Circuit Class for Mechanical Engineering Students

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Abstract

Circuit Theory and Application is a course that introduces undergraduate mechanical engineering students to electrical and electronic circuits, with emphasis on building a foundation of applications that could involve mechanical systems. Voltage, current and power are analyzed in direct and alternating current (DC and AC) circuits having components that include resisters, capacitors, inductors, diodes and operational amplifiers. Conventional courses in circuit theory use lectures and textbook readings to explain the theory, and assign paper-based problem sets of theory, possibly supplemented with circuit labs. Conceptual understanding of the course content remains a challenge for many mechanical engineering students. A series of exercises was developed to help students visualize the concepts and gain a better appreciation for how the concepts are useful in real-world situations. Some of the laboratory exercises involve applications having sensors of mechanical phenomenon and data acquisition. Some of the exercises involve building and testing circuits.

Similar to the curriculum at many universities, our program has a basic electrical circuit course for sophomore students in mechanical engineering. The course structure has a 2-hour lecture, 2-hour lab, for a 3-credit course. The following topics are introduced to students: Ohm's Law, Kirchhoff's voltage and current laws, methods of circuit analysis, as well as capacitors, inductors, binary arithmetic, Boolean algebra, logic gates, operational amplifiers, diodes and applications. Problem sets related to these topics are assigned. As reported in this paper, to improve motivation and learning, application-oriented and hands-on design labs and projects were developed, including sensors, Bode plots and filters, counter design, and data acquisition. This paper will describe some of the developed projects and labs.

Evaluations were based on student surveys (course evaluations) and student work (assigned homework, exams and lab exercises). Recent offerings of this course taught in the traditional way by the same instructors resulted in only 45% of the students receiving a "B-" or higher grade for the course. In the past 2 years, with new developed laboratory exercises, the number of students who received a "B-" or better increased to 65%. Moreover, 83% of students "agree" or "strongly agree" that application-oriented and hands-on design labs and projects helped them to better learn the course content. 86% "of the students agree" or "strongly agree" that laboratory exercises increased their interest in the subject. Such improvements in the course help students stay engaged, strengthen their understanding, and prepare for their future courses and career.

Introduction

Similar to the curriculum at many universities, our program has a basic electrical circuit course for sophomore level mechanical engineering students with the required prerequisites of calculus and physics [1-2]. The course has a weekly structure of a 2-hour lecture, 2-hour lab, for a 3-credit course. Since this is the only electrical circuits class in the mechanical engineering curriculum, a wider set of topics are covered, including DC and AC circuits with resistors, capacitors, and inductors, as well as analog and digital electronics, including some digital logic.

The course has two learning objectives. Students who pass this course will have demonstrated the ability to:

- Determine voltage, current and power in DC and AC electrical circuits.
- Build electrical systems and test for function using laboratory instruments.

In the past we taught this course in a conventional manner using lectures and readings to explain the theory, and assign paper-based problem sets of theory, supplemented with traditional circuit labs. Conceptual understanding of the course content remains a challenge for many mechanical engineering students. Many students have no conscious personal experience with these phenomena and are not naturally interested in electric circuits. A series of mechanical related exercises was developed to help students visualize the concepts and gain a better appreciation for how the concepts are useful in real-world situations [3-6].

Design of Application-oriented Labs and Projects

For the laboratory activities, 8 labs and 2 projects were designed. Table 1 shows the new revised labs and projects used in the course. Labs 3-6 were formed by combining or reimagining 6 old labs, which were Measurement of Resistors, Maximum Power Transfer, Thevenin's and Norton's Equivalent Circuit, Multisim Simulation and Superposition Theorem, Sinusoidal Waveform Measurements, and Boolean algebra. Also, 2 projects were added as shown in Table 1. All labs and projects were undertaken by groups of 2 or 3 students.

Table 1. List of Labs/Projects and Objectives

Labs or projects	Objectives
Lab 1 Ohm's law	• How to connect voltmeters and ammeters in a circuit to measure DC voltages and currents. • Demonstrate a graphical method to describe the current-voltage relationship of electric circuit components.
Lab 2 KVL and KCL	• Verify Kirchhoff's voltage law. • Verify Kirchhoff's current law.
Lab 3 Multisim (V and I)	• Build and analyze basic resistor circuits in Multisim circuit simulation software.
Lab 4 Voltage Divider Sensors	• Use Voltage Divider • Use Sensors for Force and Light that vary resistance
Lab 5 Sensors with LabView	• Use LabView with sensor circuit on a prototype board • See how sensor can output voltage value that ranges from 0 to 5 V

Lab 6 myRio ADC Temperature Control	• Make a Control System to maintain temperature within a certain range.
Lab7 Op-Amp Amplifying Circuits	• Construct op-amp circuit • Analyze op-amp circuit.
Lab 8 Digital Logic and Counters	• Build and analyze digital circuit.
Project 1 Strain Gage as Load Cell	• Test the function of a load cell to measure weights, utilizing a strain gage and Wheatstone bridge circuit.
Project 2 Filter Design	• Strengthen understanding of filters and Bode plots

The labs and projects helped the students to interact with basic theorems of circuits to show that they are true with hardware components. The labs and projects also had the students learn about and use sensors, data acquisition models, and computer programs for data acquisition and data analysis. Students used these with mechanical phenomenon, such as temperature modeling and control with a heating source, force and light sensors, and strain gages.

As an example of the developed labs, Lab 4 Voltage Divider Sensors is shown in Figure 1. One force sensitive resistor (Interlink Electronics #30-49649 Digikey 1027-1000-ND) and one light dependent resistor (Adafruit #161, Photoresistor Digikey 1528-2141-ND) were provided. Students were asked to insert the force sensitive resistor and light dependent resistor on the prototype board in a circuit, and then to use the DMM to measure resistance. The students filled out the tables for resistance values under different conditions (Table 2).

Table 2 Resistance measurement for force sensor and light sensor

Force Sensor

Condition	**Resistance (Ω)**
low (no load)	
medium	
high (heavy force)	

Light Sensor

Condition	**Resistance (Ω)**
low (dark)	
medium (ambient)	
high (bright)	

Then students used voltage power supply and DMM to build the circuit in Figure 1 for each sensor. Measure Vo to observe the voltage as applying the range of sensory input from low to high. Then replace the fixed 5 kΩ resistor at R_1 with a 5 kΩ potentiometer (Figure 2). Use trial and error to determine the optimal position for turn-screw to maximize the range of Vo for the range in sensory input. Then fill out Table 3.

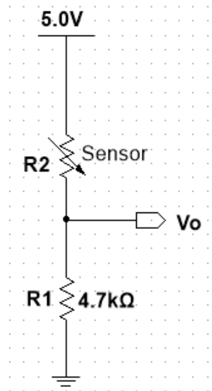


Figure 1 Sensor resistor circuit

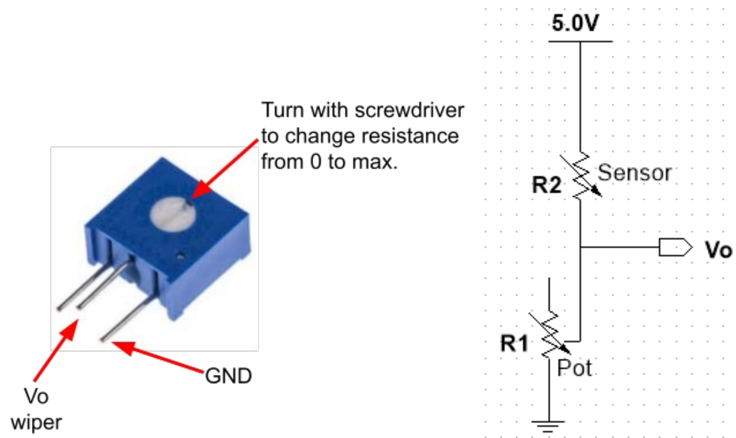


Figure 2 Sensor potentiometer circuit

Table 3 Voltage measurement for force sensor and light sensor

Force Sensor

R_1 (pot in Ω) = ____________________

Condition	Vo (V)
low (no load)	
medium	
high (heavy force)	

Light Sensor

R_1 (pot in Ω) = ____________________

Condition	Vo (V)
low (dark)	
medium (ambient)	
high (bright)	

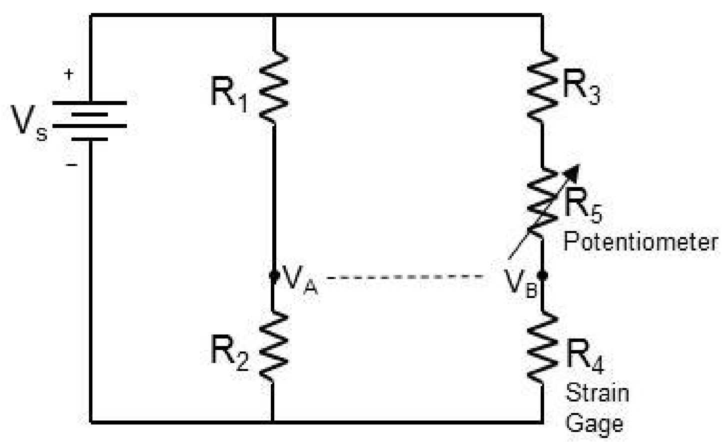
One example of projects is Project 1 Strain Gage as Load Cell. Students were asked to follow the steps:

- Clamp the load cell to the table with the C-clamp. Clamp to the end opposite of the weight platform, such that weights may be placed on the platform, and the strain gage is bonded to the top surface of the aluminum beam.
- With no weight on the table of the load cell, use DMM to measure nominal gage resistance (in circuit of Fig. 3, R_{4o}).
- On DMM, hit the math Null button, so that all new readings are displayed as (R_{new} – R_{4o}). This is the ΔR from R_{4o}.
- Add weights to the load cell platform and measure the ΔR (fill in table)

Table 4: Gage Resistance

mass (kg)	ΔR_4 (Ω)
0.0	
0.1	
0.5	
1.0	
1.5	
2.0	
2.5	
0.0	

- Build circuit diagrammed in Figure 3. The strain gage of the load cell is included in the circuit as R_4.



R_1, R_2 and R_3 are 348 Ω resistor
R_5 is potentiometer

R_4 is strain gage
V_S = 5V

Figure 3. Wheatstone Bridge Circuit

- Adjust R_5 potentiometer until V_o (the voltage between points VA and VB) = ~0.0 mV. This will "balance" the load cell such that no weight on beam results in V_o = 0.0 mV.
- Add weights and measure V_o (fill in Table 5). At the end, to measure V_A and V_B, move the DMM black lead to the circuit ground, and the red lead to V_A or V_B, respectively (only do for conditions of 0.0 kg and 2.5 kg).

Table 5: Voltage Output

mass (kg)	Measure V_o (mV)	Measure V_A (V)	Measure V_B (V)	Calculate $V_o = V_B - V_A$
0.0				
0.1		no measure	no measure	
0.5		no measure	no measure	
1.0				
1.5		no measure	no measure	
2.0		no measure	no measure	
2.5				

- Collect data for the first 2 columns in Table 5 *(while the load cell is still complete and functioning well).*
- Analyze the data in Microsoft Excel to find the Performance Equation of Load Cell. Determine y = mx + b equation, replace y with ΔR, x with W. Then determine y = mx + b equation, replace y with W, x with V_o.
- Test the Performance Equation. For 4 new mass values (use combinations of weights), place new combinations of masses on the sensing beam of load cell and measure the resulting V_o for each. Use performance equation to calculate the mass in kg (Table 6).

Table 6: Voltage Output

Actual Mass (W_{actual})	**Measured Voltage (V_o)**	**Calculated Mass (W_{calc})**	**Percent Error** | (Wcalc – Wactual) / Wcalc |
		Average % Err	

Results of New developed Labs and Projects

Course assessment of new developed labs and projects:

Table 7 provides the students' final grades when the circuit theory and application course was taught by the same instructors either with traditional labs or with the newly developed labs and projects. For all classes, Lab/project assignments took 20%, homework assignments took 20%, and exams took 60% of the overall grade. 53 students enrolled in traditional lab classes and 48 students took the course with the newly developed labs and projects over the last two years. All students in the classes completed all these laboratory assignments.

Table 7: Students final grade distribution

Final grade	A and A-	B+, B, and B-	C+, C, and C-	D+ and D	F
Traditional laboratory exercises	**17%**	**28%**	**34%**	**15%**	**6%**
New laboratory exercises	**19%**	**46%**	**27%**	**8%**	**0%**

As shown in Table 7, when students studied the course with traditional laboratory exercises, 45% of the students received A/A- and B+/B/B-. In the offering of the course using the new laboratory exercises, the number of students who received A/A- and B+/B/B- jumped to 65%. The number of students who failed the course declined from 6% to 0%.

ABET Outcome (1): An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics was used to assess the learning outcomes. The same problem was given in the final exam for both traditional lab and new lab classes. As shown in Figure 4, students' satisfactory and exemplary level was increased from 70% to about 80% for engineering and science. And satisfactory and exemplary level for math was slightly increased from 70% to 73%.

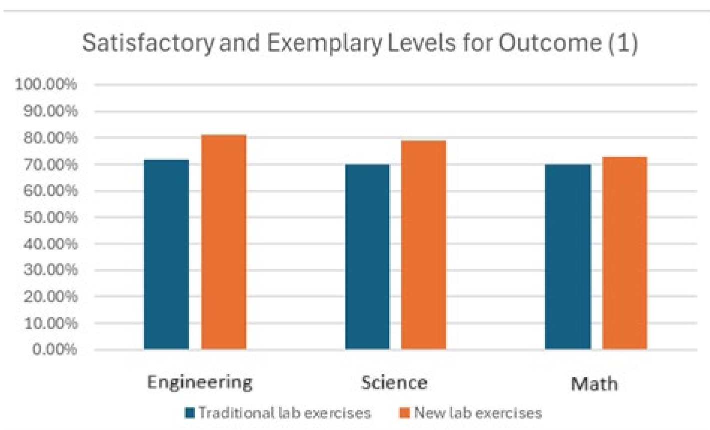


Figure 4 Results for outcome (1)

Course evaluation was conducted during the last two weeks of the semester to collect feedback to evaluate what the students thought about the course objectives. Of the 48 students who took the course in the last two years, 37 students completed the course evaluation. The results were 92% of students "agree" or "strongly agree" that they gained a basic understanding of the subject (Figure 5), and 86% of students "agree" or "strongly agree" that they developed specific skills, competencies, and points of view needed by professionals in the field most closely related to this course (Figure 6). 85% of students "agree" or "strongly agree" that they developed creative capacities (Figure 7). 75% of students "agree" or "strongly agree" that they learned to analyze and critically evaluate ideas, arguments, and points of view (Figure 8).

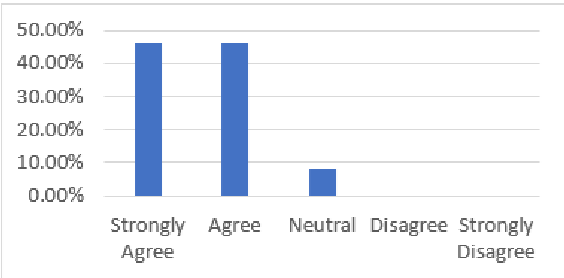


Figure 5. Gain a basic understanding of the subject

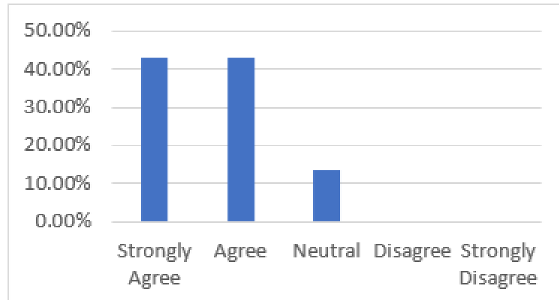


Figure 6. Develop specific skills, and points of view needed by professionals in the Field most closely related to this course

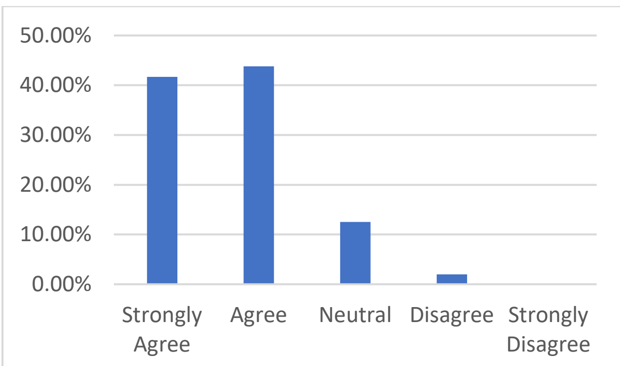


Figure 7. Develop creative capacities

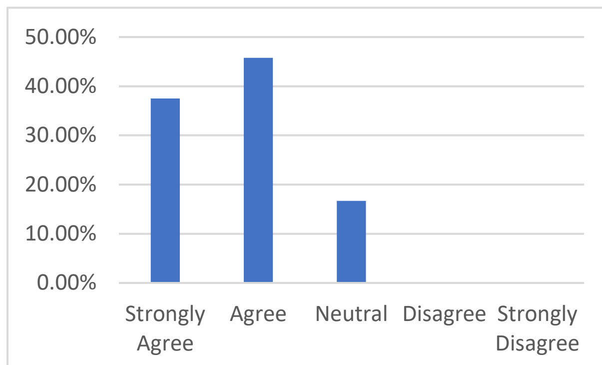


Figure 8. Learn to analyze and critically evaluate ideas, arguments, and points of view

Another survey was conducted the last week of the semester to collect feedback to evaluate what the students thought about the newly developed labs and projects. All 48 students finished the newly developed labs and projects and took the survey. 83% of students "agree" or "strongly agree" that application-oriented and hands-on design labs and projects helped them to better learn the course content (Figure 9). 86% "of the students agree" or "strongly agree" that laboratory exercises increased their interest in the subject (Figure 10).

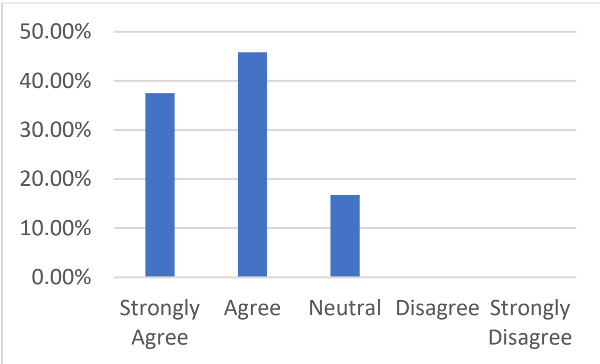


Figure 9. Labs and projects helped to better learn the course content

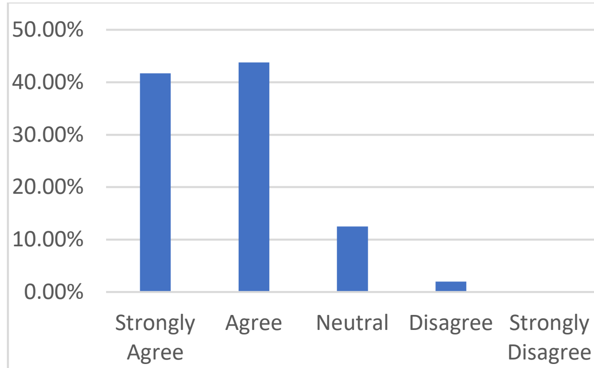


Figure 10. Labs and projects increased my interest in the subject

Discussion and Future Directions

This paper described a revised electrical circuit course for mechanical engineers. Labs and projects were added for hands on activities to allow the students to interact with basic theorems, use sensors for mechanical phenomena, program and use data acquisition systems, and use analog and digital electronics, including operational amplifiers, diodes and filters.

These labs and projects worked to increase the engagement of the students to better understand the theorems, realize how electrical systems support mechanical applications, and see that they can set up, program, use and understand these electrical circuits, often within the context of a mechanical application.

Survey results suggested the increased understanding and engagement of the students. The hands-on activities seemed to help students realize more how electrical circuits are important in mechanical applications, and enhanced student engagement, positive feelings and confidence for the new field.

Further directions include developing more labs using sensors and actuators, and having the students learn to use programmable logic devices (PLC) for a mechanical application. The impact of these new activities on student learning and engagement could also be analyzed further.

Developments such as described here help prospective future engineers better understand the theory and expand their view of their own abilities. These effects will strengthen the students and enhance their future careers.

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