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Preliminary assessment of ”ECE Engineering Laboratory” course for a redesigned first-year engineering curriculum

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Preliminary Assessment of "Electrical and Computer Engineering Laboratory" course for a redesigned first-year engineering curriculum

Abstract
Complete Research Paper: Engineering programs nationwide have redesigned their first-year engineering curriculum to improve retention rate and to foster students' success. Wentworth Institute of Technology has revised the first-year engineering curricula, for 8 engineering programs, in 2021. This paper presents the designing process of a first-year laboratory course in electrical and computer engineering that was offered for the first time in Fall 2022 as part of the redesigned first-year engineering curriculum. The course aims at providing engaging, active, and hands-on academic experience and at exposing first-year students to their chosen engineering discipline to enhance first year students' performance and motivation to continue in an engineering degree. The effectiveness of the laboratory course has been assessed using data from course assessment and from students' feedback through an exit survey. Preliminary results show a positive impact on students' performance and students' success. Insights from data analysis will be used as a metric for consideration for program continuous improvement.

Index Terms – First-Year Students, Retention, Success, Engineering Laboratory.

1. Introduction

The School of Engineering (SoE) at Wentworth Institute of Technology (WIT) in Boston, MA, consists of 8 Engineering programs. Before Fall 2022, these majors had a common first-year curriculum for Biological, Biomedical, Civil, Computer, Electrical, Electromechanical, General and Mechanical Engineering with 32 total credits evenly distributed between Mathematics, Science, English, and Engineering [1].

The impact that the first-year engineering programs have on the overall quality of student retention and student success has been investigated [2]-[4]. Studies have demonstrated how persistence in an engineering program can be drastically increased through the presence or introduction of Curricular, Co-Curricular, and Extra-curricular activities [5]. This has motivated many academic institutions to reimagine their first-year engineering programs [6], [7]. Kansas State University introduced "Engineering Launch" program among incoming first-year engineering students in the College of Engineering to help prepare students who scored low on a math placement exam to be successful in Calculus I [8]. California State University introduced a first-year engineering design course in which students have to design, build, and test a device. In addition, they have to participate in a competition [9]. Alabama A&M University re-designed the first-year engineering curricula to include two major-specific and hands-on first-year courses [10]. South Dakota State University implemented a new first-year experience titled FOCUSED (Focused Ongoing Concentrated Undergraduate Sequence in Engineering Design). This project consisted of introducing program specific and hands-on courses in the first year [11].

To address these current issues related to retention rate and student success, the SoE at the WIT assembled a First-Year Engineering Taskforce to redesign the first-year curriculum. The redesign process is explained in detail in [12], [13]. The objectives of the first-year engineering program were identified: provide students with an engaging and interesting academic experience; provide initial exposure to the student's engineering field; and provide basic laboratory and analytical engineering skills. Therefore, the 8 credits in Engineering have been redesigned to introduce 2 new engineering courses in the Fall Semester: Introduction to Engineering Seminar and Engineering Laboratory. Introduction to Engineering Seminar is an interdisciplinary seminar-based course that aims at introducing students to fundamental concepts in the area of engineering. Engineering Laboratory is a major-specific laboratory course that aims at exposing students to developing fundamental technical and laboratory skills.

This paper introduces the Engineering Laboratory course offered for the electrical and computer engineering (ECE) major. The course methodology, course goals, and course module topics are presented. Moreover, data from students' exit survey and course assessment are analyzed to evaluate the effectiveness of this new first-year course.

2. Course Implementation

2.1 Course Methodology

Engineering Laboratory is 2-credits major-specific course that has been offered for the first time in the School of Engineering for ECE students in Fall 2022. The ECE program offered six sections with approximately 20 students per section. Students were asked to work in groups of two or three during the laboratory at an assigned workbench. The course consists of one 50-minutes lecture and one 2-hours laboratory sessions every week. Both lectures and laboratory sessions were taught by the same professor to make sure there is continuity between theory and applications. Lectures were structured to cover the basic theory, principles, and practices needed to complete the associated laboratory sessions. At the end of each lecture students are asked to complete pre-lab assignments before the next laboratory session. Most of the laboratories had post-lab reports, individual or group reports according to the lab activity. The report was either a formal report, using a template that was previously provided, or an in-lab worksheet to be filled out with measurements and comments.

2.2 Course Goals

This course focuses on developing fundamental technical skills and on students' exposure to a wide range of electrical and computer related topics through a sequence of hands-on laboratories. Throughout the course, students were introduced to concepts in laboratory safety, design of experiments, measurement procedures and techniques, computer aided design, algorithmic thinking, simulation, and technical reporting. Several course learning outcomes were identified that were appropriate to make sure students develop working knowledge in the use and application of modern engineering tools and techniques required for engineering practice.

The objectives of the course are:

- Demonstrate proficiency in applying necessary laboratory safety procedures and the use of required personal protection equipment (PPE).
- Identify and operate appropriate measurement equipment for experiment procedures.
- Implement design of experiments techniques to use modern engineering tools and analysis techniques to test a thesis.
- Apply Computer Aided Design to model engineering design concepts.
- Use simulation techniques and software to predict system behavior.

- Demonstrate proficiency in synthesis techniques and equipment to implement engineering concepts.

To accomplish those course learning outcomes, seven modules, each related to a distinct and relevant topic in the ECE field, were developed and implemented through twelve laboratory sessions.

2.3 Course Modules Topics

The main goal of this first-year course is to introduce students to basic technical laboratory skills and fundamental engineering concepts with hands-on learning activities. These activities can be grouped in the following seven modules: Laboratory Safety, Circuit Simulations, Circuit Testing, Benchtop equipment, Soldering, Autonomous car, and Design of Experiments. These modules were designed, implemented, and developed. Each module consisted of one or more laboratory exercises. Table 1 lists the 12 labs along with brief description.

Table 1: List of Laboratories activities

Lab #	Lab Name	Lab Module	Post-lab Report
1	Safety	Laboratory Safety	Worksheet
2	Resistors	Circuit Testing Benchtop equipment	Worksheet
3	Simulations	Circuit Simulations	Worksheet
4	Measurements	Circuit Testing Benchtop equipment	Worksheet
5	Simulations and Measurements	Circuit Testing Circuit Simulations Benchtop equipment	Worksheet
6	Oscilloscope	Circuit Testing Benchtop equipment	Worksheet
7	Soldering	Soldering	-
8	Benchtop Pulse Width Modulation	Circuit Testing Benchtop equipment	Report
9	Arduino Pulse Width Modulation	Autonomous car	Report
10	Sensors and Conditionals	Autonomous car	Report
11	Autonomous Vehicle	Autonomous car	Report
12	Design of Experiments	Design of Experiments	Report

The laboratory sessions were held in the same order listed in Table 1. Below a more detailed description of each laboratory experiment is provided.

<u>Lab 1:</u> Safety

In this section, students were introduced to Electrical Safety and Personal Protective Equipment. Fundamental concepts as human body resistance, workplace electrical injuries, common electrical hazards, and prevention of workplace electrical incidents were introduced during lecture time.

In the laboratory, students applied the concept of human body resistance by measuring the resistance of “wet” hands and “dry” hands. The experiment consisted of using the fingers to hold the metal leads of a banana-to-alligator clips, connected to the Digital Multi-Meter (DMM) to measure the resistance. Students had to repeat the measurements with both dry hands and wet hands (using a hand sanitizer available in the lab). Finally, they had to relate the laboratory measurements with the theoretical values studied during the lecture.

<u>Lab 2:</u> Resistors

In this section, students were exposed to basic concepts of electric circuits: atom structure, electrons and protons, charge, voltage, current, wire, ground, resistance, and ohm’s law. Moreover, color codes schemes, to indicate the values of resistors and their tolerance, was introduced in class.

In the laboratory, students were provided with three unknown 3-bands resistors. The experiment consisted of using the band color code provided by the instructor, to calculate the resistance value and the tolerance. To validate the calculations, students had to measure the resistance using the DMM, and to evaluate the error between DMM reading and resistor color code.

<u>Lab 3:</u> Simulations

For this laboratory, students were introduced to DC resistive circuits, series and parallel resistors configurations, Ohm’s law, voltage division, current division, and Kirchhoff’s voltage and current laws.

In the laboratory, students simulated resistive circuits with diverse network topologies to strengthen the theoretical concepts introduced in class and to learn how to perform current and voltage measurements. Using Multisim software, students were asked to simulate three circuits and to place multimeters to properly measure current and voltage. One of the assignments required the simulation of the circuit shown in Figure 1. The goal of this exercise was to let the students understand the working principle of the Wheatstone bridge, without explaining in class, only by changing the value of resistor $R4$ and by measuring the voltage V_{OUT}.

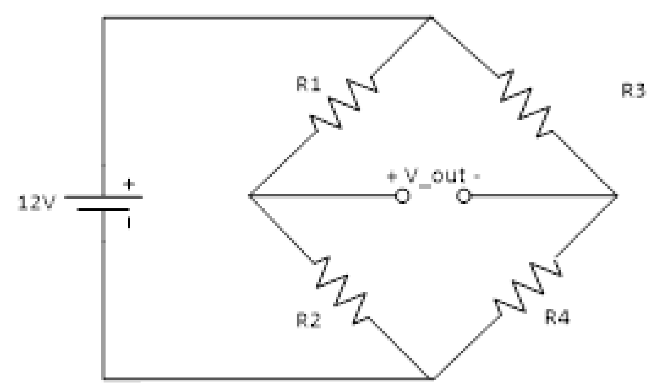

Figure 1: Wheatstone bridge

<u>Lab 4:</u> Measurements

For this section, students were exposed to benchtop equipment as DMM (for current and voltage measurements), power supply, and breadboards. Moreover, non-linear resistive elements as Light Emitting Diodes (LED) were introduced to the class. Through videos, tutorials, and instruction manuals, students learnt the working principle of each device to conduct basic circuit measurements and testing. Pre-lab assignment consisted of solving electric circuit that will be built during the lab.

During the lab session, students built the circuits shown in Figure 2 on the breadboard. Then, measurements of currents through the resistors and voltages across the resistors and LED were conducted. The main goal of this exercise was to understand how to correctly connect the DMM in a circuit to take measurements.

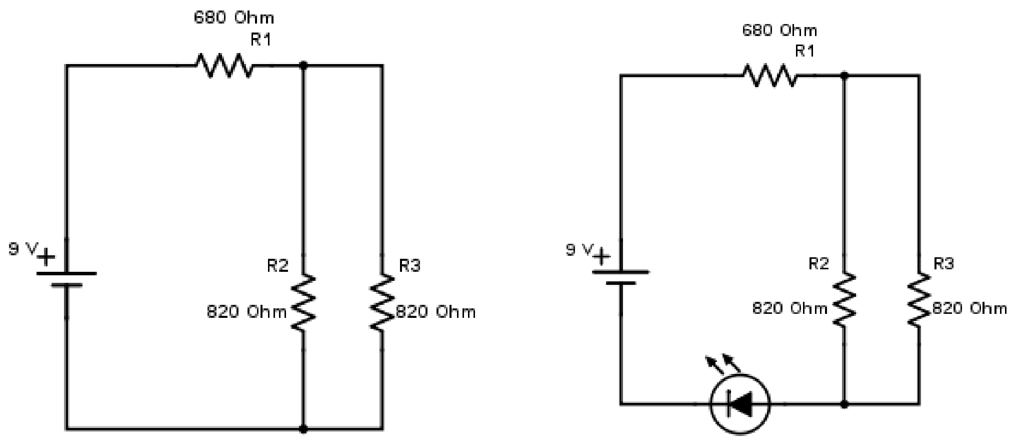

Figure 2. Example of two resistive circuits built on the breadboard during Lab 4.

<u>Lab 5:</u> Simulations and Measurements

This laboratory was introduced to strengthen the basic principles and theories in circuit analysis where students must simulate the same circuits that were analyzed in Lab 4. This lab aimed at developing critical thinking skills where students have to relate the measurements and simulations with the calculated values in the pre-lab. Thus, they are asked to interpret the values, draw conclusions, and evaluate the accuracy of the conducted experiment.

<u>Lab 6:</u> Oscilloscope

In this laboratory students were introduced to the oscilloscope and its main functionalities and applications. During lecture time a pre-lab assignment was assigned to learn oscilloscope performance (e.g., bandwidth, rise time, sample rate, etc.,), commands (e.g., trigger control, instrument control, etc.,), and oscilloscope measurements. Practice problems on the pre-lab strengthened the concepts and theories introduced in the lecture.

The lab exercise consisted of building a circuit with a resistor and a capacitor, as shown in Figure 3. Moreover, the function generator was used to create a sinusoidal voltage source to power the circuit. The oscilloscope was used to visualize the voltage drop across the capacitor and across the resistor. After signal visualization, students were asked to perform basic measurements, as amplitude, period, and phase shift, using the automatic measurement capabilities of the device.

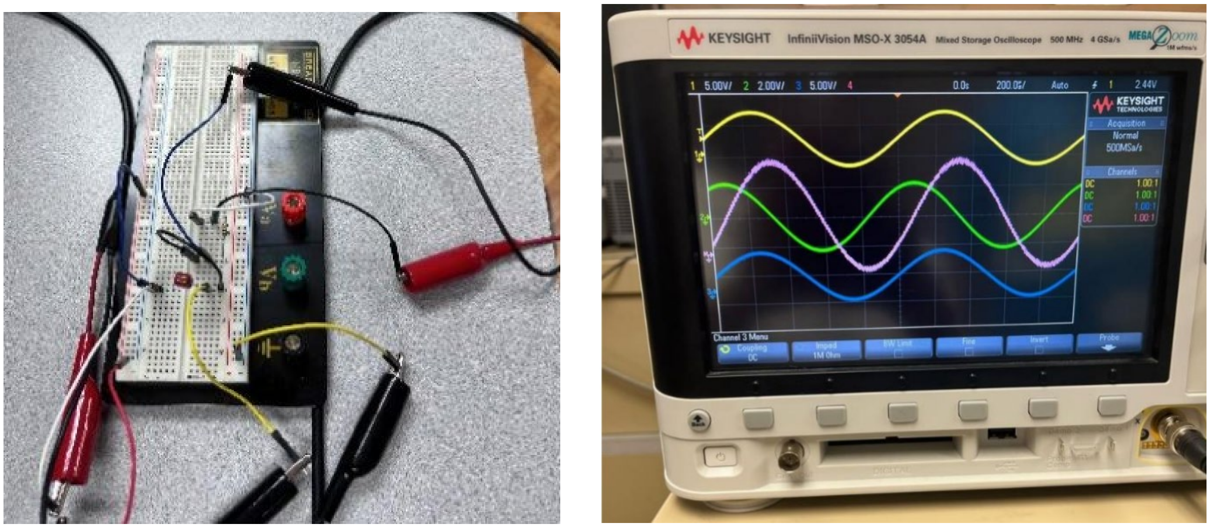

Figure 3. Circuit built in Lab 6 (left); Oscilloscope screen for voltage measurements (right).

<u>Lab 7:</u> Soldering

The laboratory focused on soldering skills. It required two sessions to make sure all students could extensively practice soldering. During lecture, students were introduced to the soldering techniques. The lecture outlined the basics of soldering irons, soldering stations, types of solder, desoldering and safety tips.

The laboratory was equipped with six soldering stations and each station had a soldering iron, fume extractor, magnifier, solder, tools, desoldering pump, etc. Each team was provided with a sound to light unit soldering kit illustrated in Figure 4 [14]. The kit consisted of a printed circuit board and several electrical components as resistors, transistors, LEDs, capacitors, potentiometer, and a microphone. In the first laboratory session students read the instructions and by reading the circuit diagram, they had to identify the various electrical components along with their polarity. After completing the introductory part, they could start the soldering process. The goal of this lab was to learn soldering skills and troubleshooting skills. Some groups did not solder the components correctly that resulted into a non-working circuit. Thus, they were asked to troubleshoot the circuit and identify and redo any bad solder joints.

<u>Lab 8:</u> Benchtop Pulse Width Modulation

Lab 8 consisted of a series of connected laboratory activities (Lab8-Lab11) that aimed at building and testing an autonomous vehicle. In lecture time students were exposed to Pulse Width Modulation (PWM) and how PWM can be used to control a servo motor. As a pre-lab activity students had to calculate frequency and duty cycles to control the servo motor available in the laboratory.

The lab exercise consisted of powering the servomotor using the DC power supply, controlling the actuator using the function generator, and visualizing the generated PWM signal with the oscilloscope. The students had to change the duty cycle of PWM signal, using the function generator, to understand how to stop the motor, how to set the maximum clockwise or counterclockwise speed, and the minimum clockwise or counterclockwise speed. The goal of this lab was to understand how to generate a PWM signal to have the servo-motor rotating with a given speed and in a given direction.

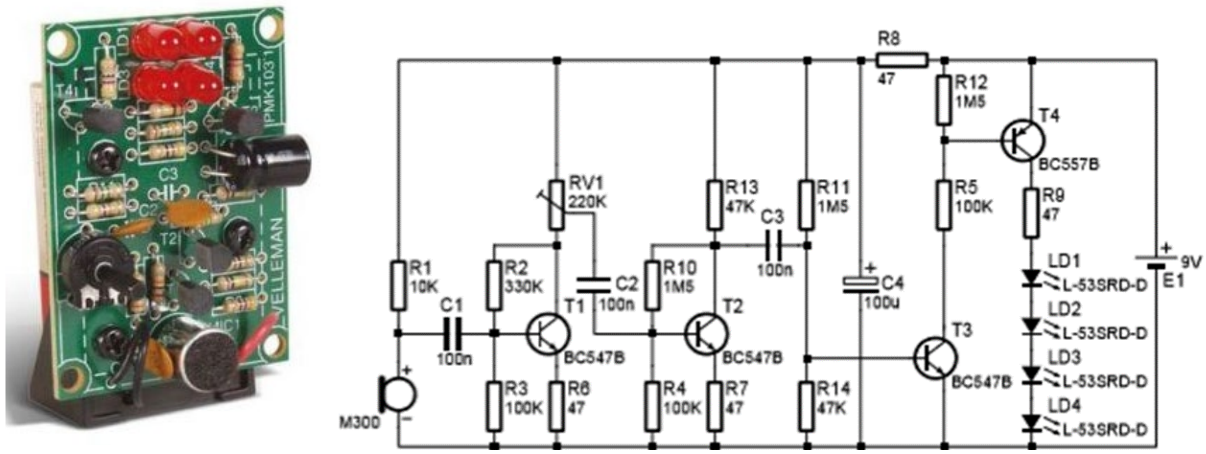

Figure 4. Sound to light soldering kit (left); Schematic diagram (right).

<u>Lab 9:</u> Arduino Pulse Width Modulation

After understanding the PWM, students were introduced to microcontroller units, the Integrated Development Environment (IDE) to write code, and basic programming concepts. In particular Arduino Uno microcontroller was introduced to the class.

Each team was provided with a Sumobot Kit [15] consisting of a smart robot car as shown in Figure 5 that can be controlled using Arduino Uno. Each team was required to properly connect the power supply to power the motors and to write a code in the Arduino IDE to control the two servomotors mounted on the rear side of the robot car. The goal of the lab was to move the car with a given speed and direction. In particular, students had to identify the duty cycle values needed to stop the car, to move the card forward and backward with different speeds.

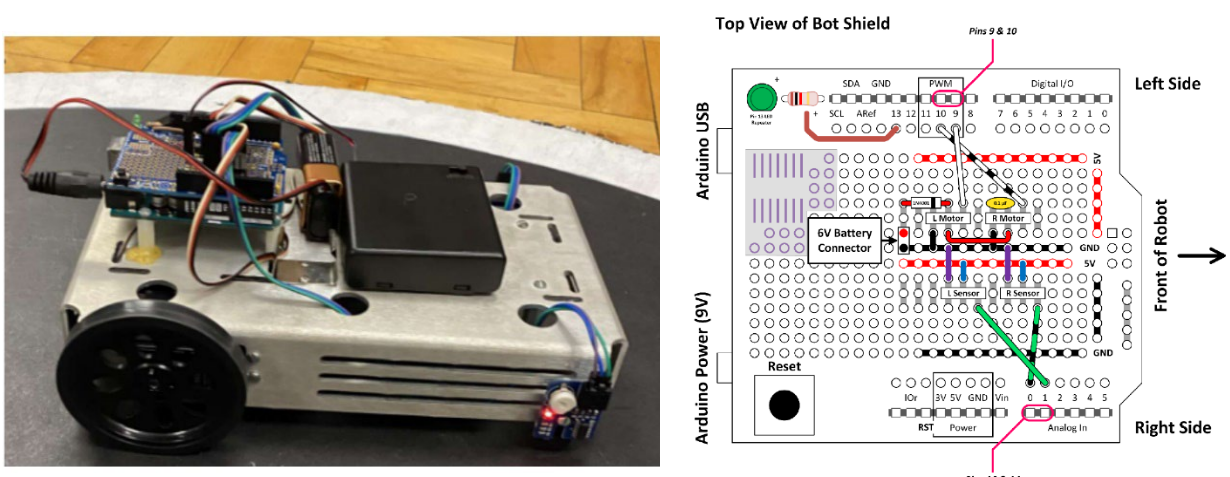

Figure 5. Sumobot Kit (left); Top view of Bot Shield (right).

<u>Lab 10:</u> Sensors and Conditionals

For this lab, students were introduced during lecture time to sensors and how optical sensors can be used for color detection. The robot car was equipped with two optical sensors located at the front side corners of the car pointed down toward the floor. The goal was to move the car forward when the sensors detected black floor and backward when they detected white floor.

The lab activity consisted of moving the car on a white and black piece of paper while the two optical sensors were connected to a DMM to read the output voltage. After understanding how the color detection process worked and measuring the output voltage for black and white detection, each team had to automate the process. Students had to read the analog input using Arduino and identify a threshold to differentiate between the two colors. Then, the code should allow the robot car to move forward when the sensors pointed towards a black floor and backwards when the sensors pointed toward white floor. At the end of this lab activity students understood how to build a robot car capable of moving on straight path according to the color floor.

<u>Lab 11:</u> Autonomous Vehicle

A pre-lecture on autonomous vehicles technology and the state-of-art of commercial autonomous vehicles was conducted.

In this final lab the smart robot car was supposed to move forward if both sensors detected black, turn left by 90° if the right sensor detected white and the left sensors saw black as shown in Figure 6, turn right by 90° if the right sensor detected black and the left sensors detected white, and move backward for few seconds and then turn either right or left if both sensors detected white. Each group was provided with a 9[V] battery to power Arduino and a 6[V] battery to power the servomotors. After making the proper battery connections and modifying the code to include right and left turn, each team had to demonstrate to the instructor. Two sumo rings (~1m diameter) were available in the lab to test the car.

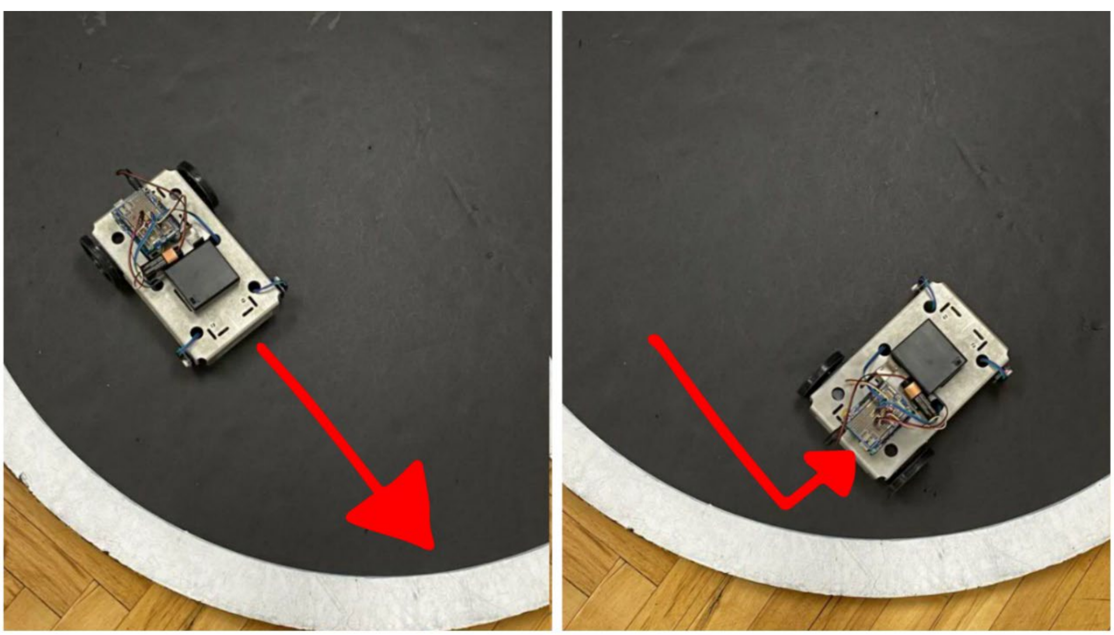

Figure 6. Autonomous Vehicle

<u>Lab 12:</u> Design of Experiments

In this laboratory students had to design and develop an experiment to determine the average value of the individual resistance in a resistor cube as shown in Figure 7. The cube had twelve resistors with equal nominal resistance. During lecture time, students were introduced to the resistor cube and three methods were studied to measure and/or calculate the equivalent resistance from two opposite nodes. Then, knowing the equipment available in the lab, they had to write a one-page proposal to describe the experiment design methodology to determine the average individual resistance in the resistor cube.

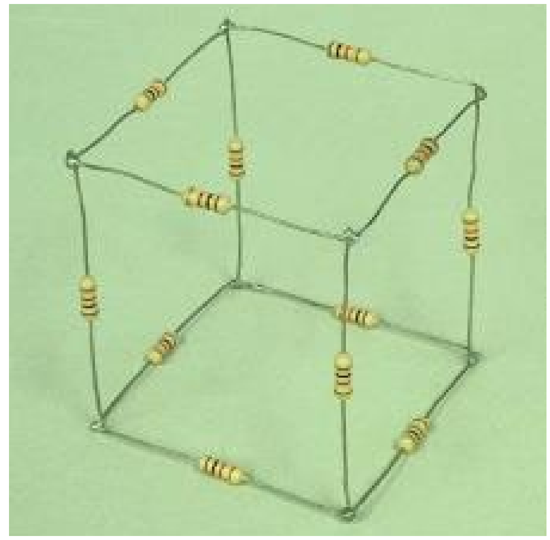

Figure 7. Resistor Cube

The lab exercise consisted of validating or refuting the proposed design using the available benchtop equipment. They were allowed in the laboratory session to discuss with the instructor the experiment design and to modify the proposal as needed. The goal of the lab was to nurture critical and independent thinking skills.

3. Results and Analysis

Initial assessment of the new Engineering Laboratory course at the program level is presented. The assessment was done using data collected from students' exit survey and from course assessment. It should be mentioned that the investigated course is required for ECE majors in their first year, therefore, no simultaneous control group exists.

3.1 Students' Exit Survey

An exit survey was provided to the students enrolled in two sections of the investigated course. The goal of the survey was to share the experience the students had with the course content, course learning, and course satisfaction. A response rate of 76% was achieved. Out of 25 students that responded to the survey, 15 were from Electrical Engineering program and 10 from Computer engineering program. The survey asked to rate on a scale of 1-5 (1 is the lowest and 5 the highest) the skill level before and after the class in the following topics: circuit simulations, circuit measurements, benchtop equipment, soldering, Arduino, and software programming. Results are illustrated in Figure 8. Figures show the number of students versus their ratings before attending the class (blue bars) and after attending the class (orange bars). Results show that students think they have built and/or have significantly improved their technical laboratory skills. To better evaluate their improvements, Figure 9 shows the average rating for the skill level before and after the class per topic. Their technical skills have dramatically increased for each topic investigated in the lab. For example, an average rating increase of 120% has been calculated for the soldering lab. The minimum improvement of 94.44% has been achieved with the benchtop equipment topic. Results clearly show a considerable improvement in students' confidence with basic engineering laboratory skills for students that attended this course.

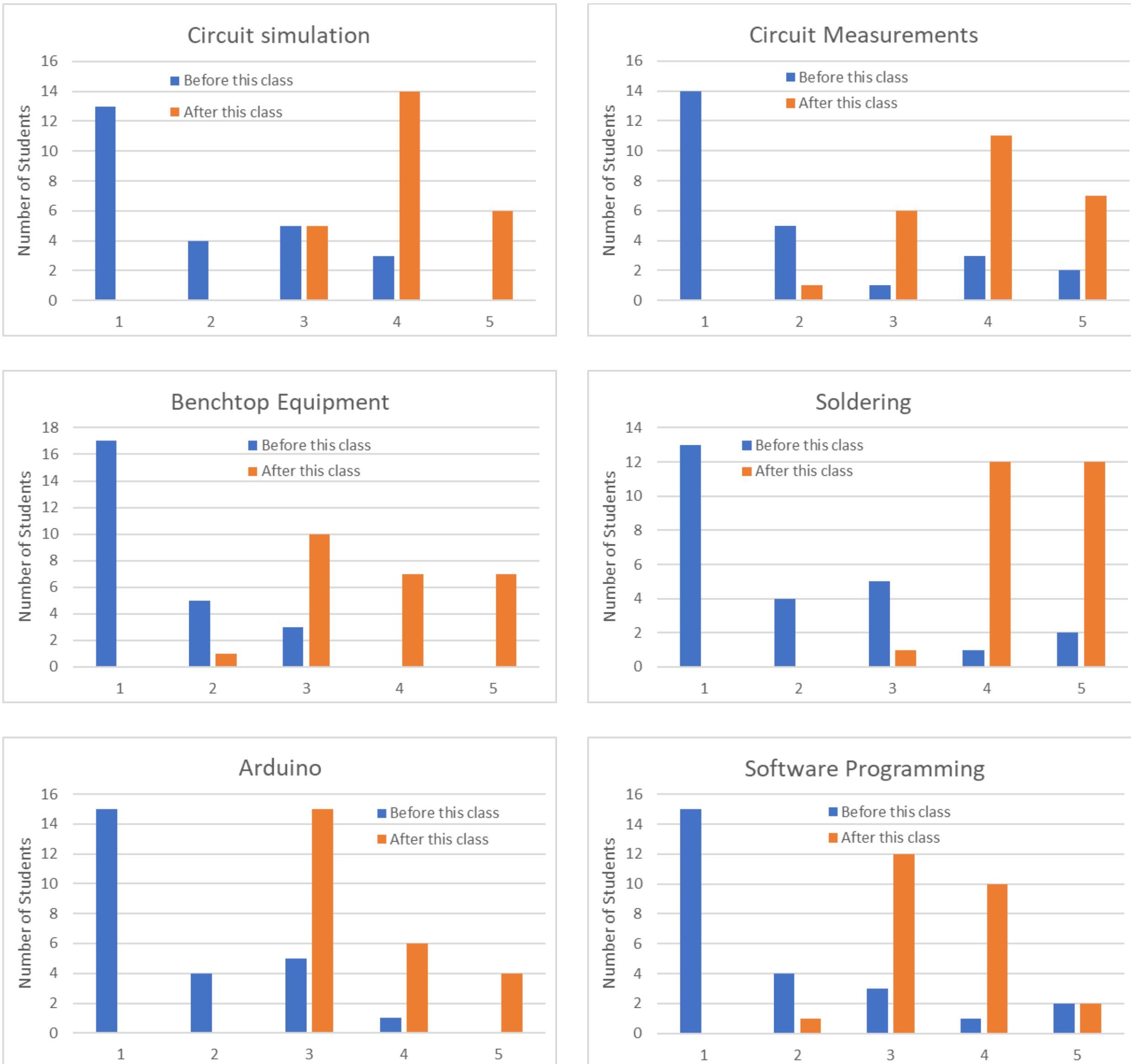

Figure 8. Skill level before and after class in: Circuit simulation, Circuit measurements, Benchtop equipment, Soldering, Arduino, and Software programming.

Figure 10 on the left shows the confidence level before and after this class on basic laboratory skills. It is noticeable that 72% of the students rated their confidence to be less or equal to 2 before the class, while 96% of the students rated their confidence level on basic laboratory skills to be higher or equal to 4 at the end of the semester. Figure 10 on the right illustrates the confidence students gained in continuing education in ECE after attending this class. Out of 25 participants, 40% rated their confidence level to be equal to 5, 48% equal to 4, and 12% equal to 3. Preliminary results, illustrated in Figures 9 and 10, suggest the effectiveness of this new freshmen laboratory course. In fact, Figure 9 shows that the students at the end of the course feel they have gained and/or improved fundamental technical and laboratory skills in their major. Whereas Figure 10 demonstrates that his new course instilled and/or strengthened the students' confidence level in continuing education in an ECE program. Such results represent two positive and preliminary outcomes that could increase students' retention in an engineering program and foster students' success.

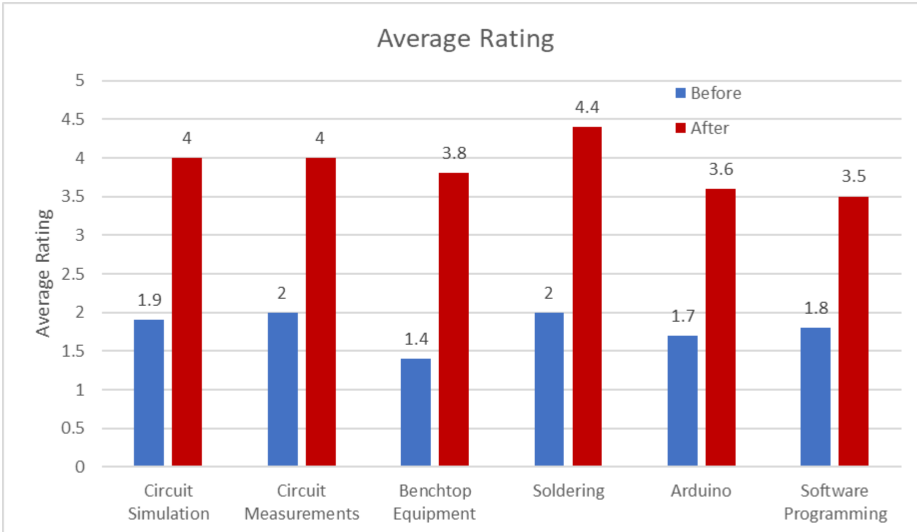

Figure 9. Average Rating before and after class

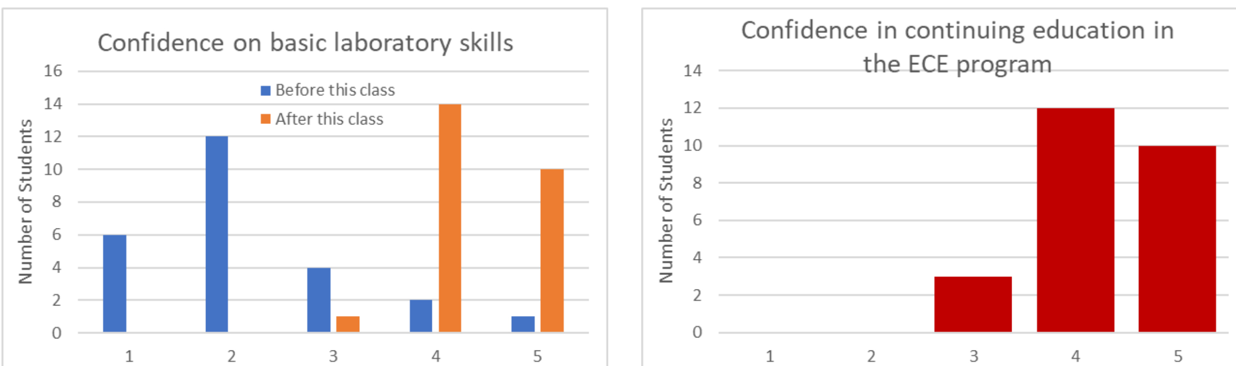

Figure 10. Confidence level on basic laboratory skills (left); Confidence in continuing education in ECE program (right).

Moreover, the survey aimed at investigating the laboratory activities that students enjoyed the most. They had the opportunity to select up to 3 topics between the following labs: Safety (Lab1), Circuit Simulations (Lab 2, Lab4), Circuit Measurements (Lab 3, Lab4), Oscilloscope (Lab 5), Soldering (Lab 6), Arduino (Lab 7, Lab 8, Lab 9, Lab 10). Results show that 84% of the students enjoyed the Soldering lab, 56% of the students preferred the Arduino laboratory series, and 20% enjoyed the Circuit Simulations and Circuit Measurements labs. The survey wanted to identify the laboratory activities that the students enjoyed the least. 52% of the students selected Oscilloscope, 40% chose the Safety lab, and 20% selected the Circuit Simulations labs.
This section of the survey wanted to identify weaknesses and strengths of the course content in order to modify and improve the course' topics/activities for the upcoming students to maximize students' experience.

3.2 Skill Assessment Data

To demonstrate the effectiveness of this course, students' exit survey cannot be used as the primary evidence of learning. In fact, student perceptions of their own skills may not accurately assess the knowledge level they will need in practice [16]. Students may perceive their learning has significantly improved by participating in the course or by enjoying the lab activity. Therefore, to quantitively prove evidence for learning and assess the technical skills, instructor evaluation on the post-lab report/worksheet is used. In particular, the average grade for laboratory activities, directly related to the technical skills illustrated in Figure 8 and 9, is used to address those technical competencies. Students are graded on their post-lab worksheets/reports and on direct observation of their skills during the laboratory sessions. Table 2 shows the lab activities used to assess the technical laboratory skills.

Table 2: Laboratory number and related skill.

Lab Number	Lab Skill
Lab 3; Lab 5	Circuit Simulations
Lab 2; Lab 4	Circuit Measurements
Lab 6; Lab 8	Benchtop Equipment
Lab 7	Soldering
Lab 9; Lab 10	Arduino
Lab 11	Software Programming

Figure 11 shows the average grade of the students that attended the lab sessions and submitted the lab report/worksheet. Each lab report was graded using a scale from 0 to 10. The high average grade (i.e., greater than 8.15) obtained for each skill demonstrates the effectiveness of the course. In particular, results quantitively demonstrate that the students gained and/or improved fundamental technical and laboratory skills in the ECE major.

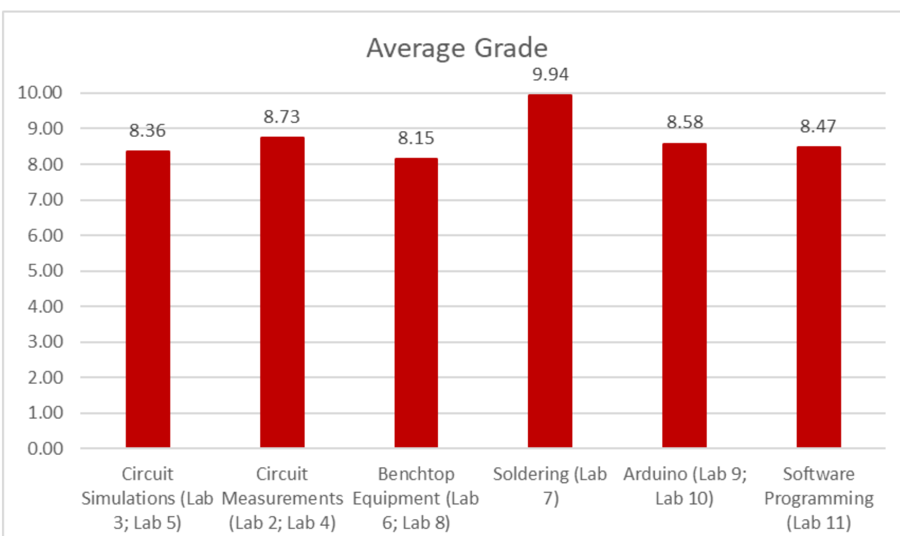

Figure 11. Average grade to assess technical skills.

To tie the students 'exit survey data with the skill assessment data, the correlation between the two data set has been computed. Positive and high correlation of 0.75 has been found. Strong correlation shows that high students' self-rating on their skills will correspond to a high average grade on the lab activity related to the same technical skill.

4. Conclusion

This paper presents the design, implementation, and preliminary results of a first-year laboratory course in the ECE program. This course was offered as part of a redesigned first-year engineering curriculum that aimed at providing engaging, and hands-on academic experience and at exposing first-year students to their chosen engineering discipline. The objective of the new curriculum is to improve students' success and increase retention rate for first-year students.

The course consists of a series of hands-on activities to expose students to basic laboratory skills and fundamental engineering concepts in the field of ECE. These activities can be grouped in the following seven modules: Laboratory Safety, Circuit Simulations, Circuit Testing, Benchtop equipment, Soldering, Autonomous car, and Design of Experiments

To evaluate the effectiveness of this course data from skill assessment and from students' exit survey was analyzed. Insights from data analysis show that the new course has positively impacted students' success based on the evaluations obtained on students' feedback. Students rated their confidence level in continuing education in the ECE program to be 4.28 on a scale from 1-5. Moreover, skills assessment data shows an average grade greater than 8.15 on a scale from 0-10) for all the lab activities tied to the investigated technical skills. Therefore, preliminary results confirm that the new proposed course can be considered successful. Insights from students' feedback will be considered for improvement for Fall 2023.

Future plans include developing a pre-course survey in addition to the exit survey and extending these surveys to all the sections in the ECE program to have higher number of participants. A long-term study will be conducted to evaluate the effectiveness of this course in guaranteeing students' success and satisfaction and in increasing the retention rate of first-year students. Moreover, the impact on students' success from diverse groups will be analyzed.

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