboratory exercise is to demonstrate first order capacitor transient behavior while providing the opportunity to launch a projectile. The students perform pre-lab calculations to determine the voltages and time constants for the highlighted circuits in Figures IV, V, and VI. These circuits provide the opportunity to witness a capacitor charging transient and two different capacitor discharging transients. The pre-lab calculations begin with calculating the transient voltage on the capacitor for the circuit in Figure IV. This includes noting that the time to steady state voltage on the capacitor is 3.44 s, which is not a long time, but does require some patience. The second calculation for the capacitor voltage discharge equation is for the circuit in Figure V. The calculated time to steady state of 22.5 ms indicates how quickly the pulse occurs after initiation. The safety circuit discharge assumes the voltage sources are disconnected in Figure VI. The steady state time of 2.5 minutes provides a good indicator for how long the students should wait after deactivation of the supplies before disassembling the circuit.

The lab procedure begins with several of the components for the coil gun already created. The students build the inductive coil by wrapping a pre-measured length of insulated copper wire around an ink pen casing with the ink and other innards removed. A magnetic projectile (a 1 cm long iron wire from a coat hanger) is loaded into the pen so the coil can magnetically couple to the wire. When the capacitor is discharged into the coil, a transient current is created. This current turns the coil into a magnet for the time the current is present. The lab does not discuss the second order effects of the inductor-capacitor circuit, instead it assumes that the inductor acts like a resistor. The coil magnet is only active for the time constant of the pulse, so the attractive force of the coil on the coat hanger wire is a pulse as well. This is sufficient to accelerate the wire, but not slow it down when the wire passes the center of the coil.

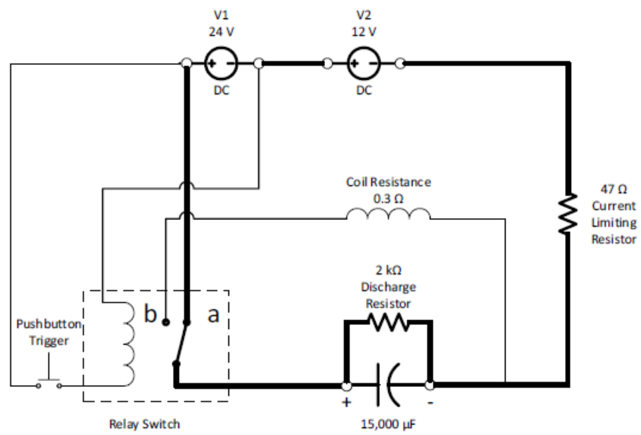

FIGURE IV
CHARGING CIRCUIT FOR THE COIL GUN CAPACITOR

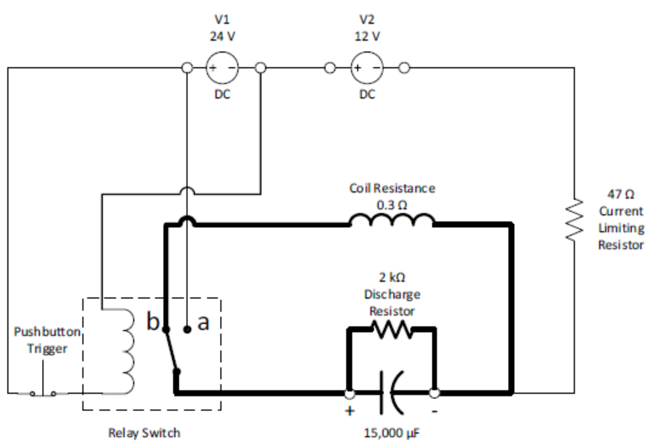

FIGURE V
DISCHARGING CIRCUIT FOR THE COIL GUN FIRING

The students are provided with a capacitor of the appropriate size and voltage rating. A safety resistor is attached to the terminals to ensure the capacitor is not charged during assembly handling. A trigger and relay box is also provided with labelled connection points. The students assemble the appropriate components and connect them using banana plug terminated wires according to the circuit in Figure VII. Upon completion of the assembly, the students fire the coil gun a number of times to see how the circuit works. After enjoying the ability to throw small metal objects around the classroom remotely, the students learn how to use the trigger menu on their oscilloscopes to capture the voltage transients for the discharging and charging of the capacitor. The students then measure the time it takes for the voltage to reach steady state in each of these transients. The final transient they measure is the long time it takes for the safety circuit to discharge the capacitor to a safe voltage. Setting this up and waiting the time required to capture the transient (approximately 4 minutes) can be frustrating for the students, but it does provide them with a chance to see how long it can take before it is safe to touch charged capacitor banks and reinforces the role of resistor size in RC transient circuit time constants.

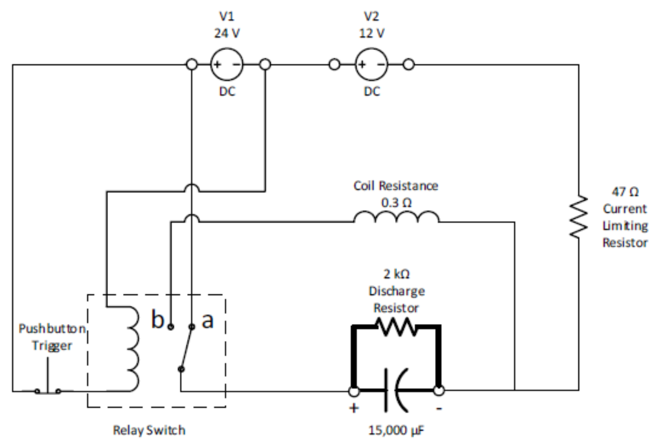

FIGURE VI
DISCHARGING CIRCUIT FOR THE CAPACITOR SAFETY

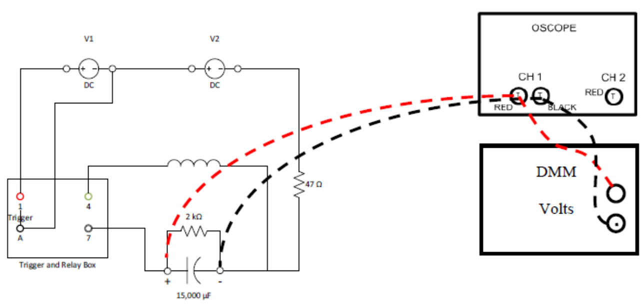

Figure 2

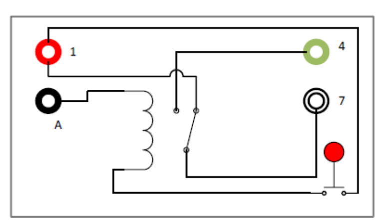

FIGURE VII
WIRING DIAGRAM FOR COIL GUN CIRCUIT

Students leaving this lab are often excited about what they have been able to accomplish and can readily link it to the military aspects of the USNA education. This lab is enjoyable for the students because it links the relatively simple assembly, analysis, and clean-up of the laboratory equipment to future career applications.

III. Home Switch Wiring

The intent of this laboratory exercise is to review the concepts of schematics and wiring diagrams, gain hands-on wiring experience, and review the concept of ground and nodal voltages. The students make a schematic diagram of a duplex outlet and switch from a wiring diagram. The lab discusses the color scheme standard for home wiring to familiarize the students with electrical code requirements and some of the reasons behind code requirements. The wiring diagram of the circuit the students build is shown in Figure VIII. Initially, the students were required to make their own wiring diagram for the circuit; however, student complaints and instructor frustration with the difficulty of explaining the circuit led to the inclusion of the diagram in Figure VIII. The assembled circuit will look like the wired boxes, outlet, and switch shown in Figure IX. This laboratory exercise is straightforward and provides an approachable hands-on experience for the students near the middle of the semester.

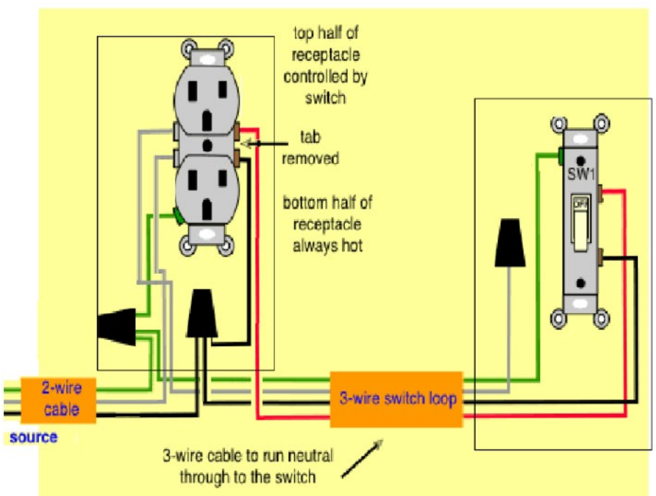

FIGURE VIII
WIRING DIAGRAM OF THE DUPLEX OUTLET AND SWITCH [4]

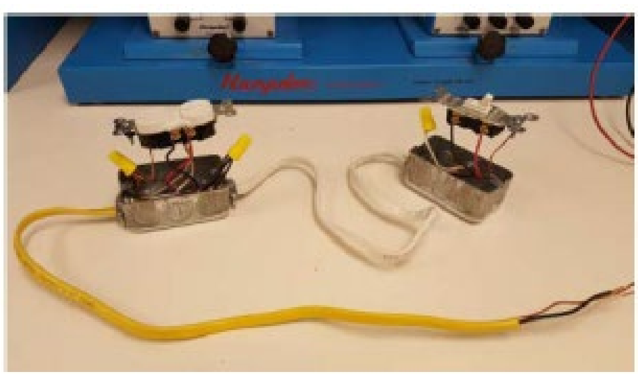

FIGURE IX
THE ASSEMBLED CIRCUIT

The lab procedure begins with the students preparing the wiring boxes for the cables to enter in clamped containment. The students strip the cable to expose the wires and then strip the ends of the wires for the connections. The students discover that the nodes in the wiring diagram are locations where wire nuts are used to connect multiple wires. The use of two wires that only run inside the box for the duplex outlet is a revelation to many of the students. The continuity checks and ground checks performed on the circuit before the testing with a light bulb are also a good chance for the students to experience a sense of accomplishment. The lab concludes with questions about the wire color meanings, why the ground wire is used, and a discussion of the construction of the enclosure boxes.

IV. AC Power Meters

The intent of this laboratory exercise is to reinforce the concepts of the power triangle for AC circuits. A P3 P4400 Kill A Watt brand electricity usage monitor (power meter) is used to measure the real and apparent power from three different load combinations. The three different loads are pictured in Figures X, XI, and XII. The students learn about real, reactive, and apparent power by relating the quantities through measurements taken on the power meter.

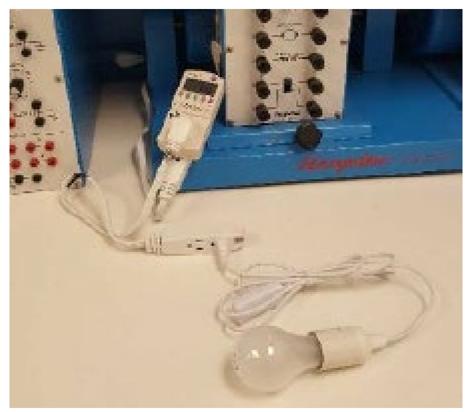

FIGURE X
REAL POWER LOAD CONSISTING OF A LIGHT BULB

FIGURE XI
LAGGING POWER FACTOR LOAD CONSISTING OF A FAN

FIGURE XII
LAGGING POWER FACTOR LOAD CONSISTING OF THE COMBINED LIGHT BULB AND FAN

The lab procedure begins with the students measuring the real power, apparent power, and power factor of the light bulb as shown in Figure X. The light bulb is mostly a resistive load, so the real power and apparent power should match, with a power factor of 1. The students then measure the real power, apparent power, and power factor when a fan is turned on to maximum load. This results in a power factor of approximately 0.6 and the need to calculate the reactive power. The students then estimate what they would expect for the real power, reactive power, and power factor when the loads are combined and measured by the Power meter. The students are often surprised by the two-dimensional math requirement and how it impacts their load measurements. The students confirm their measurements and look for the error between their calculated numbers and measured numbers. This laboratory exercise provides an excellent opportunity to see how the power triangle impacts real life load decisions.

V. DC Skateboard Machine (Electric Vehicle Testing)

The intent of this laboratory exercise is to review the principles of DC motors and demonstrate electric vehicle concepts. An oscilloscope is connected to a DC electric skateboard to measure the voltage at the motor and the current to the motor through a current clamp meter. The instrumented electric skateboard is shown in Figure XIII. The students learn how load impacts the current and voltage signals to a DC motor while moving and steering an electric vehicle that they can ride.

The lab procedure begins with the students measuring the voltage and current waveforms from the electric skateboard's motor on an oscilloscope. The skateboard motor is run with the wheels in the air to enable stationary testing. The students observe what happens to the voltage and current applied to the motor when the motor is commanded to run at different speeds. The students then apply a load to the motor by placing their finger on the rotating skateboard wheel. The load on the wheel is reflected on the oscilloscope by an increased current with a lower frequency oscillation of the waveform due to the slower rotational velocity of the wheel.

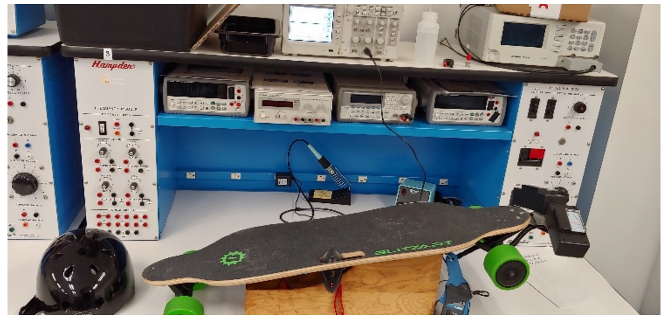

FIGURE XIII
ELECTRIC SKATEBOARD WITH INSTRUMENTS

The students then sit on the skateboard for moving tests. They are able to observe the changes in voltage and current from the meters on the skateboard as they command different speeds. The spike in current as the electric vehicle starts moving, enforces the reality of the back emf and the high current that enables acceleration of the motor.

STUDENT FEEDBACK

The laboratory exercises have been used in the class during both the spring and fall semesters since the Spring semester of 2018. At the end of each semester, the students are asked a number of questions about the class on Student Opinion Forms (SOFs). These SOFs included questions about the new laboratory experiments during this timeframe. The first set of questions asked whether the student agreed that each lab was educational, engaging, and relevant and should be continued next year in place of a more traditional lab on a similar topic. The responses for each lab are shown in Figures XIV through XVIII. The charts show that the students feel these labs are useful and should be continued. The high number of N/A responses for the DC Skateboard Machine lab are because this lab is performed late in the semester and the students may respond to the SOF before they have performed the lab.

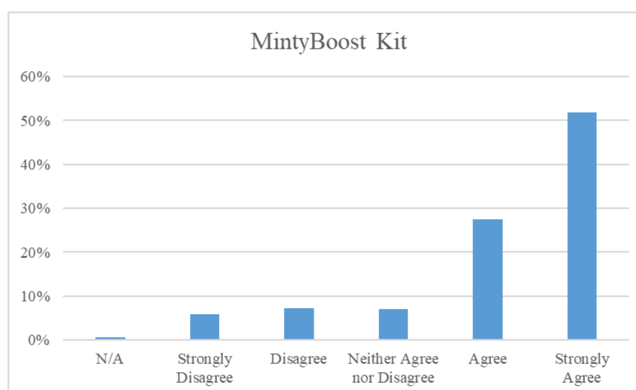

FIGURE XIV
CHART OF PERCENTAGE RESPONSES FOR THE MINTYBOOST KIT LAB

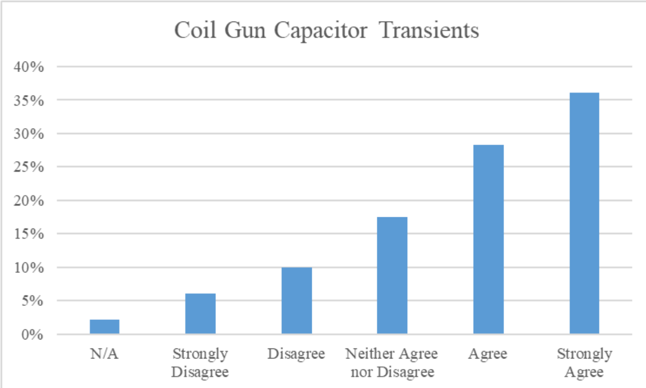

FIGURE XV
CHART OF PERCENTAGE RESPONSES FOR THE COIL GUN CAPACITOR TRANSIENTS LAB

The Coil Gun Capacitor Transients lab has the lowest percentage for agreeing with the benefits of the lab. This indicates that the lab is difficult to link to their experiences and may indicate a need to more thoroughly explain the relevance during the lab period.

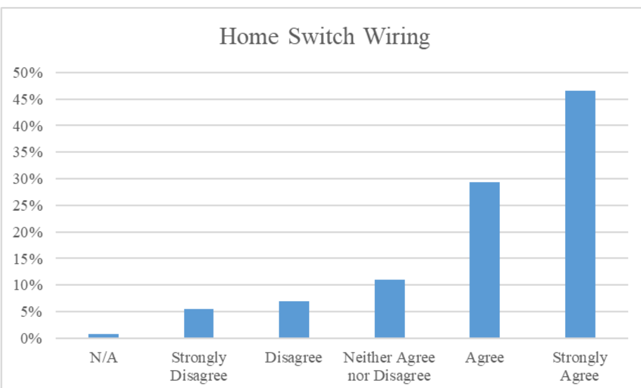

FIGURE XVI
CHART OF PERCENTAGE RESPONSES FOR THE HOME SWITCH WIRING LAB

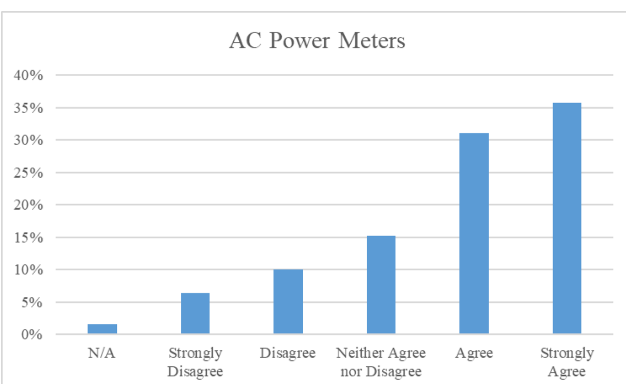

FIGURE XVII
CHART OF PERCENTAGE RESPONSES FOR THE AC POWER METERS LAB

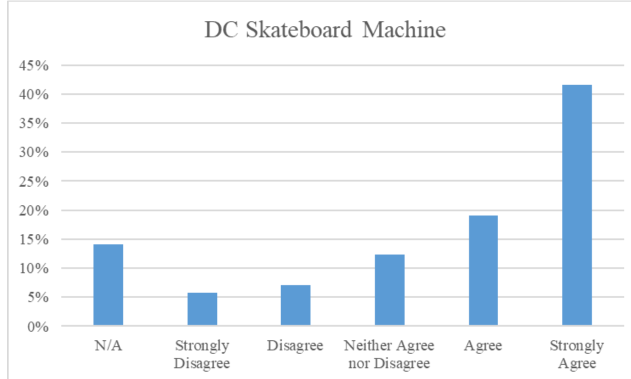

FIGURE XVIII
CHART OF PERCENTAGE RESPONSES FOR THE DC SKATEBOARD MACHINE LAB

The students were also asked to rank these new labs in the order that they believed the labs to be most educationally valuable. The students ranked the five labs in order. The highest ranked lab received a score of 5, with subsequent labs receiving scores of 4, 3, 2, and 1. If a student did not rank the lab, that lab received no points from the student. If a student stated the lab was not valuable, a score of -1 was assigned. If the student stated that all other labs were the same after ranking two or three, the other labs received no score. The results of these rankings are shown in Figure XIX. The students felt strongly that the MintyBoost Kit and the Home Switch Wiring labs were valuable and placed the least value on the Coil Gun Capacitor Transient Lab. This matches the impression that the students had in the previous charts. What is surprising is how well the DC Skateboard Machine lab ranked despite the number of students who had not performed the lab. That lab appears to have resonated well with many of the students who were able to do it before the SOF, but was still lagging the MintyBoost Kit and the Home Switch Wiring labs.

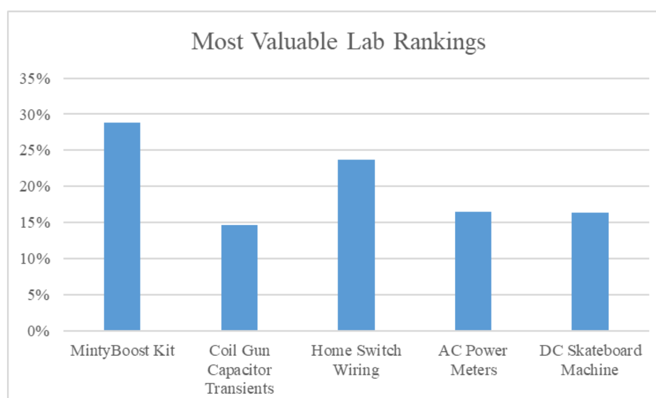

FIGURE XIX
CHART RANKING THE LABS FOR RELEVANCE

CONCLUSIONS

In this paper, five laboratory exercises that were developed and utilized in an Electrical Engineering class for non-STEM majors were presented. These exercises were created to bring relevancy to the material for the students, update the curriculum with newer technologies, and allow the students to take home something they created. The results of student polling indicate that the laboratory exercises have been well received and are improving student interest in these topics. These exercises continue to be used in the course at USNA with an ongoing positive response from the students. Methods to refresh additional course laboratory experiments continue to be investigated as additional technology is developed.

ACKNOWLEDGMENT

The authors would like to acknowledge the contributions to the development of these labs of the hundreds of Midshipman students who performed them. Each semester, the labs were improved by feedback from the students as they performed the labs and showed their enthusiasm for the various parts of the labs. The authors would also like to acknowledge the contributions of the professors and instructors who adjusted from their comfortable, known lab experiments to try these new labs with the students. Those instructors are: Daniel Opila, Christopher Martino, Jedediah Lomax, Brent West, John Stevens, Joseph Parker, Eric Ransom, Jesse Atwood, Michael Gardner, Seth Jones, Andrew Iobst, Christopher Perez, Kyle Milden, Andrew Smith, Steven Yee, Jacob Springer, J. Spence Lankford, Miguel Martinez-Ibanez, Antonio Mayo-Lopez, Gregory Coxson, Christopher Anderson, R. Brian Jenkins, Louiza Sellami, and Deborah Mechtel

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