Employment of Active Learning Pedagogy Throughout a Makerspace-Based, First-Year Introduction to Engineering Course

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Abstract

This Complete Evidence-based Practice paper is focused on the development and implementation of active learning pedagogy applied within an introductory course in engineering fundamentals at the J. B. Speed School of Engineering (SSoE) at the University of Louisville (UofL). The course, titled *Engineering Methods, Tools, and Practice II* (ENGR 111), is the second component of a two-course sequence and is primarily focused on application and integration of fundamental engineering skills introduced and practiced in the first component of the sequence (ENGR 110). Fundamental skills integrated within ENGR 111 include 3D printing, basic research fundamentals, circuitry, communication, critical thinking, design, engineering ethics, hand tool usage, problem solving, programming, project management, teamwork, and technical writing. The course is required for all first-year SSoE students (no less than 450 per year) and is housed within and delivered via a 15,000 ft^2 makerspace. The ENGR 110/111 sequence is relatively new, resultant from the desire to restructure the previous iteration of the institution's introductory engineering course. A key motivational factor in the desire to restructure included aspiration(s) to conform to modern research in engineering education methodologies, especially the implementation of active learning.

Active learning has been defined as "any instructional method that engages students in the learning process". Generally, active learning refers to activities that are introduced into the classroom, with the core elements of student activity and engagement in the learning process. In summary, active learning necessitates students to do meaningful learning activities in conjunction with thinking about what they are doing and why.

Literature suggest a main reason that students leave engineering is the lack of engineering related experiences in the first year. Accordingly, ENGR 111 was developed with this in mind; creating curricular experiences that tie directly into the engineering experience. Inclusion of active learning pedagogy in ENGR 111 further enhances these efforts.

ENGR 111 employs various forms of active learning, implementing no less than five different types of recognized active learning within the course structure, including collaborative, cooperative, problem-based, project-based, and discovery-based learning. Collaborative learning is present throughout due to the team-based nature of the course. One example of cooperative learning present in ENGR 111 is periodic peer evaluations amongst team members with respect to teamwork effectiveness. The ENGR 111 Cornerstone project is an example of project-based learning, where students work toward completion of a fully realized project. Finally, discovery-based learning is employed throughout ENGR 111 course lesson plans.

In the Spring 2019 iteration of ENGR 111, students were surveyed a ten-point Likert scale on their intentions to continue pursuing an engineering major. Students were then instructed to answer a follow-up question that asked the degree of impact their ENGR 111 experience had on their answer to the previous question. Out of the 440 total students surveyed, over 80% expressed high levels (i.e. Likert values of 8-10) of intent to continue pursuit of engineering. For each of these respective

identified high levels, no less than 72% stated that ENGR 111 had at least somewhat of an impact on these intentions.

Introduction

In the fall of 2014, faculty members at the J. B. Speed School of Engineering (SSoE) began restructuring the school's existing courses that focused on introducing students to the fundamentals of engineering. In the fall of 2016, when these changes went into effect, SSoE transitioned from a single introductory engineering course for first-year students (no less than 450 students each year) to a two-course sequence. The first component of this sequence, *Engineering Methods, Tools, & Practice I* (ENGR 110), is structurally analogous to the previous introductory course and is primarily focused on introduction to and practice with fundamental engineering skills. The second component, *Engineering Methods, Tools, and Practice II* (ENGR 111), is primarily focused on application and integration of the skills developed in ENGR 110. There are a variety of skills taught in ENGR 111, including 3D design, programming, teamwork, and critical thinking.

Potentially one of the most unique features of ENGR 111 is that the course is conducted in a makerspace; more specifically, a 15,000 ft^2 makerspace called the Engineering Garage (EG). Typically, makerspaces are used to offer training in new skills and/or knowledge [1]. Universities have been providing various machine shops, computer-aided engineering tools, and project-testing areas for some time now, but neglect to house these facilities in a single location [2]. Those that do implement such centralized accommodations often only do so for informal settings. Utilizing a makerspace for housing an introductory course in engineering, such as ENGR 111, creates a more formal setting for the use of these facilities.

Conventional first-year engineering curricula require students to complete multiple gateway courses that oftentimes deal with abstract material with little perceived engineering context. As a result, students end up believing that all engineering courses will be similar, and some ultimately leave for other professional arenas where applications can be understood much earlier in academic career(s). One method being used by the SSoE to mitigate this issue is a cooperative education program (co-op) that provides students the benefit of experiencing direct engineering applications in a real-world context. SSoE students are required to partake in no less than three co-op semesters working as a full-time, in-training engineer(s). However, students do not begin these co-ops until late in their sophomore year, by which time many students have already left for other majors as described above. Thus ENGR 111 is an ideal first-year supplement to impending co-op experience(s), since the course has been constructed in such a way that students receive early exposure to the engineering profession, without the need for highly technical knowledge that most engineering laboratory courses require. A pertinent means of keeping students invested in the course, as well as the engineering profession, is through active learning techniques. Studies have shown that an active learning environment produces strong indications of success and increased student persistence in engineering [3] [4] [5].

Course leadership initiated ENGR 111 development with a primary objective to, as much as possible, base course pedagogy in active learning methodology to take advantage of the resultant benefits to the student(s). Active learning can be defined as "any instructional method that engages students in the learning process" [6], yet active learning is often juxtaposed to the traditional lecture where students inactively receive information from the lecture. Generally, active learning refers to activities that are introduced into the classroom, with the core elements of student activity and engagement in the learning process. In summary, active learning necessitates students to do meaningful learning activities in conjunction with thinking about what they are doing and why [7].

However, it is difficult to provide unanimously agreed-upon definitions of various forms of active learning. Nevertheless, ENGR 111 has implemented no less than five different types of recognized active learning within its curriculum, including collaborative, cooperative, problem-based, project-based, and discovery-based learning. Collaborative learning can refer to any pedagogical method where students work together in small groups toward a common goal [6], with its fundamental element being an emphasis on student interactions instead of learning as a solitary activity. Cooperative learning takes place when students pursue common goals as a group while being assessed individually [8] [9] and has been shown to increase students' sense of belonging [10]. Problem-based learning is applicable to the design challenges given in ENGR 111 and is a type of active learning where a problem is presented at the beginning of an instructional lesson and used to provide the motivation and context for the learning that follows [6]. The Cornerstone project is an example of project-based learning, where students work toward completion of a fully realized project. Typically, the project is something tangible and utilizes a hands-on approach [11] [12] [13] and can be either ill- or well-defined. The first-year Cornerstone project in ENGR 111 tends to be more well-defined in comparison to the more ill-defined Capstone project experiences during respective senior years. Finally, discovery-based learning in employed throughout ENGR 111 course lesson plans. In discovery-based learning, students are given tasks, such as explaining observations or answering a question, with the educational objective of discovering the underlying engineering phenomenon [14] [15].

ENGR 111 Course Overview

As previously mentioned, the ENGR 111 course structure is based on scaffolding students towards a final project, the Cornerstone Project. To accomplish this, students spend the entire semester working with the same project to gain familiarity. Only a handful of introductory classes are spent in a classroom, but all other classes of the semester and spent in the makerspace working towards finalizing this project. In this case, ENGR 111 employs the building and design of a windmill generation system as the Cornerstone Project, as shown in Figure 1. Students construct the initial base, nacelle, and blade assembly, conduct performance experiments, design enhancements, and acquire real-time data pertaining to system efficiency and power output.

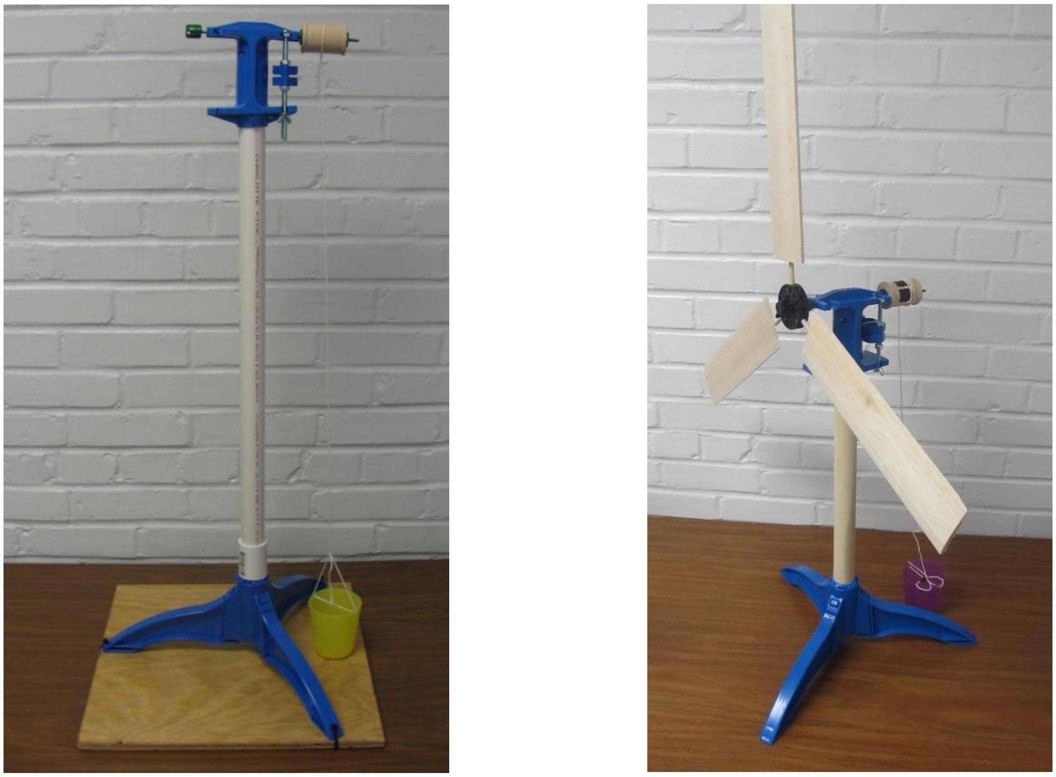

Figure 1: Example configurations of the windmill assembly used in ENGR 111.

The bulk of work performed by students in ENGR 111 is via their teams. Teamwork is one of the most highly stressed skills in the course and is among the lecture topics in the prerequisite course ENGR 110. This is additionally an important factor leading into students' co-op experiences, as one of the qualities being looked for in co-op hires is good teamwork abilities. Students are assigned to teams of 3-4 upon the first week of ENGR 111 and remain in those teams for the entirety of the course. Students complete most of the activities in this course, the majority of which are laboratory-based activities, within their teams, excluding a few individual assignments. This collaborative learning experience allows students to utilize team members' strengths to succeed where they would otherwise struggle, which helps boost student confidence.

As previously mentioned, the bulk of activities in ENGR 111 are laboratory-based, in which students are given instructions for building and testing their windmills. For example, some class periods allow students to experimentally determine the optimal configuration of their windmill structure, such as the optimal number of windmill blades, the pitch of those blades, and the mechanical load that produces the most power. Such activities create a discovery-based learning environment where students learn key engineering concepts through their own efforts as opposed to simply reading about the results of other engineers.

There are two topics in the course which deviate from the collaborative learning described above, that require individual assessment – 3D modelling and a pair of introductory Arduino quizzes. For these topics, students are encouraged to discuss the work with their teammates as they individually complete the activities. This use of cooperative learning encompasses many of the benefits of collaborative learning, as students still work together to accomplish a goal and learn from each other's efforts. However, as these tasks are individually assessed, students are more likely to take part in the assignments from beginning to end. An additional example of cooperative learning used in ENGR 111 is three teamwork evaluations for the semester. Each student receives individual teamwork scores based on a review from their teammates on that student's performance in their group. When providing these reviews, instructors stress that students provide honest evaluations of one another (i.e. that students not attending class or assisting with labs should not receive good scores). This structure allows for instructors to catch problematic group dynamics as they appear and help teach students basic conflict resolution methods.

Design activities include student mandates for designing, printing, and testing a motor mount that effectively houses student-constructed AC motors onto their windmill assembly (Figures 2-3) – in which a set of related criteria and constraints are provided [16]. These constraints simulate design criteria for the student-created parts, such as material usage maximums and the interface with existing structures. Additional design challenges students partake in include a (mandatory) tachometer bracket for determining windmill speed and (optional) windmill blade design optimization. Student teams are provided two class periods to create their initial design, and then may use time after the completion of subsequent activities to test and refine their designs. Through problem-based learning in this fashion, students experience the engineering field in a more concrete way and learn to use their critical thinking skills, as taught in ENGR 110, to find a viable solution to the given problem.

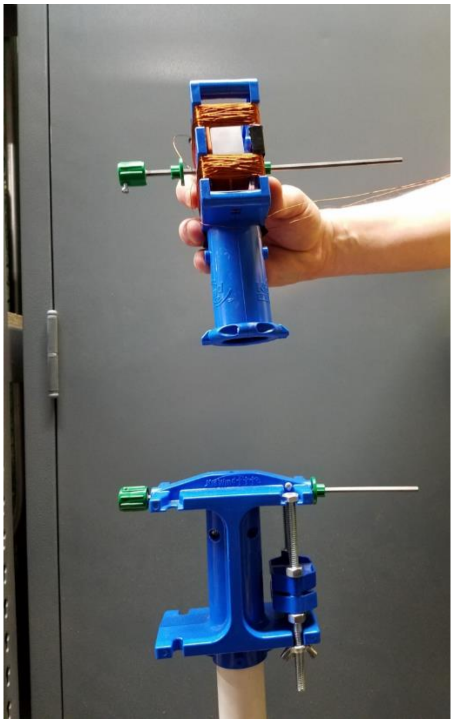

Figure 2: Visualization of design problem given to students for connecting two parts of their windmill assembly.

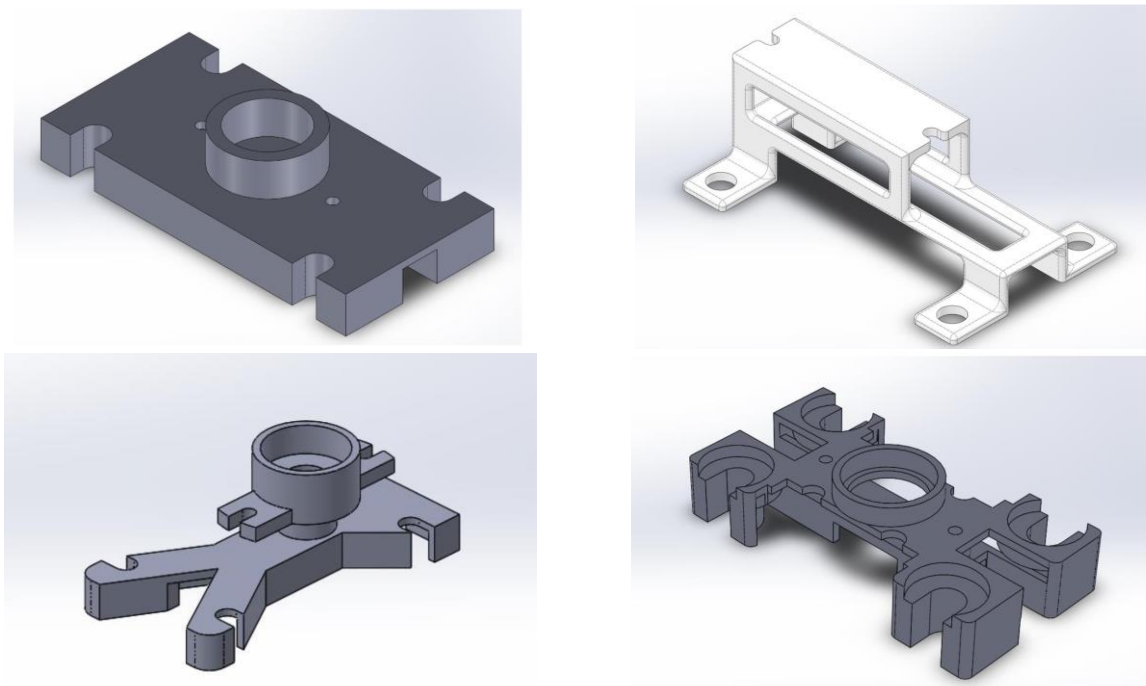

Figure 3: Example Motor Mounts from Student Submissions.

As stated previously, student efforts in ENGR 111 culminate towards their end-of-semester Cornerstone Project. For this project, students work together in their teams to combine knowledge from throughout the semester to gather real-time data for their windmills. Specifically, teams design a mount for a tachometer, program a series of platforms (Arduino and Programmable Logic Controllers), and monitor the performance of their windmill systems. This utilization of project-based learning requires the utilization of mathematics, 3D design, and device programming, which simulates the complexity and interdisciplinary nature of engineering projects that might arise in industry.

Student Survey Results

In the Spring 2019 iteration of the course, 481 students were presented with a survey of questions regarding their experiences in ENGR 111. All surveys were institutionally-approved (IRB), had no associated grade for students, and responses were given anonymously. Among these were two questions regarding student perceptions towards persistence, which 440 students answered:

To what extent do you intend to keep pursuing an engineering major? The answer for this survey question was a ten-point Likert scale, where 1 is *Definitely Will Not* and 10 is *Definitely Will.*

Please indicate below how much (if any) impact your ENGR 111 experience had on the answer you provided on the previous question related to your intent to keep pursuing an engineering major. The provided options for this prompt were *No Impact*, *Somewhat Impact*, and *Significant Impact*.

Figure 4 shows the distribution of student responses to the first survey question, in which it can be seen that the most popular (47.27%) response was a *Ten*. Additionally, it can be seen that the majority of students responded with a high likelihood of continuing in engineering, with 83.41% of students responding with at least an *Eight*. However, this alone does not provide any insight into the role ENGR 111 plays with student desire to pursue an engineering degree.

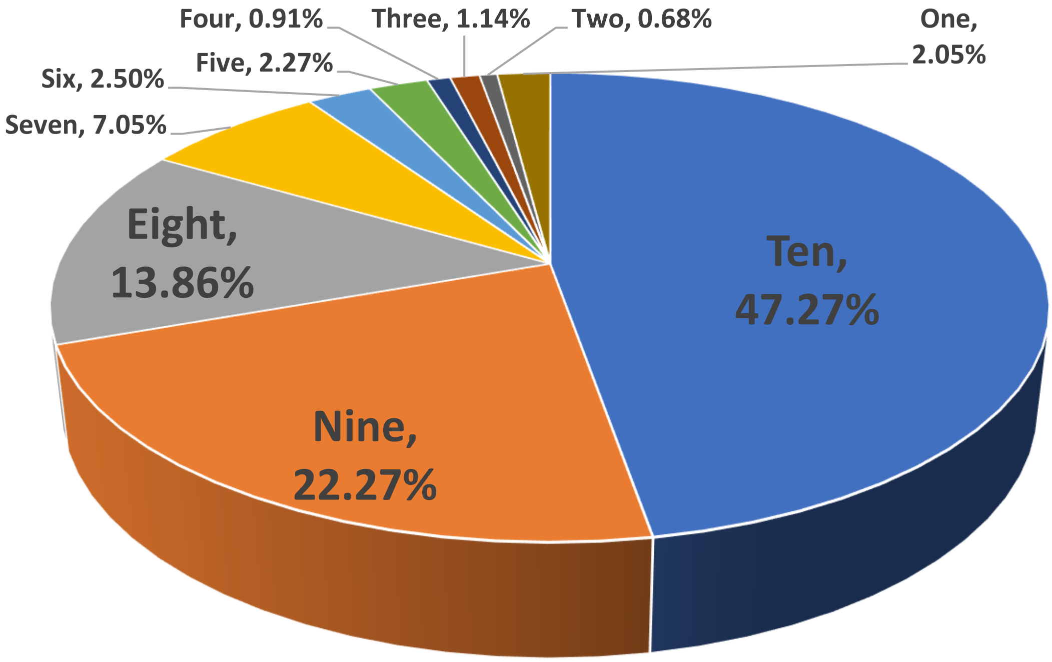

Figure 4: Student responses on their likelihood to continue pursuing an engineering major.

However, Figure 5 shows student responses to both the first and second survey questions. Responses to the first questions are shown along the x axis (with totals next to the category), and the distribution of responses to the second question are shown on the y axis. The total number of students who responded with a high likelihood of continuing to pursue an engineering degree (responding *Eight*, *Nine*, or *Ten*) is 367 students. Of those, the number of students who stated that ENGR 111 had *Significant* or *Somewhat Impact* on that decision totals 279, or 76.02%. This indicates that students who have a strong desire to pursue an engineering degree at the SSoE after their first-year attribute at least some of that desire to the ENGR 111 course.

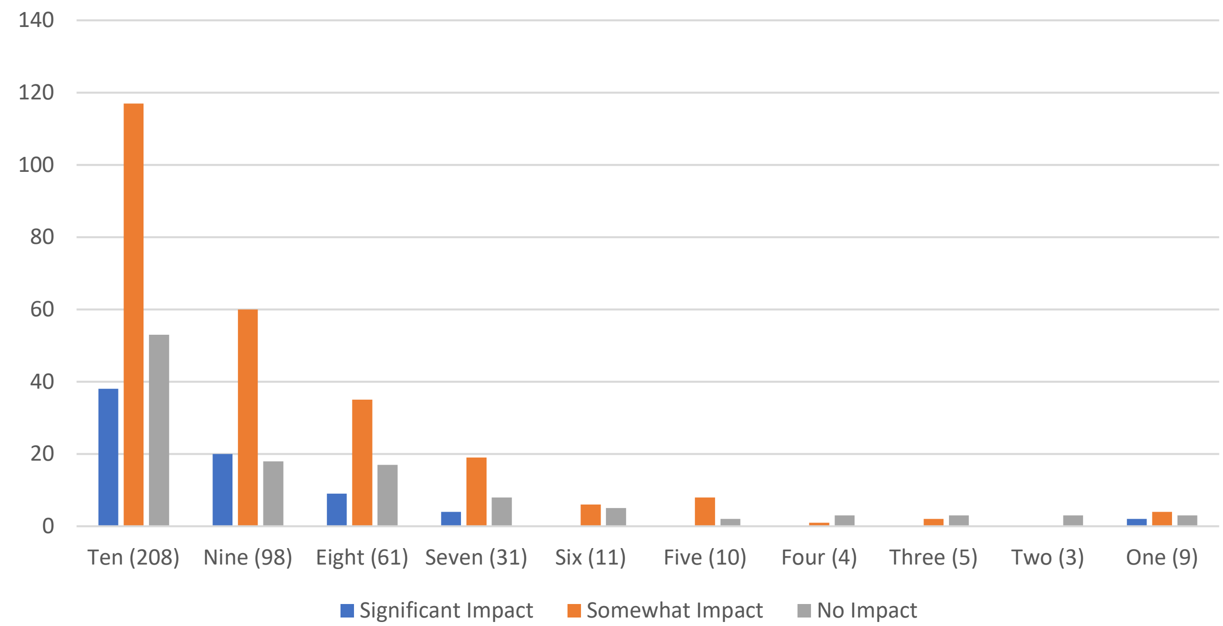

Figure 5: Student responses on the impact ENGR 111 had on their likelihood to pursue an engineering major.

Additionally, 444 of 481 students replied to a statement in this survey regarding their sense of belonging:

ENGR 111 has enhanced my sense of belonging at SSoE. The answer for this survey question was a five-point Likert scale ranging from *Strongly Agree* to *Strongly Disagree*.

Figure 6 shows that over half of students (55.33%) responded with either *Agree* or *Strongly Agree* to this statement, indicating that this course makes the majority of students feel like they belong in this engineering school. Additionally, it can be seen that merely 11.11% of students disagreed with this statement to some extent.

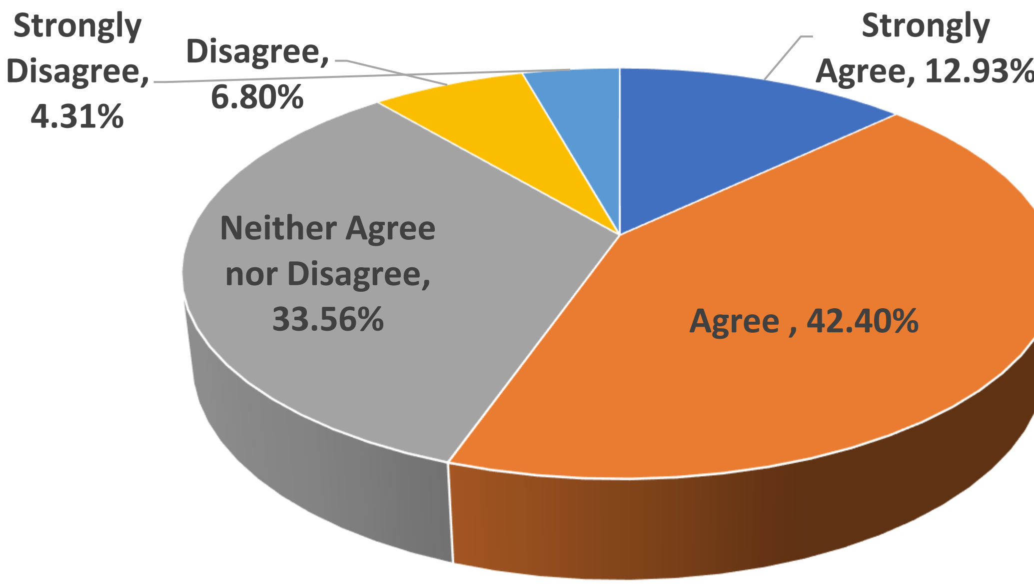

Figure 6: Student responses on the impact ENGR 111 had on their sense of belonging in this engineering school.

Conclusions and Future Work

At the SSoE, first-year students are taught the fundamentals of engineering through a two-course sequence. The second of these courses, ENGR 111, is predominantly based in active learning pedagogy to help students gain insight into the field of engineering early in their academic career, as well as improve student desire to continue pursuing an engineering degree. Survey results from the Spring 2019 iteration of the course indicate that over 80% of students have a high likelihood to continue pursuing an engineering degree after taking the course, and over 75% of those students attribute at least some of that desire to ENGR 111. While the survey data presented above is promising, concrete data related to actual student retention still needs to be assessed in solidifying the trends outlined here. Such data is indeed collected by SSoE, yet was not available at the time of writing this article. Future research will certainly include longitudinal tracking with respect to student retention, once that data becomes available.

Instructor perceptions of the active learning in this course are overall positive. Both the collaborative and cooperative aspects of the course appear to get students heavily interacting with one another. While students in groups often reach a "divide and conquer" strategy, instructors have found that students gain substantial understanding of how to divide work and how to work with the strengths and weaknesses of their teammates. Included in the aforementioned survey was the question *How has ENGR 111 assisted in your understanding of the engineering profession?* Some qualitative student responses pertained to teamwork, such as "It made me realize how communication and team work plays a huge factor in engineering" and "It has helped me realize the significance of teamwork in addition to how the types of engineering (disciplines) intertwine”. Instructors are rather confident that students are gaining valuable knowledge on both teamwork in general as well as working with other types of engineers.

Additionally, instructors have noted the problem-based, discovery-based, and project-based learning aspects of the course appear to motivate students beyond how they might perform in a traditional classroom setting. Students appear more excited to perform class work; much of this excitement stems from students feeling more part of the engineering profession. Student responses to the previous question also pertain greatly to students feeling more like engineers as a result of this course: “Because this class was more hands on, it really taught me how to think like an engineer” and “I was able to actually experience an engineering pathway”. Instructors are pleased with student excitement and engagement during class.

Although ENGR 111 is predominantly based in active learning, there remains three fundamental engineering topics that are still delivered in the course by means of traditional lecture: project management, technical writing, and introduction to design. Current efforts are ongoing to further student engagement, interest, and attention by removing this remaining lecture-based pedagogy and replacing with active learning curriculum; specifically, Classroom Response System (CRS) workshop pedagogy. Implementation of these topics from lecture-based to CRS-based is planned for the next course iteration (Spring 2020), which will result in a first-year engineering experience based exclusively in active learning. CRS allow students to respond to questions displayed on a screen. Once students input their responses using remote devices, the results are instantly collected, summarized and displayed to the class in a visual format. Using CRS augments the feedback process by ensuring anonymity, rapidly and efficiently gathering and summarizing student responses, and averting students from copying answers from their peers. Due to real-time classroom feedback, the instructor has an opportunity to reinforce classroom discussion about concepts being covered. In other studies, CRS have been used to improve student attention, engagement, and interaction [17] [18], improve attendance [19], stimulate peer and class discussion [20], provide feedback for both students and instructors [21], and improve learning performance [22].

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