Creation, Development, and Delivery of a New Interactive First-Year Introduction to Engineering Course

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Abstract

This complete evidence-based practice paper is focused on the initiation, development, and execution of the second component of a two-course sequence for first-year engineering students at a large, public university in the southeastern U.S. This sequence was developed with input from an engineering school-wide committee and represents a thorough restructuring of the school's first-year introduction to engineering program. The restructuring was designed to support the J.B. Speed School of Engineering's effort to have a common first year throughout all engineering majors. The new course sequence provides students with a more applicable and realistic exposure to the engineering experience. The second component of this sequence (*Engineering Methods, Tools, & Practice II*) exclusively takes place in the Engineering Garage (EG), a 15,000 ft^2 makerspace that provides the course with individual classrooms in addition to laboratory-analogous workstations that further augments course delivery. Key logistical challenges, such as student safety and space accommodations, that needed to be overcome for full course realization are discussed.

Each academic year, more than 500 first-year engineering students are exposed to this interactive course, which introduces students to fundamental engineering skills – including teamwork, design, project management, technical writing, critical thinking, programming, communication (including written, oral, and graphical), and an introduction to engineering research. The course includes extensive introductory design pedagogy coupled with project management; including two individual design challenges during the semester, and culminating in a team-based Cornerstone project that all students present at the end of the semester. For conveying key instructional topics to the students, a few select classes are held in the EG classroom(s), while additional instruction is delivered online via supplementary, instructor-created videos. The majority of the course meetings days occur in the EG makerspace and these meetings are activity-based.

Course instruction and activities are designed to methodically expose students to the aforementioned skills, as well as other topics that pertain to engineering fundamentals. Many of the course deliverables have been designed to be dual-purpose, in that they build student understanding of essential engineering skills while also assisting progression towards Cornerstone project completion. The vast majority of in-class activities are team-based, with teams created very early in the semester to be diverse in both background and discipline. Key features of the course include various student-utilized hand tools, various software, Arduino-based circuitry, 3D printers, and hardware-based Programmable Logic Controllers (PLCs).

This course has quickly become high-profile amongst students, faculty, and metropolitan industry alike. End-of-semester surveys suggest strong, positive student feedback pertaining to teamwork development. Other institutional entities such as the entrepreneurship school have partnered with course administrators to educate students on topics synergistic with engineering. New course features have been added with the help of local industries. Future work includes adding new Cornerstone projects with the help and cooperation of local industry partners.

Introduction

In the fall of 2014, the J.B. Speed School of Engineering at the University of Louisville (UofL) commenced an endeavor to overhaul the institution's existing course(s) focused on introducing students to the fundamentals and profession of engineering. After a nearly two-year period of development, the resultant two-course sequence, required for all first-year engineering students, was inaugurated in the Fall 2016 semester. The first component of this sequence, *Engineering Methods, Tools, & Practice I* (ENGR 110), was structurally analogous to the previously-existing introductory course; although, numerous modifications to related pedagogy were made. The second component, *Engineering Methods, Tools, & Practice II* (ENGR 111), was built from "scratch", and thusly accounted for the vast majority of the aforementioned development time. ENGR 111 is the primary focus of this article, of which the principal purpose is to share basic details pertaining to course creation, development, and delivery.

Course Creation

Initiation began in November 2014 with a desire to rethink how students are introduced to the engineering profession, in large part motivated by an aspiration to conform to the latest research in engineering education strategies and the opportunity of uniquely impacting the first-year experience via a newly-created makerspace on the university campus. Another large motivating factor in the desire to restructure the program was the fact that nearly one third of retained J.B. Speed School of Engineering students changed their majors by the end of the first year, which resulted in having to take additional courses that delayed their standard progression towards graduating. Alternately, replacing stand-alone courses in the fundamental areas of introduction to engineering, graphics, and introductory programming with an integrated two-course sequence would allow for a common first year beneficial to *all* students. Additional motivations for the restructure included the yearning to enhance student potential for success in subsequent courses, and to deliver a more substantial, realistic first-year exposure to the engineering design process.

Accordingly, a committee, comprised of representation from all J.B. Speed School of Engineering Departments, was established to evaluate the existing applicable curriculum, and charged with making a recommendation on the foundation for the replacement sequence. The committee reviewed similar courses offered at engineering colleges with common first-year programs, came to a consensus on essential methods, tools, and skills for all engineers, and developed a set of desired student learning outcomes. A two-course sequence was proposed, and the committee agreed the sequence would be required for all first-year J.B. Speed School of Engineering students, and that the two courses would each be two credit hours. The first course in the sequence (ENGR 110: *Engineering Methods, Tools, & Practice I*) would be primarily classroom-based, with a focus on introduction to, and practice with, fundamental engineering skills. The second course (ENGR 111: *Engineering Methods, Tools, & Practice II*) would be held in the Engineering Education Garage (EG), which is the aforementioned (15,000 ft^2) makerspace, and would focus on fundamental engineering skills application and integration.

Seven different fundamental engineering topics were mandated by the committee as follows:

1. Engineering Professionalism (ethics, culture, and risk)
2. Basic Computational and Programming skills

3. Communication (graphical, oral and written)
4. Problem Solving
5. Design Analysis
6. Teamwork
7. Project Management

It is also pertinent to note the committee additionally mandated that the Paul-Elder Critical Thinking Framework [1-6] be taught and utilized throughout the sequence, and that diversity issues would be discussed as part of the professionalism topic area.

Course Development

Key logistical considerations, with respect to personnel and the EG facility (Figure 1), that had to be accounted for prior to course inauguration included safety, space and resource accommodations, and manpower. Student safety is obviously paramount, and the first week of classes are comprised of a heavy focus on training students on guidelines in accordance with facility, university, and state guidelines; in addition to expected safety practices throughout the duration of the course. All requisite safety supplies and equipment, such as safety glasses, hearing protection, and first aid kits, are provided, installed, and/or available within the EG makerspace. In addition to a large makerspace, the EG also houses two adjacent classrooms that can be combined to accommodate up to 96 students. The first week of classes is held exclusively within the classroom(s), and students are not allowed to take part in makerspace activities, which commence in the second week, until they have satisfactorily completed a safety proficiency exam at the end of the first week. Throughout the remainder of the semester, safety checks are administered for each and every student during each and every class held within the makerspace. Requirements in compliance with these checks include safety glasses being worn, no open-toed shoes, and no loose or hanging jewelry. Violations of these requirements result in point deductions from individual student safety scores, which constitute a portion of the course grade. Additionally, course administrators reserve the right to apply further safety deductions and/or remove a student from the makerspace if he or she is deemed in violation of other "common sense" safety practices and/or engaging in egregiously careless behavior.

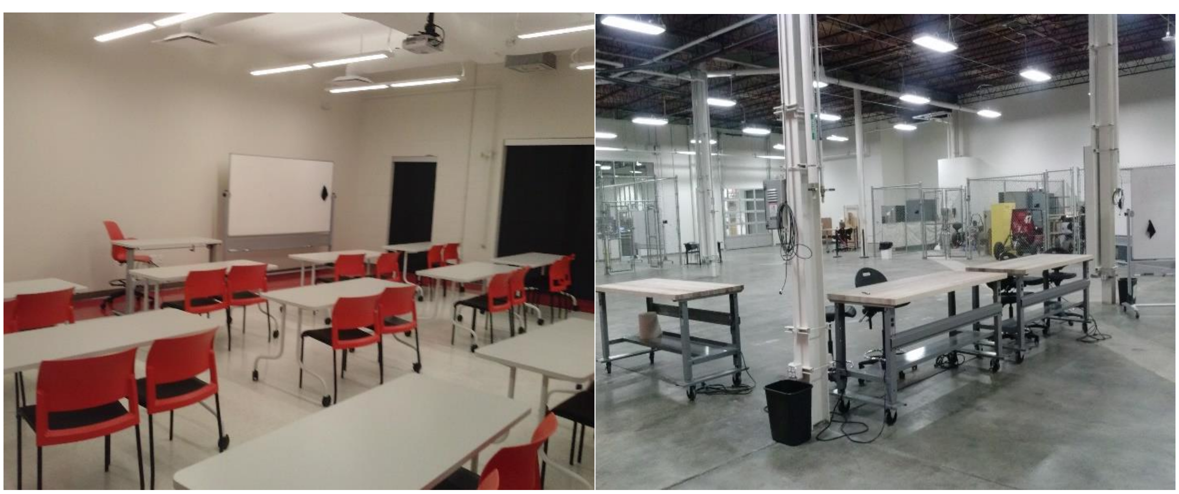

Figure 1. The Engineering Garage (EG) facility. Including the EG classroom (left) and the EG makerspace (right).

Concerning space and resource accommodations, several strategies were established during the developmental phase for the course. ENGR 111 is course taken annually by no less than 500 J.B. Speed School of Engineering students. The course is distributed across 12 sections, with two sections allotted per class, resulting in six different classes of which three consecutive classes are held on Mondays & Wednesdays, while the remaining three are consecutively held on Tuesdays and Thursdays. Each respective class can accommodate as many as 96 students, or 24 (3-4 person) teams. Accordingly, provision of required tools, materials, and supplies for each and every individual student and/or team is not financially viable. In light of this, six separate pods were created within the EG makerspace, containing four individual team workstations within each respective pod. Prior to the start of the first class each day, three tool cabinets (Figure 2) are stationed between adjacent pods and individual, team-assigned cabinet shelves are shared across each respective class. For example, the tool cabinet facing the pod that houses teams 1-4, has four distinct shelves labeled for each team; the shelve reserved for team 1 is shared amongst team 1 members across all six classes, and so on for each additional team within each class. Some of the items supplied within these tool cabinets include hand tools, non-consumable supplies for experimentation, and binders containing hard copies of lesson plans. Also located within the EG makerspace are team cabinets that store individual team totes. Team cabinets are supplementary to the tool cabinets and respective totes store items that are not conducive to sharing amongst other teams, such as individual safety glasses, electronics components, and parts used to construct individual team projects. Finally, one additional makerspace area reserved for ENGR 111 is a course cage (Figure 3) that houses a workspace for course administrators, storage area for all student projects, and the course 3D printers.

Figure 2. Sample tool cabinet utilized in ENGR 111.

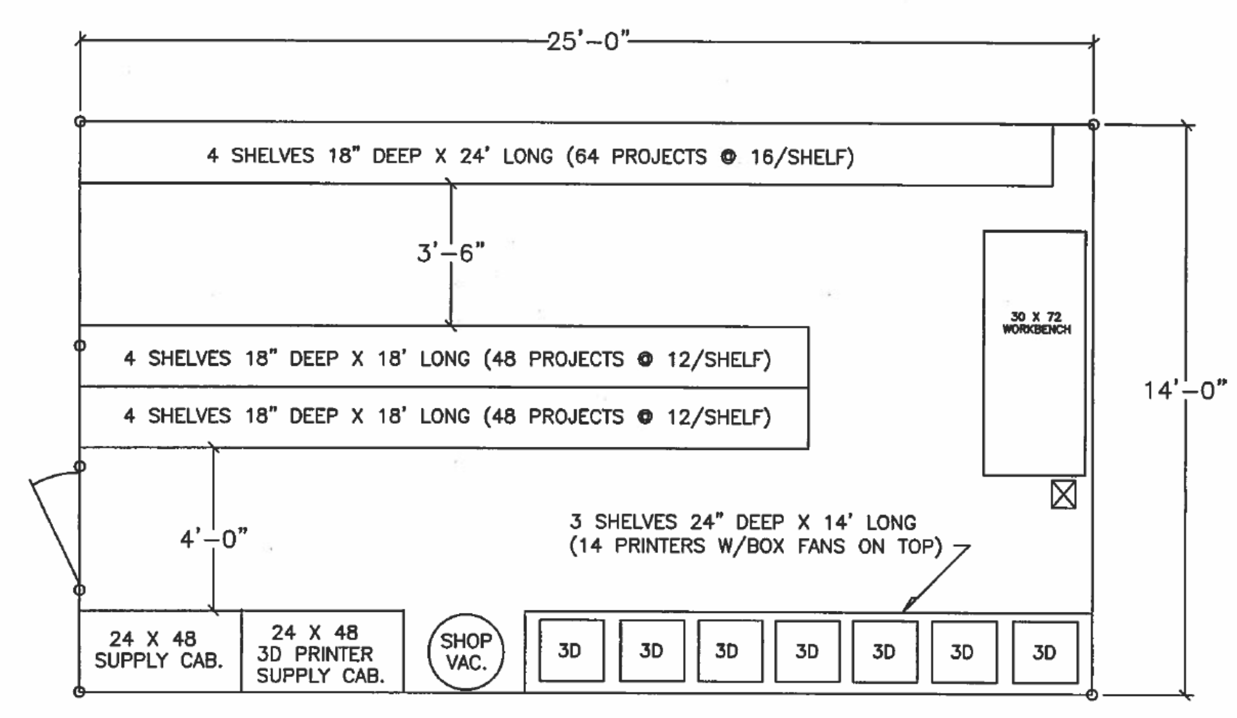

Figure 3. Schematic of the ENGR 111 course cage housed within the EG.

Logistical considerations related to course manpower have proven just as critical as those concerning safety and space readiness. Four faculty from the Department of Engineering Fundamentals are assigned to the course to ensure that assistance, support, and resources are effectively administered for the large number of students, often participating in a multitude of tasks during each class. In addition to providing student supervision and guidance during class hours, additional tasks include maintaining course tools, parts, and equipment, sustaining course-related communication with students outside of class, creating and monitoring student teams, and grading student deliverables. To further strengthen manpower, numerous J.B. Speed School of Engineering graduate student applicants are interviewed annually, resulting in the hiring of seven teaching assistants (TAs). A combination of instructors and TAs of no less than six is typically required for manning each respective class.

It is pertinent to note at this point that the fundamental topic of teamwork received great attention during the developmental stages of the course. The significance of effective teamwork is obvious when considering the abundance of interdisciplinary, team-based undertakings within the modern-day engineering profession [7]**.** Furthermore, for the past several years, when employers, including those partnered with the school's cooperative (co-op) education program (mandatory for J.B. Speed students) and those hiring graduating students, are asked what abilities they are looking for in potential engineering employees, the top answer has consistently been effective teamwork skills. Given that conveying teamworking capabilities may prove difficult for graduating students, the school recognizes the need to establish itself amongst prospective employers as an effective team-building institution. This begins early on for each J.B. Speed School of Engineering student with the ENGR 110 – ENGR 111 sequence. Preliminary instruction and experience in ENGR 110 includes the development of concurrent communication skills, attributes of a successful team, team role delegation, and conflict resolution. ENGR 111 is predominantly focused on the team experience, and the vast majority of class activities and deliverables are team-based. In-class lesson plans, especially those associated with building towards the course's final project, are scaffolded in a manner such that resolution becomes more dependent on team dynamics as the semester progresses. ENGR 111 teams are created during the first week of the course utilizing the CATME online tool [8-10]**.** Early in the first week, students go online to fill out demographic information on identified sex, race, and engineering discipline. By the end of the first week, 3-4 person teams are created in a manner to prevent minority isolation [11] while maintaining interdisciplinary mixture across all teams. Throughout the semester, students are required to evaluate their teammates (also conducted via CATME) on three different occasions. These peer evaluations are correlated into a teamwork effectiveness score that constitutes a portion of the course grade. During these peer evaluations, students are also given a chance to provide specific, comments on team-related issues, concerns, or the like that only instructors can see; thus providing course administrators the opportunity to address extenuating situations accordingly.

In addition to the aforementioned committee mandates, several other engineering topics were identified as fundamental skills applicable across all disciplines. These topics, which were assimilated within the course curriculum, include research fundamentals, conventional hand tool usage, technical writing, circuitry basics, cloud storage, and 3D printing. Likewise, partnerships and collaborations synergistic with the engineering profession have been fostered with university entities external to the J.B. Speed School of Engineering to further augment the ENGR 111 experience. Such alliances include presentation(s) from the UofL's STEM librarian to further student understanding of research potential, and supplemental team building and leadership training via the chair of UofL's Army ROTC chapter. Representatives from UofL's Forcht Center for Entrepreneurship in the College of Business [12] visit the class to educate students on the basics of entrepreneurship and an opportunity to earn a minor in entrepreneurship concurrent with their engineering degree. Student instruction associated to 3D printing includes a tour of the UofL's Advanced Manufacturing Competency Center (AMCC), and course facilitators have worked alongside local industry on collaborative development of various course pedagogical features, such as the implementation of Programmable Logic Controllers (PLCs). Furthermore, leaders from the school's Recognized Student Organizations (RSOs) are given class time to speak to students and raise awareness and potential interest in getting involved with rewarding extracurricular experiences. Additional information pertaining to course structure, including integration of the fundamental engineering topics and synergistic collaborations discussed thus far, can be found in the following section.

Course Delivery

The official title of the final project all ENGR 111 students work towards through the semester is the "Cornerstone Project". All J.B. Speed School of Engineering students conclude their undergraduate career with the completion of a Capstone Project. Starting in the spring of 2019, as a result of the attention and interest ENGR 111 has received from J.B. Speed School of Engineering faculty and metropolitan industry alike, J.B. Speed School of Engineering will be launching a "Cornerstone to Capstone" endeavor. This event strives to convey the J.B. Speed School of Engineering undergraduate experience, and will feature representation of the Cornerstone Project and presentations on various Capstone Projects, while associated faculty, students, industry representatives, and other interested entities gather for a semester-end networking and celebration.

The Cornerstone Project for current course iteration(s) involves the construction, optimization, and mechanical design of a windmill system; which includes the integration of a windmill, student-built AC motors, DC motors, circuitry, and data acquisition systems. Near the end of the semester, a single class day is set aside exclusively for Cornerstone Project demonstrations. Demonstration assessment is divided into two separate components, one dedicated to the windmill motor mount design (detailed below), and the other dedicated to student-programmed windmill parameter display. By means of integrated circuitry and programming executed via Arduinos platform and Programmable Logic Controllers (PLCs) [13], Cornerstone demonstration(s) related to the programming aspect involves the inclusion of an LCD screen that displays five different, real-time windmill system parameters upon toggling of a pushbutton. These displayed parameters are 1) windmill speed (in revolutions per minute), 2) windmill system power output, 3) windmill blade efficiency, 4) windmill motor efficiency, and 5) windmill system efficiency. A rubric has been created and utilized by course instructors for assessing the demonstration component of the course grade. Sample images showing Demonstration Day “in action” are shown in Figure 4. An additional rubric is concurrently used to record individual project parameters and assess windmill system design criteria including creativity, aesthetics, durability, and usability – in addition to the effectiveness of student team oral presentations that occurs during demonstration. These demonstration rubrics do not affect course grade, although they are used to determine the student teams selected to participate in the aforementioned Cornerstone to Capstone endeavor. The final deliverable for the course that all students are required to turn in at the end of the semester is a final report, expected to conform to technical writing guidelines and is predominantly related to the Cornerstone Project. Throughout the semester up to Cornerstone demonstrations, course instruction, activities, and deliverables have been designed in a dual-purpose manner, in that they augment student practice of essential engineering skills while at the same time scaffolding progression towards Cornerstone Project completion. An overview of this sequence follows in the remaining text of this section.

Figure 4. Sample images of ENGR 111 Demonstration Day.

The vast majority of classes are held within the EG makerspace, while the remaining few meetings occur within the EG classroom(s) in which key instructional topics are presented. Supplementary instruction is delivered online via instructor-created videos, many of which require student follow-up quizzes upon viewing. For class days that occur within the EG makerspace, students are provided binders containing lesson plans, which are also digitally available for students to review prior to class. Respective lesson plans contain the purpose of that class's activities, the fundamental engineering skill areas being practices, a listing of tools, supplies, and materials needed, an information section that students can reference (such as resistor rating charts, conversion factors, formulas, etc.), and instructions pertaining to that day's activities. Also included at the end of respective lesson plans are deliverables sheets that students are responsible for filling out and turning in at the end of class. Deliverables sheets consist of varying content, such as team role establishments, recorded measurements, calculations, and follow-up questions rooted in critical thinking elements.

As previously alluded to, the first week of classes are held within the EG classrooms and consists of a heavy focus on safety. Due to the uniqueness of the course, the very first item of business on the first day is thorough review of the course syllabus, overview of the course schedule and logistics, and a brief "peek" at the makerspace. The second day of week one is primarily focused on project management, covering key basics such as project charters, PERT charts, milestones, and critical paths. Students conduct an in-class activity creating Gantt charts in Microsoft (MS) Excel, and an additional assignment requiring students to create Gantt charts in MS Project is due later in the semester.

The second week of the course begins the first week in the makerspace. During this week, students are introduced to basics of circuitry components and symbols while concurrently building electronics kits. Some very basic circuits utilizing the Arduino microcontroller, an LED, a resistor, and a pushbutton, configured in parallel and series, are also created. Tool familiarization begins this week with practice using dial calipers and micrometers. Additional exposure to conventional hand tool usage is provided in conjunction with constructing the windmill base and tower.

The next two classes return to the classroom, with the first class focused on the theme of innovation, in which the topics of entrepreneurship, research, and technical writing are presented. The second class is dedicated to introduction in design. This includes the first exposure for many students to the engineering design process, including key related terms and concepts such as criteria and constraints, decision matrices, and the iterative nature of the process. Other related discussion is on the similarities and differences between science and engineering, and significant advancements in prototyping over the past few decades, along with student engagement in a Family Feud-style game focused on the most useful tools utilized in engineering design.

Upon returning to the makerspace, students finish windmill construction and optimization. Students also measure windmill power (by lifting weights) using two different blade materials (chipboard and/or balsa wood) and determine which material their team has chosen to use for the duration of the course. Follow-up questions on the associated deliverables sheet requires teams to answer what *inferences* led to their decision, and what are the *implications* of that decision. Continuing windmill optimization includes student testing of windmill power output at various solidity, various blade pitches, and lifting increasing increments of weights. Teams are required to generate related power curves with MS Excel, followed by resultant team decisions on configurations that will be used for the remainder of the course.

One final class is held in the EG classroom when students spend the period working on 3D modelling software. The following class in the makerspace teaches students how to use the 3D printers used for the course, accompanied by the aforementioned tour of the AMCC. Subsequent classes resume work with circuitry partaking in activities where students study the basics of electricity, prove Ohm’s Law, and are introduced to diodes and potentiometers. Students also construct AC motors, which are then integrated with circuitry while learning about capacitors and rectifiers.

Design pedagogy for ENGR 111 includes two challenges that must be accomplished to fully realize the Cornerstone Project completion. The first design is for students to design an AC motor mount; that is, an assembly that allows the AC motor to be fastened to the top of the windmill, in which gearing for both the windmill and AC motor are meshed so that the AC motor is turning along with the windmill thus producing electricity that is supplied to team breadboards (see Figure 5 for visual reference). For this mandatory design challenge, a list of instructor-created design criteria and constraints is provided to the student teams. Proficiency in adhering to these criteria and constraints is what informs the rubric for the motor mount design component of Cornerstone demonstrations. The second required design involves the construction of a bracket for mounting the electronic infrared sensors used to create the tachometer for the windmill. Since design is an iterative process, student teams are allowed multiple chances to design, draft, print, and test their parts up until demonstration day. A third design for the course is windmill blade design, which is optional for students. For those that wish to tackle this option, a supplemental video discussing blade optimization such as airfoils and planform shape(s) is made available for team reference. Due to time constraints, less than 1% of the groups do not tackle the blade optimization design project.

The final classes of the semester, prior to those concluding with finalizing the Cornerstone Project and final report, are concerned with activities that educate students on programming with Arduinos and PLCs, including interaction with circuitry and serial interface. Sample activities include the creation of a basic calculator program with the Arduino, and scaffolding the ladder logic that will be used to measure windmill speed (in conjunction with the tachometer) with the PLC. Students also add a DC motor to their windmill system, in turn creating a circuit and associated program that that runs the windmill system in reverse, that is, electrically drive the DC motor which drives the windmill. The configuration is later used during mechanical experimentation in which a “leaky bucket” problem (that students are exposed to in their *Engineering Analysis II* first-year course) is simulated via the windmill system. Students are then tasked with critically reflecting on theoretical power values versus Arduino-measured values.

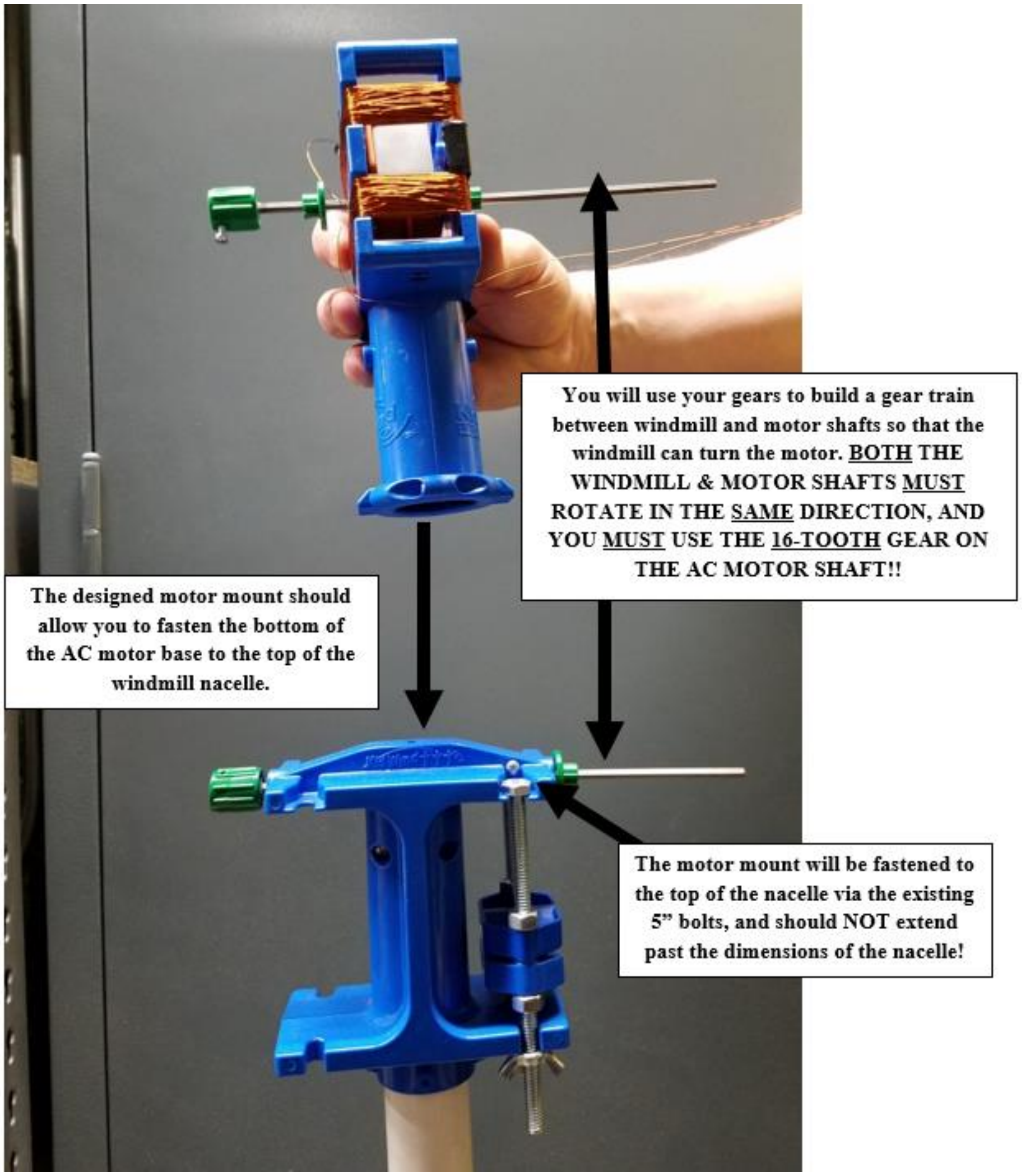

Figure 5. Visual representation of AC motor mount design challenge.

Preliminary Course Feedback

At the conclusion of the semester(s), students were tasked with answering survey questions created by course administrators as an assessment tool for course-related aspects. Two quantitative queries, presented using a Likert scale, related to the teamwork experience in the course were

- "*ENGR 111 has enhanced my ability to work effectively in a team*" and
- "*ENGR 111 has enhanced my understanding of the significance of effective teamwork*".

The Likert scale was distributed across five conventional categories: "strongly agree", "agree", "neither agree nor disagree", "disagree", and "strongly disagree". Results of student responses for the Spring 2017 (S17) and Spring 2018 (S18) semesters are shown in Figures 6-7. There were

503 total students, respectively, in both S17 and S18 semesters. Figures 6-7suggest strong positive student feedback with respect to teamwork. More specifically, responses to course enhancement of teamworking ability were 88.3% positive (“strongly agree” plus “agree”) for S17 and 87.1% positive in S18, while negative responses (“strongly disagree” plus “disagree”) for S17 and S18 were 3.4% and 4.2%, respectively. Responses related to course enhancement of understanding the significance of teamwork were 87.7% positive and 4.2% negative for S17, and 89.6% positive and 2.9% negative for S18.

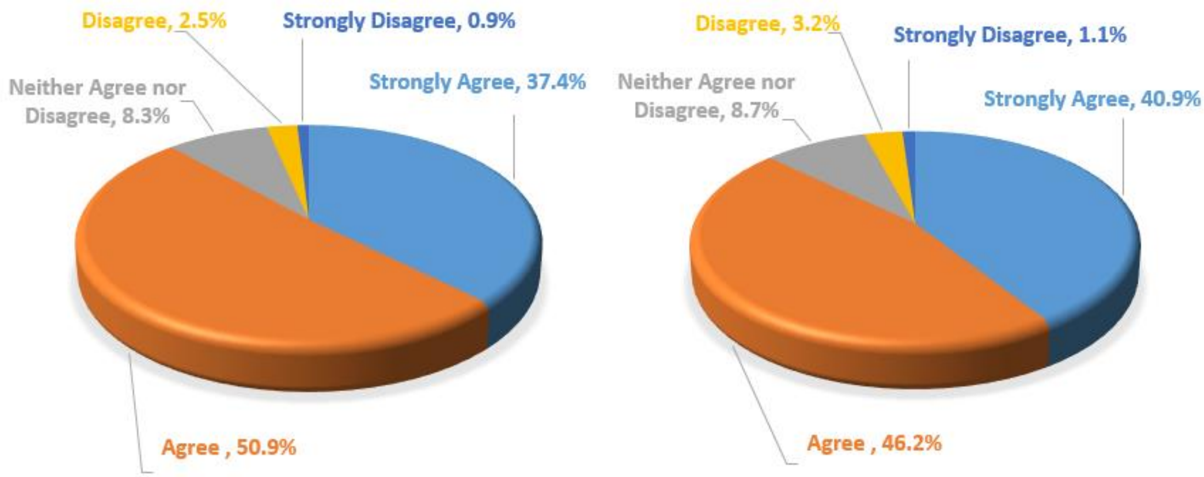

Figure 6. Results of student responses to “ENGR 111 has enhanced my ability to work effectively in a team” for Spring 2017 (left) and Spring 2018 (right).

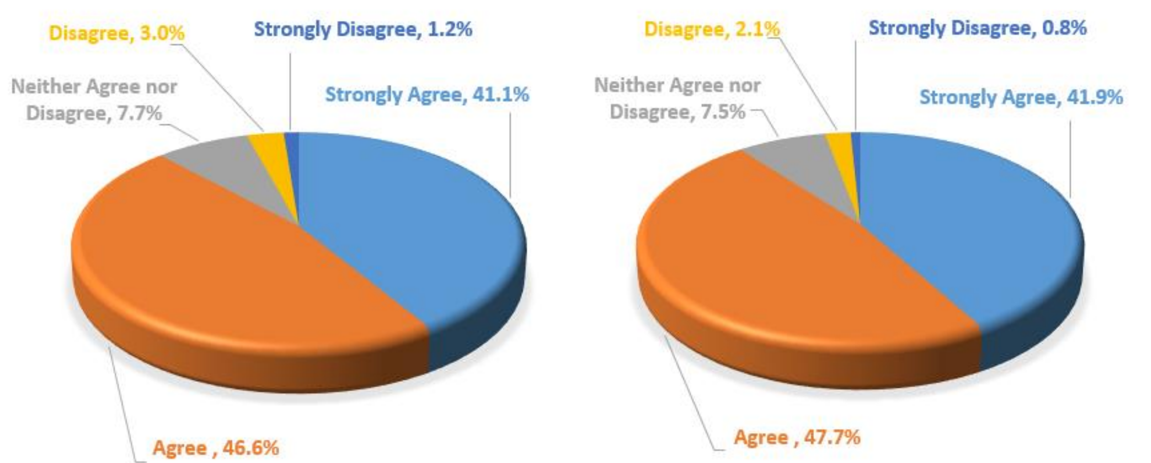

Figure 7. Results of student responses to “ENGR 111 has enhanced my understanding of the significance of effective teamwork” for Spring 2017 (left) and Spring 2018 (right).

Future Work

The intent of this paper is preliminary dissemination of ENGR 111 and to initiate discussion in the academic community by means of conveying a basic course overview. Furthermore, the authors of this paper fully intend to produce numerous journal publications, related to this course, and with much greater detail. The most significant planned modification(s) with respect to future iterations of ENGR 111 is the development of different Cornerstone Project(s) that can be substituted in place of the existing windmill system version. Due to the aforementioned dual-purpose intent of lesson plans, the incorporation of alternative Cornerstone Projects will necessitate changing approximately half of the existing lesson plans, including the creation of new design challenges, so that they maintain the same corresponding practices in fundamental engineering skills while appropriately building towards the applicable final project. These new Cornerstone Projects will be collaboratively developed with local industry. Currently, course administrators are working with the local wastewater treatment facility) on development a Cornerstone Project consisting of a water filtration system. Other regional industry that have expressed interest in collaborative Cornerstone development include an international shipping company and a local appliance manufacturer. These partnerships, in addition to continuing efforts to refine interactive activities, increase synergy between industry and the university, improve supplemental instruction, and will serve to further strengthen an introductory engineering course that has already been well-received by students, faculty, and local industry.

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