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Comparing Circuitry Interest in Engineering Between Different Hands-On Projects

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At the University of Louisville's J. B. Speed School of Engineering, all students of each engineering discipline are required to take a two-course introduction to engineering sequence. The first course, *Engineering Methods, Tools, & Practice I* (ENGR 110), covers basic skills that are fundamental to the engineering profession. The second course, *Engineering Methods, Tools, & Practice II* (ENGR 111), has students expand on these skills and apply them to a hands-on semester-long project. The second course takes places in a 15,000 square foot makerspace with room for students to work in teams of 3-4 on a project that incorporates many engineering skills, one of which is a basic introduction to circuitry.

While engineering students are first taught programming in ENGR 110, their first exposure to circuitry occurs in the second course in the sequence. In ENGR 111, students first learn about circuitry components before constructing very basic circuits with an Arduino. Then, students learn about circuitry principles such as Ohm's Law and build more basic circuits with an emphasis on state measurements.

This first exposure to circuitry concepts takes place in the middle of a semester-long project that student teams work to complete. Both projects were introduced to students before the module on circuitry, but the *Introduction to Circuitry* lab takes place well before the actual integration of the project with course skills. Project 1 took place during the spring of 2022 and was comprised of a windmill generation system. The circuitry utilized in this project includes a basic resistor for the generative load along with a basic voltage measurement of this output. There is also a proximity sensor circuit that is used as a tachometer to measure the rotational speed of the windmill. Project 2 took place during the 2023 spring semester and was comprised of a water filtration system. This project also incorporated measurement circuitry to monitor the system but used an ultrasonic sensor to act as a tank level indicator for measuring tank volume. The large difference in circuitry for this project is the use of a controls circuit in the form of a motor driver used to manage the behavior of a pump and electronic valve.

At the end of the dedicated *Introduction to Circuitry* module, students were asked to complete a survey regarding their interest in engineering with respect to circuitry. This survey included 6 Likert-scale questions that quantify their situational interest with respect to circuitry. Additionally, students took another survey after completing their final course project, asking about a variety of interest-related topics. One of these questions asks about interest because of becoming more proficient in circuitry.

The purpose of this paper is to assess if students learning the same circuitry skills derive differing levels of interest in circuitry between the two different projects. This will be accomplished by assessing student progression between the situational interest survey and the end of semester survey. If there are significant differences between overall student progression, this indicates that one of these projects provokes more interest than the other. If there is no significant difference, and both results are reasonably high in terms of interest levels, then the choice of project causes no harm on student interest.

Introduction

The University of Louisville's J. B. Speed School of Engineering (SSoE) has a required first-year two-course sequence that all incoming engineering students are required to take regardless of their major. The courses are titled: *Engineering Methods, Tools, & Practice I* (ENGR 110), and *Engineering Methods, Tools, & Practice II* (ENGR 111). ENGR 110 is the first course and is an introduction of the profession and fundamentals of engineering directed towards first-year students. The second course (ENGR 111) is a makerspace-based course and is taught in a 15,000 ft^2 makerspace that is under direction of the SSoE. ENGR 111 focuses on application and integration of the fundamental learned in ENGR 110. Circuitry and programming have been identified as fundamental skills for all engineering majors. ENGR 110 introduces the students to programming fundamentals using the Python programming language. ENGR 111 has students applying the programming fundamentals while integrating circuitry.

ENGR 111 was developed to use Arduino microcontrollers (Arduinos) as the primary programming environment. One motivator for this decision was to show students that core programming fundamentals are the same across multiple programming languages, i.e., an *if* statement is still a conditional that may have slightly different syntax. Arduinos are used in ENGR 111 due to the ease in teaching basic circuitry and the interaction with the circuitry via programming.

The ENGR 111 course has a team-based Cornerstone project that all students complete, demonstrate, and present at the end of the semester. The course instruction, activities, and deliverables throughout the semester are designed to move students towards completion of their Cornerstone project. The semester schedule scaffolds progression towards the comprehensive cornerstone project that each student group completes. These Cornerstone projects are designed as semester long projects that span multiple lab sessions. The long-term nature of the project helps simulate how engineering functions in industry [1]. The team-based project also involves hands-on learning and utilizes the presence of multiple instructors and teaching assistants to assist the students [2] [3].

Introduction to Circuitry Lab

Regardless of the Cornerstone project used in ENGR 111, an Introduction to Circuitry Lab takes place before the final project begins. This module is identical in both courses and covers the basics of circuit components and creating them on a breadboard from a schematic drawing. There are three fundamental topics covered in this module: Ohm's Law, LEDs, and short-circuits. This circuitry lab is the first lab where some of the students have ever used breadboards and built circuits. After the introduction lab, there are a few more labs scaffolding the students' knowledge of circuitry to help them during the creation of their final cornerstone project.

Project 1: Windmill System Cornerstone

The first cornerstone project involves the construction and design of a windmill system (Project 1). Project 1 requires the integration of a windmill, DC motors, student-built AC motors, circuitry, data acquisition, manipulation of the acquired data, and the display of the data results.

Figure 1 shows images of ENGR 111 students working on Project 1, and examples of the respective windmill systems are visible.

Figure 1: Project 1: Windmill System Cornerstone images with students finalizing their cornerstone systems for demonstration.

Project 1 requires the students to measure the rotational speed of the bench-scale windmill powered by a fan to simulate wind. The rotational speed is measured by the students using a proximity sensor. The proximity sensor is read by the Arduino, and the Arduino is used to calculate the timing of the windmill blades passing through the proximity sensor. There is a small DC motor which outputs a basic electrical load. The students utilize these measurements for calculations that determine the overall performance of the windmill system. Mechanically, the students may attempt to improve their system performance by adjusting the blade pitch and output load sizing.

The key to achieving the above values is the circuitry that ties everything together. The circuitry allows the Arduino to receive signals from the proximity and from the DC motor. The Arduino will then display information to the LCD in the circuit. A pushbutton is used in the circuit to cycle through the different data fields the Arduino is calculating. A schematic of the complete circuit used in Project 1 is shown in Figure 2.

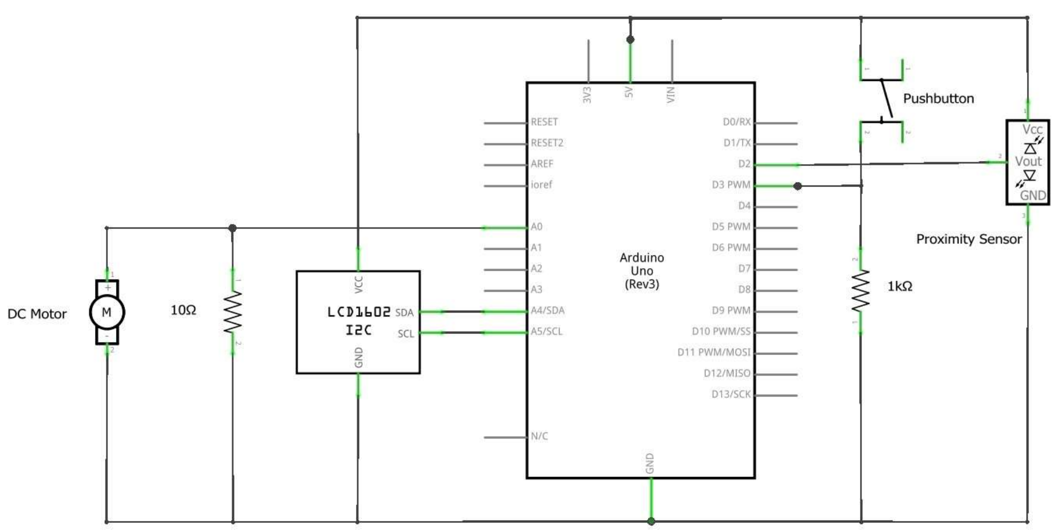

Figure 2: Project 1: Windmill System Cornerstone Schematic

Project 2: Water Filtration System

The second cornerstone project involves creation, control, and use of a water filtration system (Project 2). Project 2 integrates a water filtration system, student-built filtration canisters, circuitry, data acquisition, microcontroller control of a pump and valve to control the water flow, and the display of results calculated from the data. Figure 3 shows a completed water filtration system Cornerstone project, while Figure 4 shows a student adding water to the system.

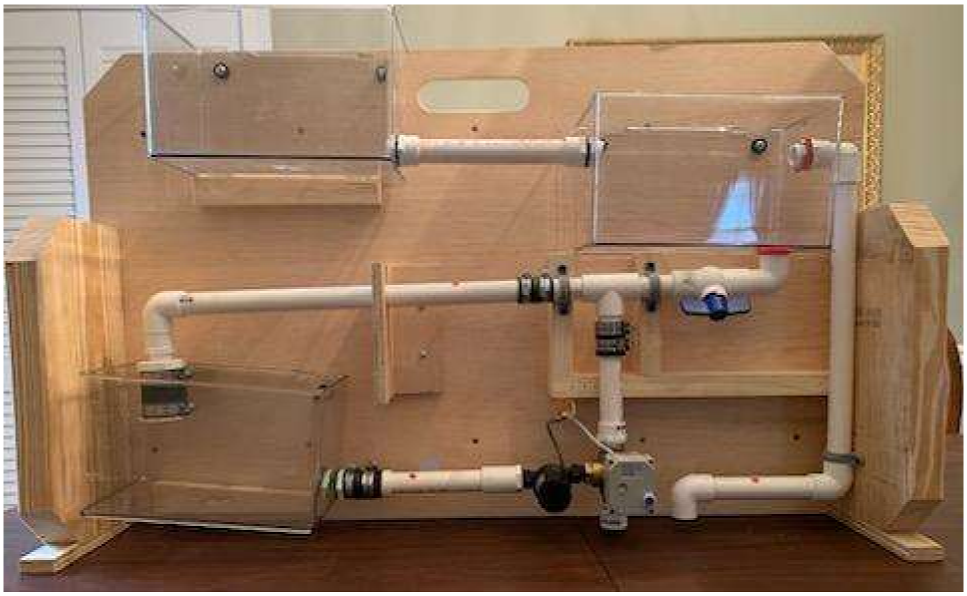

Figure 3: Representation of Project 2: Water Filtration System Cornerstone

Figure 4: Student adding water to Project 2

Project 2 requires the students to incorporate two sensors: a turbidity sensor used for measuring water cleanliness, and an ultrasonic distance sensor for determining the water level in one of the tanks. The ultrasonic sensor is integral to the final water filtration system, since the water level is used to inform a variety of system states. The water level is used to ensure the downstream pump only operates when there is enough water to be pumped. The water level is also used in calculating tank volume and flow rate of the water.

Once again, like Project 1, the circuitry ties all the sensors, motors, and pumps together with the microcontroller. The circuitry allows the Arduino to receive signals from the turbidity sensor and the ultrasonic sensor. The Arduino will then display information to the LCD in the circuit, while using a pushbutton to cycle through the different data fields that the Arduino is calculating. The Arduino is also controlling the pump and valve in Project 2. The Arduino checks the turbidity (cleanliness of the water) and determines if the water is clean enough to exit the system or if it needs to be recirculated. If it is to be recirculated, the valve stays closed, and the pump will push the water up into the system for another round of filtration. If the water is clean enough, then the valve will open and the water will be pumped out of the system. A schematic of the complete circuit used in Project 2 is shown in Figure 5.

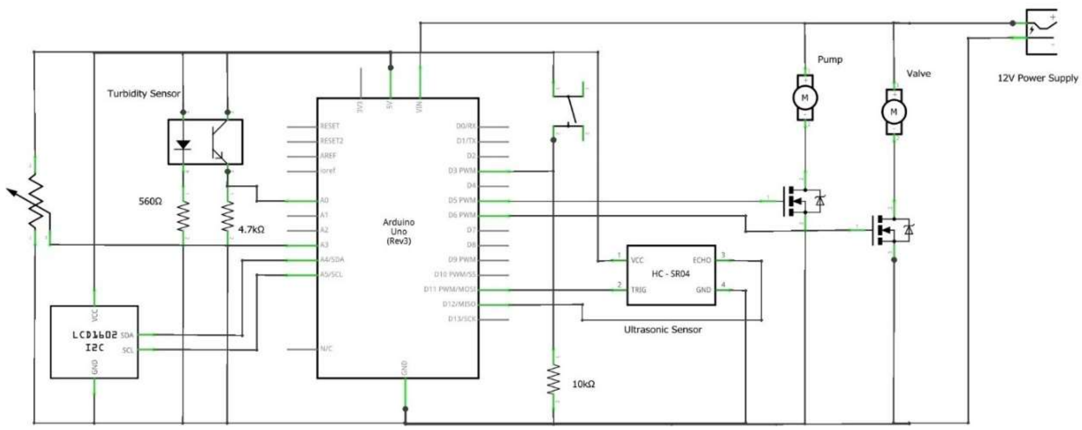

Figure 5: Project 2 Schematic

Study Methodology

At the end of the Introduction to Circuitry lesson, students are required to take a survey regarding their interest in circuitry. Included in this survey are six questions with a Likert scale response, where 1 corresponds to "Not True at All" and 5 corresponds to "Completely True". The questions are as follows:

Q1: When we learn about circuitry in ENGR 111, related instruction and activities grabbed my attention.
Q2: Class work on circuitry makes engineering more exciting.
Q3: I look forward to continuing practice with circuitry because I find it engaging.
Q4: I found the tasks I did in ENGR 111 related to circuitry to be interesting.
Q5: Circuitry is a worthwhile topic to me because it is useful for the engineering profession.
Q6: ENGR 111 was effective in conveying the value of circuitry skills in engineering.

Also, at the end of each semester, students are expected to take a survey about their interest in engineering. Among these questions is one that pertains to their interaction with circuitry, with a Likert scale response where 1 corresponds to "Interest Greatly Decreased" and 5 corresponds to "Interest Greatly Increased". It is provided to students as follows:

Q7: My interest in the engineering profession was strengthened in ENGR 111 because of personal satisfaction in becoming more proficient in: Circuitry.

The primary goal of this study is to see how the Cornerstone Project circuitry experience impacts student interest in engineering. Since the first survey takes place before the Cornerstone project, and the second survey afterwards, these are treated as "pre" and "post" surveys.

Since the first survey has six questions that wholistically considers each student's interest in the topic of circuitry, a Cronbach Alpha coefficient was found for each cohort's dataset to determine cohesion. Coefficients for the Spring 22 and Spring 23 cohorts were found to be 0.911 and 0.930 respectively, indicating excellent internal consistency for these six questions.

In order to determine a quantified progression between two different sets of data, each survey set was normalized about its total possible score using

$$S_{ITC} = \frac{\sum Q_{ITC}}{30} \tag{1}$$

and

$$S_{EOS} = \frac{Q_{EOS}}{1} \tag{2}$$

where S_{ITC}, S_{EOS} are normalized scores for the Introduction to Circuitry (ITC) and End of Semester (EOS) surveys respectively, and Q_{ITC}, Q_{EOS} are the question results per student of each survey. This results in a score for each student that is between 0 and 1.

Next, each students' scores must be compared to show progression from the ITC to EOS survey. This is accomplished through

$$S_{final} = S_{EOS} - S_{ITC} \tag{3}$$

where S_{final} is a final score that is between -1 and 1. Due to its construction, a final score of 1 is only possible with a $S_{EOS} = 1$ (interest in engineering greatly increased due to circuitry) and a $S_{ITC} = 0$ (no interest in circuitry after first lab experience). This clearly indicates a positive effect from the Cornerstone project. Reversing these outcomes (i.e. a final score of -1) presents a negative effect from the Cornerstone project.

Results and Discussion

The final scores for each student in both the Spring 22 and Spring 23 cohorts was determined. Then, these scores were compared using a t-Test to determine if there exists a statistical difference between the two cohorts' scores with a significance threshold of $p < 0.05$. Results from this test are shown below in Table 1.

Table 1: Results of Comparing Circuitry Interest between two Cornerstone Projects

Property	Spring 2022	Spring 2023
Cornerstone Project	Windmill	Water Filtration
Number of Students	301	348
Average Final Score	-0.019	-0.009
Variance in Final Score	0.041	0.063
t-Test p value	0.582	

With a p value of 0.582, which is much greater than the required 0.05, there is clearly no significant difference in final scores between these two cohorts. This indicates that, in general, the progression of student interest in circuitry before and after their Cornerstone experience is similar between the two projects. This means that the Cornerstone projects' circuitry experience has similar effects on student interest in engineering.

It is also noteworthy that the final score averages for both projects are very close to 0. This indicates that, on average, students' Cornerstone experience with circuitry does not have much effect on their interest in engineering – that is to say, their interest level in circuitry before the cornerstone is about the same as their interest level in engineering due to circuitry after the cornerstone.

As the survey questions in this study are among many others that help to capture student interest based on many other course features, there is substantial evidence [4] [5] that the structure of this course helps to foster student interest in the field of engineering. The results of this study indicate that the specific features of each Cornerstone project do not detract from this notion, and that both are suitable contexts in which students can get engaged. This further reinforces a desire for future work that involves expanding to more divers Cornerstone experiences for students.

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