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WiP: Comparing Course Topic Perceptions between Different Hands-On Projects

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WiP: Comparing Course Topic Perceptions Between Different Hands-On Projects

This work-in-progress paper is focused on assessing first-year engineering student perceptions in instructional effectiveness for several key fundamental engineering skill topics; compared between two different iterations of the same course, but with different Cornerstone projects. At the J. B. Speed School of Engineering, all engineering students are required to take a two-course introduction to engineering sequence. The first course, *Engineering Methods, Tools, & Practice I* (ENGR 110), includes introduction and practice in skills fundamental to the engineering profession. The second course, *Engineering Methods, Tools, & Practice II* (ENGR 111), involves interdisciplinary student teams expanding on and applying these skills by means of a hands-on Cornerstone project. ENGR 111 takes place in a 15,000 square foot makerspace and features pedagogy in numerous institutionally-identified fundamental engineering skills.

Each of these aforementioned skills are practiced in ENGR 111 through both discrete instruction as well as integration with a culminating Cornerstone project. For instance, early in the semester, students are exposed to the basics pertaining to 3D printing technology – in addition to training in how to properly covert 3D CAD models into files that the 3D printers (utilized in the course) can read and use to create the modeled part. The developed understanding and skills in 3D printing is later utilized by students during course design challenges in addition to semester-concluding team demonstrations of respective Cornerstone projects.

As alluded to, the engineering system that a Cornerstone project represents may vary amongst different iterations of the ENGR 111 course; and the focus of this paper is specific to two different semesters with dissimilar Cornerstone systems. The Cornerstone utilized during the Spring 2022 semester (Project 1) was a bench-scale windmill generation system. Alternately, the Cornerstone utilized during the Spring 2023 semester (Project 2) was a bench-scale water filtration system. At the end of each of these semesters, students were asked to complete a survey ranking perceived effectiveness for six of the key skills practiced during their ENGR 111 experience. Specifically, students were required to provide a forced-choice ranking ("*Rank the following ENGR 111 topics that you feel were most EFFECTIVE in helping you deepen your understanding of the fundamental skills, knowledge, and qualities of an engineer*"), in which a ranking of "1" was deemed most effective, down to a ranking of "6" for the topic deemed least effective. The six topics included in the survey were: Teamwork, Technical Writing, 3D Modeling/Printing, Design, Circuitry, and Programming. The purpose of this study is to assess the potential impact of interchanging Cornerstone systems on student course perception(s) holistically. Preliminary results show that, for the fundamental topic of engineering design, there is a statistically significant difference between the rankings of the two cohorts.

Introduction

Since the fall semester of 2016, all first-year students at the J. B. Speed School of Engineering at the University of Louisville are required to take a two-course sequence focused on introduction, practice, and application of fundamental engineering skills. The first course in the sequence (ENGR 110) primarily focuses on introduction and practice. The second course in the sequence (ENGR 111) takes place in a 15,000 ft^2 makerspace, is exclusively based in active learning, and is home to J. B. Speed School of Engineering's Cornerstone project.

The Cornerstone project in ENGR 111 is a bench-scale unit that simulates a system. At the end of the semester, student teams demonstrate instructor-prompted system features, including programming with integrated circuitry and student-designed components. The majority of course activities during the semester leading up to the Cornerstone demonstrations focus on various fundamental engineering skill practice and application, all the while building and optimizing the Cornerstone system leading up to demonstration. For most ENGR 111 students, the Cornerstone project is their first exposure to the engineering design process. ENGR 111 leaders are continuing efforts to develop no less than four different Cornerstone systems that can be cycled out for subsequent (spring and/or summer) course iterations; as of now, two different Cornerstone projects have been developed and delivered. Furthermore, course leaders also endeavor to work with industry partners in new Cornerstone development, further augmenting a synergistic relationship between the school, students, and industry. The second developed Cornerstone project was first deployed during the Spring 2023 semester and was developed in conjunction with personnel from the Metropolitan Sewer District.

The effectiveness of formal makerspace-based engineering courses involves a variety of pedagogical entities that have been explored previously. Among these are the many benefits of active learning, which include increased student persistence in engineering programs [1]. Of the numerous types of active learning, cooperative learning in particular can help boost students' sense of belonging [2]. This leads to an important emphasis on teamwork in engineering courses, which is a significant element of engineering when interdisciplinary teams are prevalent in the engineering profession [3]. Ultimately, these elements of a makerspace course are influenced by a desire to boost student motivation, which is initiated by the expectancy-value theory of motivation [4].

The ENGR 111 course experience has provided an excellent platform for studies of the aforementioned elements of Engineering Education. Previous works have investigated logistical components of such a course, active learning implementation, and student feedback and perceptions [5][6][7]. However, almost this entire body of investigation has been completed within the confines of a single project experience, namely a Windmill project. The long-term goal of this course is to vary the context of the learning objectives with different project experiences each year, and recently a second project was finalized and utilized for a full cohort of students. The purpose of this study is to investigate any differences in student perceptions of the course between the two projects. It is worth noting that this paper repurposes data collected for an alternate study [7].

Course Description

This course is designed to be composed of constant hands-on learning experiences that scaffold towards the Cornerstone project. While the concept of the Cornerstone project is described earlier in the semester, the schedule of course activities slowly progresses students towards this final project. This means that course instruction and activities start with fundamental concepts that are somewhat isolated from each other but contribute to the completion of their Cornerstone project. Each of these components is then necessary for students to conclude the Cornerstone project itself at the end of the semester.

In the Spring 2022 semester, students completed a windmill Cornerstone project. The final project had students use a fan to turn windmill blades, which through gears would turn either an AC or DC generator to create power. Students measure various system states about the performance of the system. In the Spring 2023 semester, the final project for students was a water filtration system. The final project had students pumping water between various tanks and measuring how clean it was in real time. Students would use this information to determine if the water should be allowed to leave the system. Figure 1 in the appendix shows teams of students working on each project.

The ENGR 111 curriculum has six key features that are fundamental to the learning objectives of the course. Each of these features is described in detail below. The difference per feature between each Cornerstone varies.

Teamwork

In ENGR 111, students are assigned to teams of 3-4 within the first week of classes and remain in these teams for the duration of the semester. Teams are created with two major objectives in mind: ensure that minorities (gender and race/ethnicity) are not isolated, and limit repeating declared majors when possible. The second objective is of particular importance as it helps to simulate interdisciplinary engineering teams that students may face in the workforce. Additionally, students are tasked with evaluating each other within their teams three times per semester as a part of their teamwork grade for the course. This method is identical regardless of Cornerstone.

3D Modeling

Students in this course are required to complete a series of 3D Modeling assignments using Solidworks, a 3D computer-aided design (CAD) software. Students are provided video tutorials for the creation of 4-5 different models that showcase different modeling features that they may find useful later in the semester. These assignments are completed individually and outside of class. While this method is used for both Cornerstone projects, the videos themselves are not all identical. This is because the expected features students might encounter can vary between the two projects, so the tutorials are curated for that experience.

Engineering Design

A major learning objective for this course is for students to gain an introductory experience with design principles, particularly in tandem with 3D modeling. Students are given two “design challenges” each semester that require them to solve a problem using 3D modeling and design.

For each challenge, teams are given a series of criteria and constraints that their design must follow, and then 3-4 weeks of time to iterate on their designs.

This feature contains a large difference between the two Cornerstone projects, as the design challenges are not shared. For the windmill project, the two design challenges are: 1) a mount that allows for an AC motor to be connected to the geartrain of the rotating blades that can also hold a sensor used to measure its rotational speed, and 2) a rocket launcher chassis used to supply compressed air to a small rocket that must travel at a certain angle and distance. It may be noted the rocket launcher design is the only (of the four different designs stated in this section) not directly integrated within the Cornerstone system. This design was introduced during the COVID pandemic and, due to success in employment under the remote course setting, it was decided to keep this as a second design upon return to in-person instruction. Figure 2 in the appendix shows examples of these two different Cornerstone systems.

For the water filtration project, the two design challenges are: 1) housing for a turbidity (water cleanliness) sensor that is in-line with piping, and 2) a housing for an ultrasonic (distance) sensor mounted above a tank of water to act as a "tank-level indicator", providing real-time water level measurements (Figure 3 in the appendix).

Technical Writing

Teams of students are required to document their experiences with their first design challenge in the form of a technical report. Students are instructed on basic principles of technical writing and given strict guidelines for the curation of their reports. This is also repeated for their first experiment as well, meaning that each team will write two technical reports per semester. The requirements of these reports are identical between Cornerstone projects, though the content is different due to the varying designs and experiments themselves.

Circuitry

Since at least one design challenge involves the positioning of a sensor, it is important that students become familiar with the basic concepts of Circuitry. Students are taught the basic principles of electrical circuits, covering concepts such as Ohm's Law and short-circuits.

One large difference between the two cohorts is that additional out-of-class assignments were added to this curriculum (i.e. the windmill Cornerstone students did not have these assignments, but the water filtration Cornerstone students did). These assignments used a circuit simulation website called Tinkercad and were similar in structure to the 3D modeling assignments. Students were tasked with following along with a video tutorial that leads them through the creation of a circuit that they then submit.

Both Cornerstone projects involve circuitry as needed to power and gather data from sensors. Figures 4 and 5 display schematics for each of the project circuit designs. Both projects incorporate an LCD circuit for displaying information and a pushbutton circuit that toggles what is displayed on the LCD. In the windmill project, the only sensor is a proximity sensor used for determining rotational speed of the windmill blades. Otherwise, there is also a small DC generator that is turned through gears connected to the windmill blades that powers a resistor.

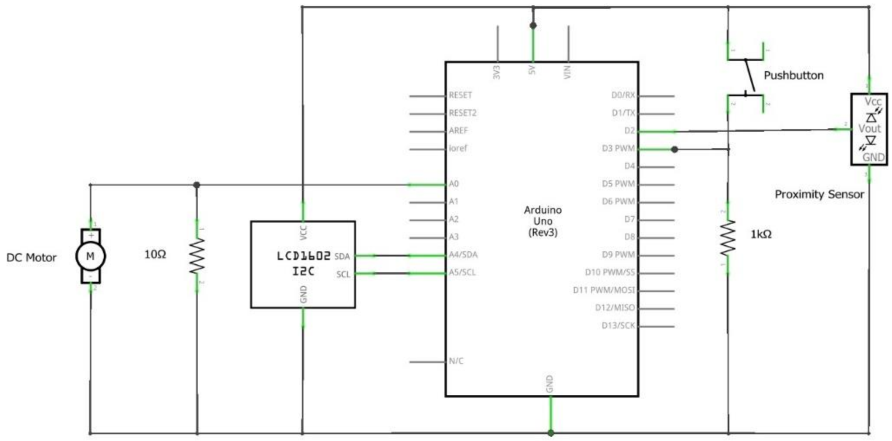

Figure 4: Windmill System Cornerstone Schematic

The water filtration project involves two sensors, as mentioned previously: a turbidity sensor that measure how many particulates are in water, and an ultrasonic sensor that measures distance. Additionally, there are two controlled circuits in this project. There is a pump that can be turned on or off, and a 3-way valve that can move water in one of two directions. Both of these required the use of a motor driver circuit.

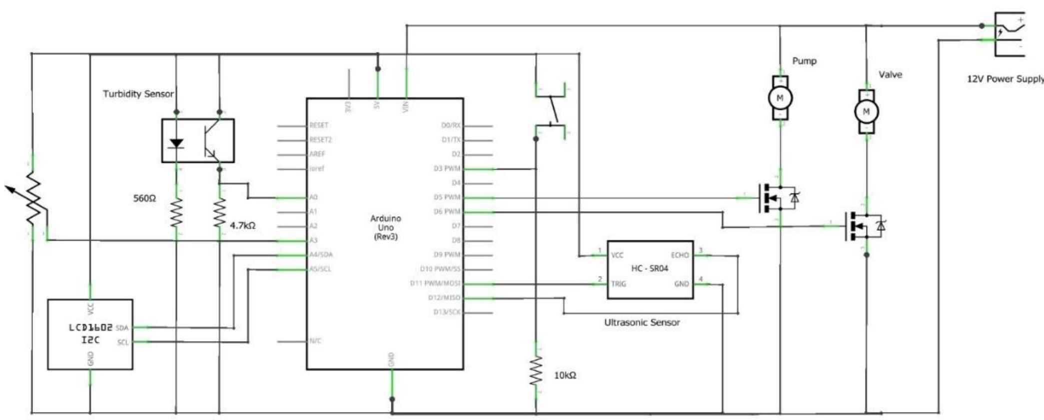

Figure 5: Water Filtration System Cornerstone Schematic

Programming

Another important concept in this course is Programming, which students perform using Arduino Unos. Students have multiple labs that help them get used to the Arduino programming language and let them use programming to start becoming familiar with its uses for the Cornerstone system. The first two modules that introduce programming are identical between the two Cornerstone projects, and the third programming module is specific to each.

Most of the time that student teams spend preparing their Cornerstone projects is on the programming portion of the project. Both projects involve programming the LCD and pushbutton functionality to display information gathered from the system. For the windmill project, teams must use physics relationships to calculate the power and efficiency of the windmill using its measured rotational velocity and DC generator voltage. This means that the programming is almost entirely based on measuring system states and calculating quantities based on those measurements.

This is quite different from the programming needed for the water filtration project. First, teams used geometric relationships to determine the volume of water in a skewed tank based on the height of the water. Then, students used this volume measurement to determine if the pump should be allowed to run (to prevent the pump from running dry). Finally, the turbidity measurement is used by students to control the 3-way valve, which either directs water back to filtration or allows it to leave the system entirely. This means that the programming for this project involves both measurement and control.

Methods

The purpose of this paper is to share preliminary findings on the potential impact of interchanging Cornerstone system projects on student perception(s) of 6 fundamental engineering course topics. Specifically, force-choice ranking data, previously collected for another study, was repurposed here; providing preliminary examination of potential changes in ranking across cohorts with different Cornerstone experiences. Students in ENGR 111 for both cohorts (Spring 22, windmill system, n=364; Spring 23, water system, n=340) responded to these force-choice ranking question as follows:

Prompt: *Rank the following ENGR 111 topics that you feel were most EFFECTIVE in helping you deepen your understanding of the fundamental skills, knowledge, and qualities of an engineer* (1 = MOST EFFECTIVE, 6 = LEAST EFFECTIVE).
Choices: *Engineering Design, Circuitry, Teamwork, 3D Modeling, Programming, Technical Writing.*

Student responses were sorted such that each topic included a list of numbers ranging from 1-6 for each cohort. This allowed for a two-sample t-test to be completed on each topic. An F-Test was conducted first to test for variance, and all samples were found to be of equal variance. A Bonferroni correction was utilized to account for 6 separate t-Tests being conducted. This means that rather than a $p \leq 0.05$ being needed to indicate significant differences, a $p \leq 0.0083$ was used instead.

Results and Discussion

The results of each t-test are summarized in Table 1 below.

Table 1: Results of Two-Sample t-tests for each major topic of ENGR 111 between two cohorts.

Topic	S22 Mean	S23 Mean	P Value
Engineering Design	2.71	3.16	0.00021
Teamwork	2.73	2.74	0.91663
3D Modeling	3.12	3.20	0.45773
Circuitry	3.78	3.63	0.14709
Programming	4.06	4.24	0.16109
Technical Writing	4.42	4.21	0.12225

It is pertinent to note 1) that mean effectiveness for S22 shown in Table 1 are displayed in "ascending" order (that is, aggregate mean is displayed for most effective (lowest value) to least effective (highest value)), and 2) based on numerous years of observation and experience teaching ENGR 111, the ranked order of perceived effectiveness for S22 shown in Table 1 is analogous to what would have been predicted. Concerns in potential S22 student disengagement due to the (second design challenge) rocket launcher lack of integration with the windmill were mitigated by the fact that Engineering Design received the highest aggregate ranking. For the S23 cohort, Engineering Design was deemed second-most effective (versus most effective by the S22 cohort), and this topic was supplanted in S23 as most effective by Teamwork (which was deemed second-most effective in S22). 3D Modeling & Circuitry remained third-most effective and fourth-most effective, respectively, for both cohorts. For the S22 cohort, the topics of Programming & Technical Writing were deemed second-least effective and least effective, respectively, while these two topics swapped placement in S23 with Programming being deemed least effective (Technical Writing moved up to second-least effective). Even when using a Bonferroni correction, there is still a significant difference in the mean score of Engineering Design's effectiveness between cohorts.

There are many reasons why this significant difference exists for the effectiveness of Engineering Design in ENGR 111. The difference in Cornerstone Projects plays a large role in setting context for the design projects that students work on. It's possible that students found a windmill to be a better context for design as opposed to a water filtration system. It's also possible that there is a perceived difficulty difference between the design projects for each cohort that is affecting the perceived effectiveness. This is particularly highlighted with the design of the Turbidity Sensor challenge, which required students to be incredibly precise with measurements. Due to the need for the sensor to be snugly contained within the designed part, students often redesigned for minor dimension adjustments. Also, students had an expectation that the snugness of this fit would convert to watertightness and were often disappointed when that was not the case.

There are many differences between each Cornerstone project that could cause these small shifts in mean effectiveness scores. The fact that the water filtration project programming included system control in addition to measurement, whereas the windmill project only included measurement, could have caused some students to be more overwhelmed. The use of Tinkercad assignments when introducing students to circuitry in Spring 23 may have helped students feel more at ease with the topic when the Cornerstone arrived.

Besides Engineering Design, the only other clear front-runner for highest ranked effectiveness is Teamwork. This remains the case for both cohorts. But while Engineering Design was barely more effective than Teamwork (in fact considered the most effective topic) in Spring 22, it only barely kept second place in front of 3D Modeling in Spring 23. Additionally, the minimum and maximum averages for each cohort shifted. In Spring 22, the average placement of topics ranges from 2.71 – 4.42 (1.71 difference), whereas in Spring 23 the topic averages range from 2.74 – 4.24 (1.50 difference). This indicates that, in general, the effectiveness of each topic relative to the course as a whole became much closer (in S23).

A key consideration in assessing the results shown in Table 1 is the limitation(s) inherent with utilizing force-choice ranking question(s) for the purpose of this study. If a student were to change the placement of one topic, some combination of the other 5 must be altered. For the purposes of Engineering Design's effectiveness, this implies some combination of 1) a student found Engineering Design to be of a particular effectiveness and fit other topics around it, or 2) a student found other topics to be of a particular effectiveness and fit Engineering Design around those. In either case, one topic cannot exist in a vacuum. The nature of the question dictates that each topic is relative to the others. This also means that there is no guarantee that students even considered any topics to be ineffective, just that they were forced to rank some features over others. Furthermore, while none of the other topics showed significant differences between cohorts, the fact that one of them did means that each topic inherently must have played some role in this change. Because this question creates a "zero-sum" system, each other topic must have somewhat small changes that add up to the significant change for Engineering Design between cohorts.

If the sequential ranking of the fundamental engineering topic effectiveness shown in Table 1 varied significantly between S22 and S23, there would be greater preliminary concern that interchanging Cornerstone experience(s) is indeed having an undesirable overall impact on course pedagogical practice and objectives. Regardless, additional means of more effectively studying changed student perceptions in fundamental engineering topic delivery are planned for future iterations of ENGR 111. As previously stated, the data used here comes from answers to a question intentionally designed as a forced-choice ranking for the purposes of another study. However, the authors were interested in this topic and wanted to see if it pointed towards any useful differences between the two projects. For example, a Likert-type survey in which students separately rate perceived effectiveness of each topic (versus forced rankings that by nature place topics at "the bottom" of a listing) will allow much more nuanced analyses; whereas mean scores associated with these types of responses will allow more direct and individual assessment of trends associated with differing Cornerstone experiences. Due to the preliminary results shown here, newly collected data related to perceived effectiveness of Engineering Design across varying Cornerstone experiences will be of particular interest.

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Appendix

Figure 1: Student team working on the windmill (left) and water filtration (right) Cornerstone projects.

Figure 2: Examples of windmill Cornerstone first (left) and second (right) design challenges.

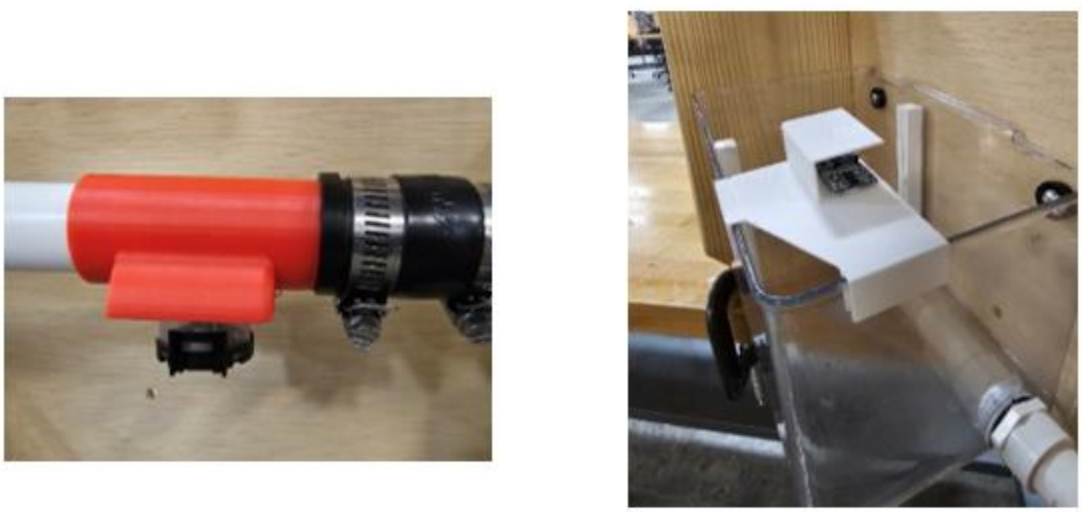

Figure 3: Examples of water filtration Cornerstone first (left) and second (right) design challenges.