Structure of a Human-Centered & Societal-Based First-Year Makerspace Design Course

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This complete curricular practice work shows the full learning module mapping, makerspace classroom structure, and pre- and post- student maker skills confidence survey from a human-centered first-year multidisciplinary design course. "Engineering Design and Society" is a first-year course created for students of all engineering majors to understand larger impact they can make in serving society through practicing human-centered design. Students learn the importance of human-centered design, practice fundamental makerspace skills (hand & power tools, solid modeling, 3D printing, Arduino based sensors and actuators, programming, etc.), and collaborate in multidisciplinary teams to research, design, build, test, document, and present on their human-centered functional prototype. The integration of human-centered design and end-users as part of first-year design experience is important for promoting student interest and retention within engineering [1].

Characteristics that differentiate "Engineering Design and Society" as a novel first year course include the importance placed on human-centered design for first-year students. First-year engineering design courses in the last couple of decades have been designed as project-based and hands-on. First-year projects differ across universities, but typical projects can include a focus on designing and building prototypes, working in teams, full- and small-scale projects, case-study analysis, reverse engineering, and the integration of engineering, math, and science courses [2]. The course described in this paper builds on the effective components of project-based, hands-on first-year design projects, and uses the human centered design process to frame an approach where students are encouraged to incorporate the user, environment, and ethical considerations throughout the process. The course has capacity for over 1,600 students annually at the University of Florida providing meaningful individual hands-on makerspace skills to each student, and physical functional prototype creation using 3D printing and Arduino-based engineering sensors & actuators (not just modeling or computer simulation of designs).

Balanced delivery of course characteristics is achieved through optimizing three student engagement methods: a) active learning through a makerspace classroom, b) utilization of undergraduate peer mentors for student support, and c) self-directed student learning through online module delivery. This complete work breaks the course into 15 modules and for each module, maps out the taxonomy-based learning objectives, self-directed content, makerspace content, and assessments that check those learning objectives in support of the overall course goals. This work is structured in a manner to provide enough module detail and flexibility to facilitate other universities that wish to establish human-centered based first-year courses to serve the needs and culture of their own student populations.

Background

"Engineering Design & Society" was developed by the Engineering Education Department at the University of Florida to serve the needs of students from all engineering majors of having a meaningful hands-on experiential learning course during their first-year on campus.

The defined course goals for first-year students of Engineering Design & Society are:

1) Understand and practice the human-centered engineering design process for a societal based project.
2) Learn techniques to solve open-ended engineering challenges.
3) Promote a culture of making by introducing solid modeling, programming, sensors, data acquisition, 3D printing, and other maker tools.
4) Build teamwork and cooperative learning skills through participation in multidisciplinary teams and active engineering project management.
5) Build professional skills in background research & written, pictorial, and oral communication methods.
6) Raise awareness of ethics and contemporary issues in engineering design related to a global society.
7) Introduce engineering students to the various engineering majors and their roles within society.
8) Inform students of opportunities for experiential learning related to their majors throughout the college of engineering and community.

Makerspace Classroom and General Course Structure

A makerspace classroom layout, illustrated in Figure 1, was designed to serve the unique active learning needs of the Engineering Design & Society course. The main aspects considered in the design of the classroom were balancing open access to makerspace tools for first-year students, student safety, collaborative learning, flipped classroom instruction, and peer mentoring for student skills support.

The classroom is designed to serve sections of 48 students, working in teams of six. The space includes student and professor worktables that all contain makerspace tools, such as power and hand tools, and equipment for working with digital electronics. The professor table has an overhead camera and the capability to control the student monitors at each table. The professor is able to demonstrate the use of a tool under the camera and the monitor at each student worktable will show a live feed of the professor's work. The professor can also choose to display a video or other media at each student monitor from the professor worktable.

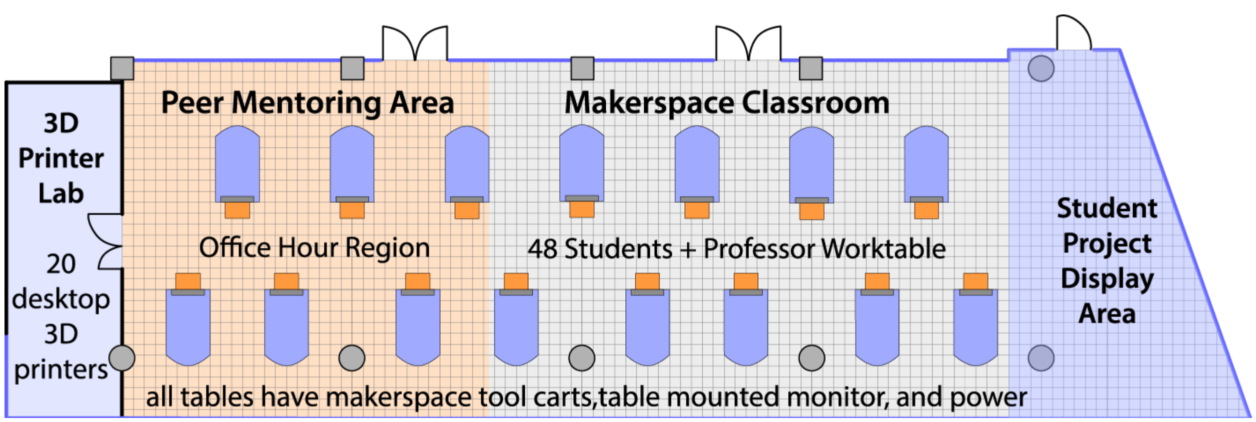

Figure 1: Layout of makerspace classroom for first-year Engineering Design & Society course.

The Engineering Design & Society course utilizes peer mentors to assist the professor with each section of the course to ensure first-year student safety and assistance learning the makerspace tools. Each section of 48 students has a dedicated professor and two peer mentors. Peer mentors are undergraduate students who previously completed the course and demonstrated a natural ability to mentor and assist students. Peer mentors are paid hourly for their work, and take student privacy and safety training for serving as assistants in an undergraduate course. Peer mentoring provides the needed attention to make the makerspace experience individualized for each student's needs and entering level of experience with makerspace tools. A portion of the larger makerspace is used for peer mentors to serve students from other sections needing access to tools and 3D printers to work on their projects throughout the day. The classroom itself has glass walls on three sides, and is on the ground floor of the building, so students working in the makerspace can be seen from both the outside of the building, and the inner building atrium. This physical transparency helps for both student safety, and for external stakeholders for fundraising and promotion of the course and college goals for hands-on learning.

A 3D printer lab, which is dedicated to the Engineering Design & Society course, is attached to the main classroom and equipped with 20 desktop 3D printers. Students learn to individually operate the 3D printers as part of the course curriculum. Additionally, there is a display area with floor power, where students' final projects, i.e. the functional human-centered prototypes, can be publicly displayed.

Engineering Design & Society is a single semester, two-credit hour course. This two-credit hour format allows enough time for students to learn the basic skills emphasized in the course, while affording departments the flexibility to fit the first-year design course into their curriculum. The course structure, half-lecture and half-laboratory course, is designed to optimize the use of the makerspace classroom. The lecture half is structured as online videos and other learning content students need to complete before coming to the live laboratory makerspace portion of class. Students attend the live makerspace class once per week for a two-hour block of time. The laboratory half is structured for students to work in teams, utilize the makerspace tools, and receive feedback from the professor and peer mentors on their projects. With the combined online lecture and live laboratory format, students are expected to complete approximately one hour per week of online material prior to coming to the makerspace classroom. These materials are directly related to the hands-on activities students will perform in class. Assessments within the course are a balance of individual and team assignments to check both student's individual and collaborative learning goals.

The deliberate design of the course structure and physical learning environment allows for the scheduling of up to 35 sections of the course per year (14 fall, 14 spring, 7 summer), with 48 students per section, this would serve 1,680 student per year. The room has capacity for up to a capacity of 60 students per section (with increased peer mentors per section) to serve up to 2,100 students per year. However, based on projected needs for the next few years, the sections should not exceed 48 students per section.

Week-by-Week Course Modules

A team of faculty, representing six different engineering disciplines, performed a Bloom's taxonomy-based mapping of course content for Engineering Design and Society to create a 15

Module structure to support the defined course goals. The fall and spring semesters have 15 weeks in a semester, so for the majority of the year each module represents one week of content. The modules outlined in Figures 2 through 13 are structured to show a mapping of the course by module subject, learning objectives, pre-class online content, in-makerspace class content, and post-class assessment.

The course grading scheme is 45% Homework (9 assignments worth 5% each); 15% Quizzes and Surveys; 25% Final Design Report; and 15% Final Design Presentation. Final Design Report grades are weighted by team member peer evaluations, if needed.

The purpose of the team's Final Design Report and Final Design Presentation is to describe and justify their final design and process using a human centered design approach. Students are encouraged to frame and document their approach such that it ensures that the needs of the user are taken into account throughout the design process. Sections required in the Final Design Report include: Title Page; Table of Contents; Human-Centered User Needs; Design Justifications; Ethical & Environmental Considerations; User Manual with List of Parts/Functions; Engineering Drawings; Pictures of Final Prototype; Flowchart; Commented Code; Design Limitations; and Appendix. The required sections and structure of the final design project deliverables aim to facilitate students in reporting and reflecting on the integrative, iterative nature of the design project in this course.

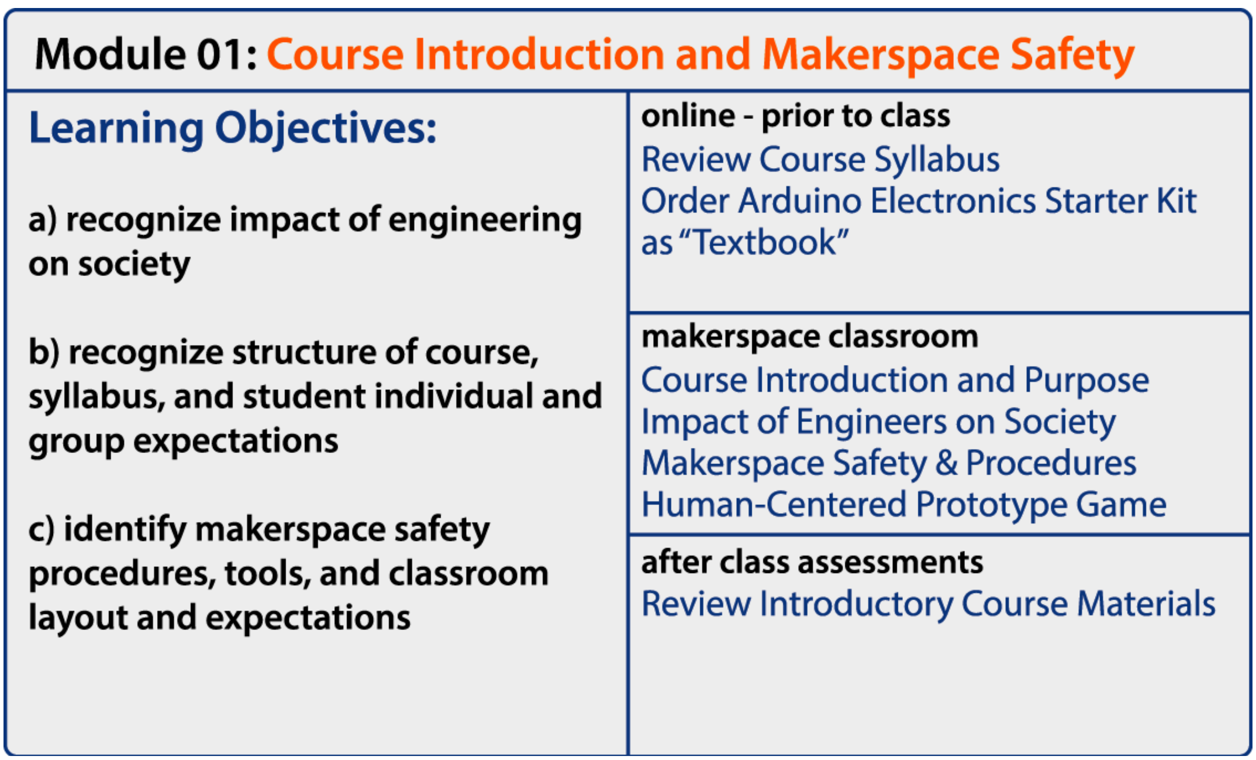

Figure 2: Module 01: Course Introduction and Makerspace Safety

Module 02: Human-Centered Engineering Design

Learning Objectives:	
a) describe and explain parts of the human-centered design process b) practice a collaborative open-ended challenge using the human-centered design process c) understand use of engineering design notebooks within design d) identify engineering major and student society options	**online - prior to class** Human-Centered Design Engineering Design Notebooks Engineering Majors Student Organizations **makerspace classroom** Human-Centered Group Prototype Design & Build Challenge Ethics Case Studies Activity Peer Mentor Introduction **after class assessments** Quiz 01 (human-centered design, majors, student societies) Educational Survey 01 (initial benchmarking survey)

Figure 3: Module 02: Human-Centered Engineering Design

Module 03: Teamwork, Memos, Ethics & Environment

Learning Objectives:	
a) recognize roles in diverse multidisciplinary team b) create functional team charter c) structure an engineering memo d) understand and reflect on role of ethics and environmental considerations in design process	**online - prior to class** Teamwork & Team Charters Engineering Memos Ethics and Environmental Considerations in Design **makerspace classroom** Team Reveals, Team Charter Draft Ethics and Environment Activity Solid Modeling Software Setup Hand/Power Tools Introduction **after class assessments** Homework 01 (individual engineering memo on ethics & environment) Solid Modeling Online Tutorial

Figure 4: Module 03: Teamwork, Memos, Ethics & Environment

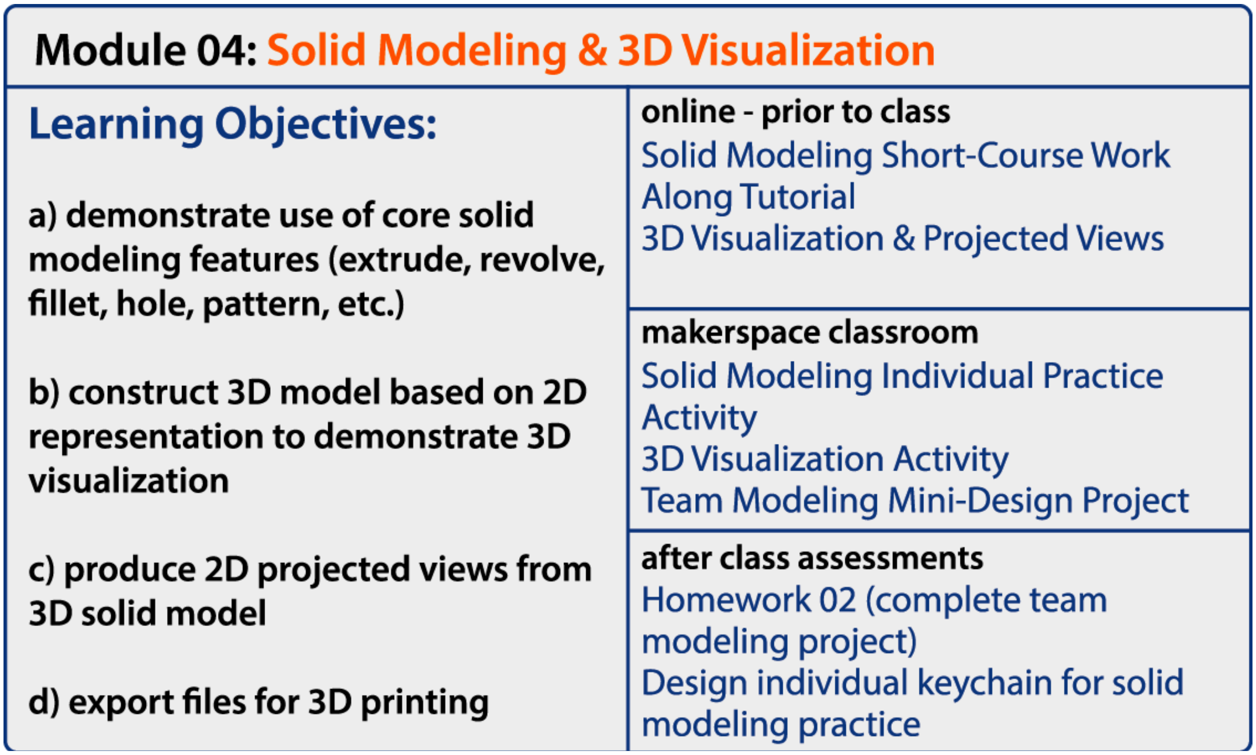

Figure 5: Module 04: Solid Modeling & 3D Visualization

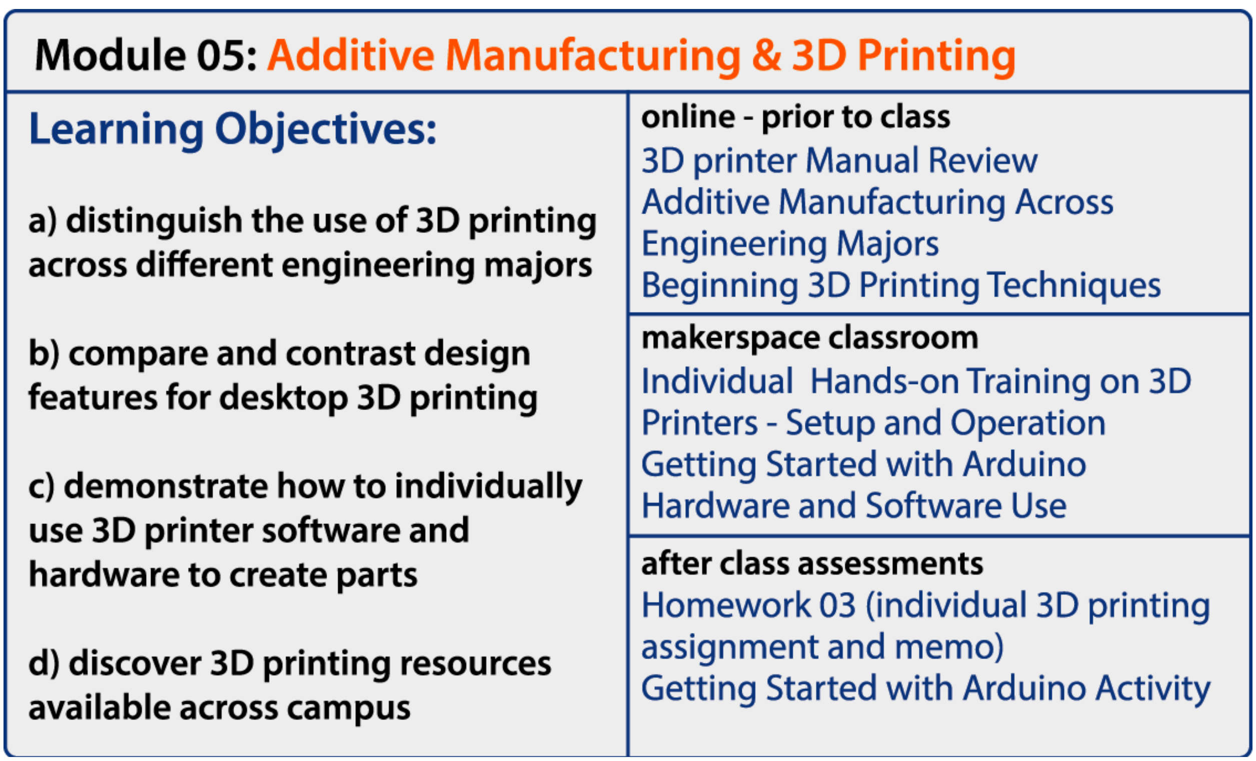

Figure 6: Module 05: Additive Manufacturing & 3D Printing

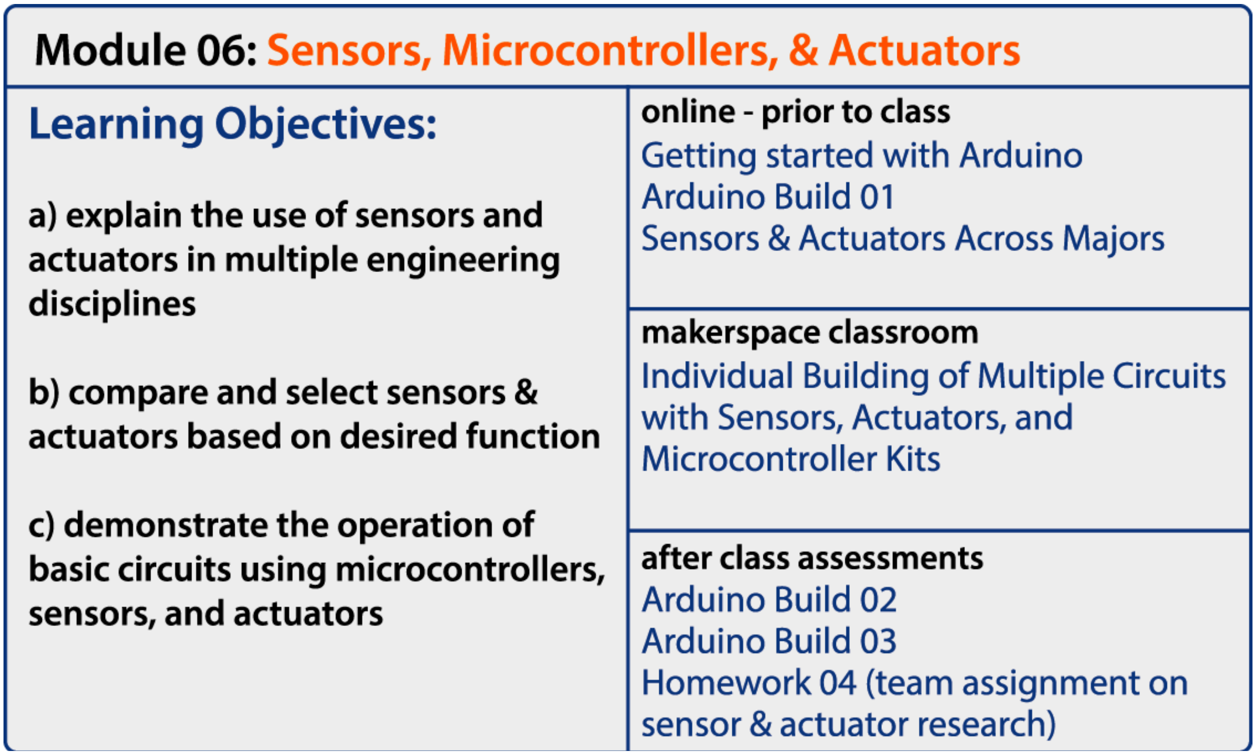

Figure 7: Module 06: Sensors, Microcontroller, & Actuators

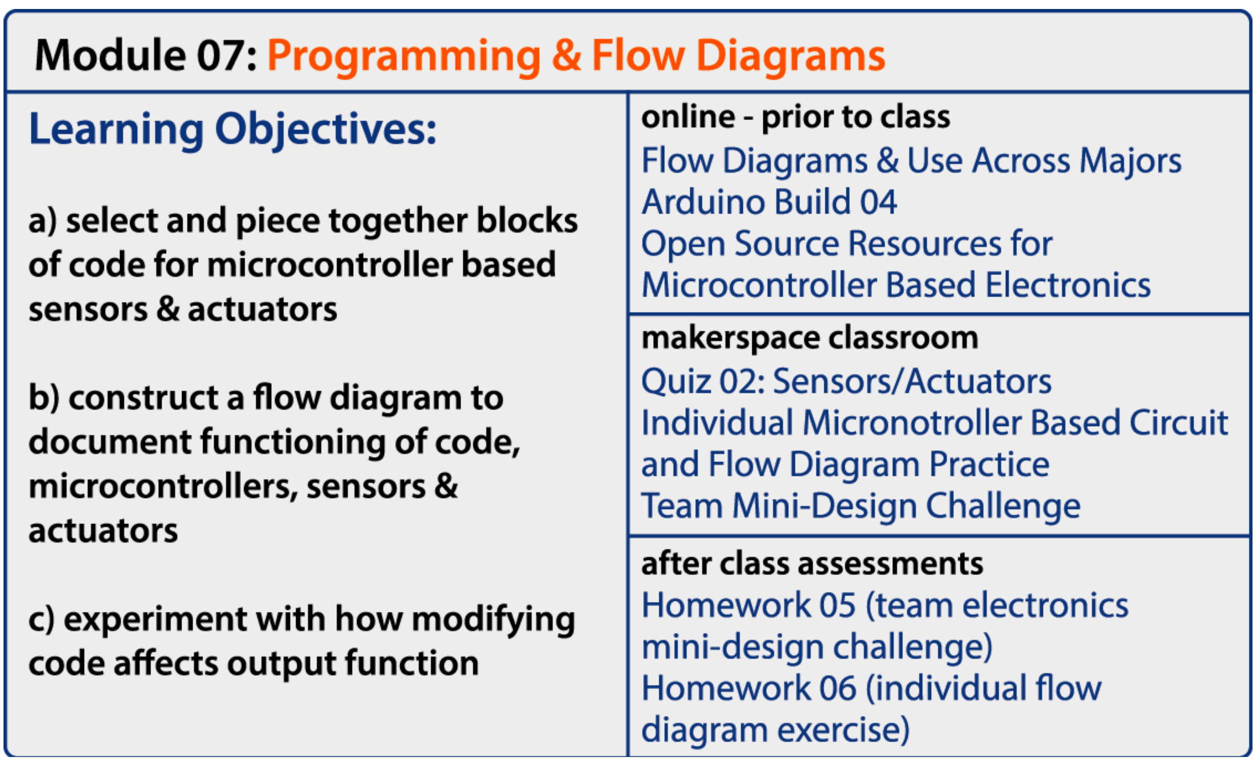

Figure 8: Module 07: Programming & Flow Diagrams

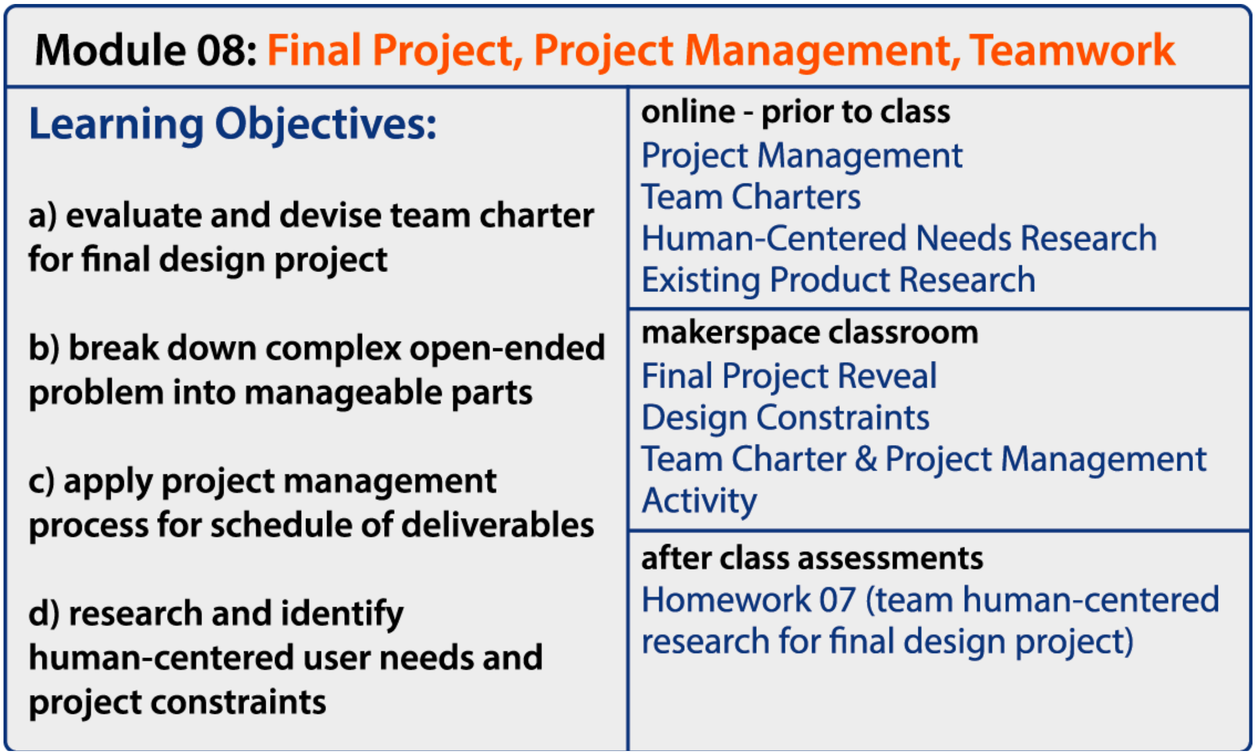

Figure 9: Module 08: Final Project, Project Management, Teamwork

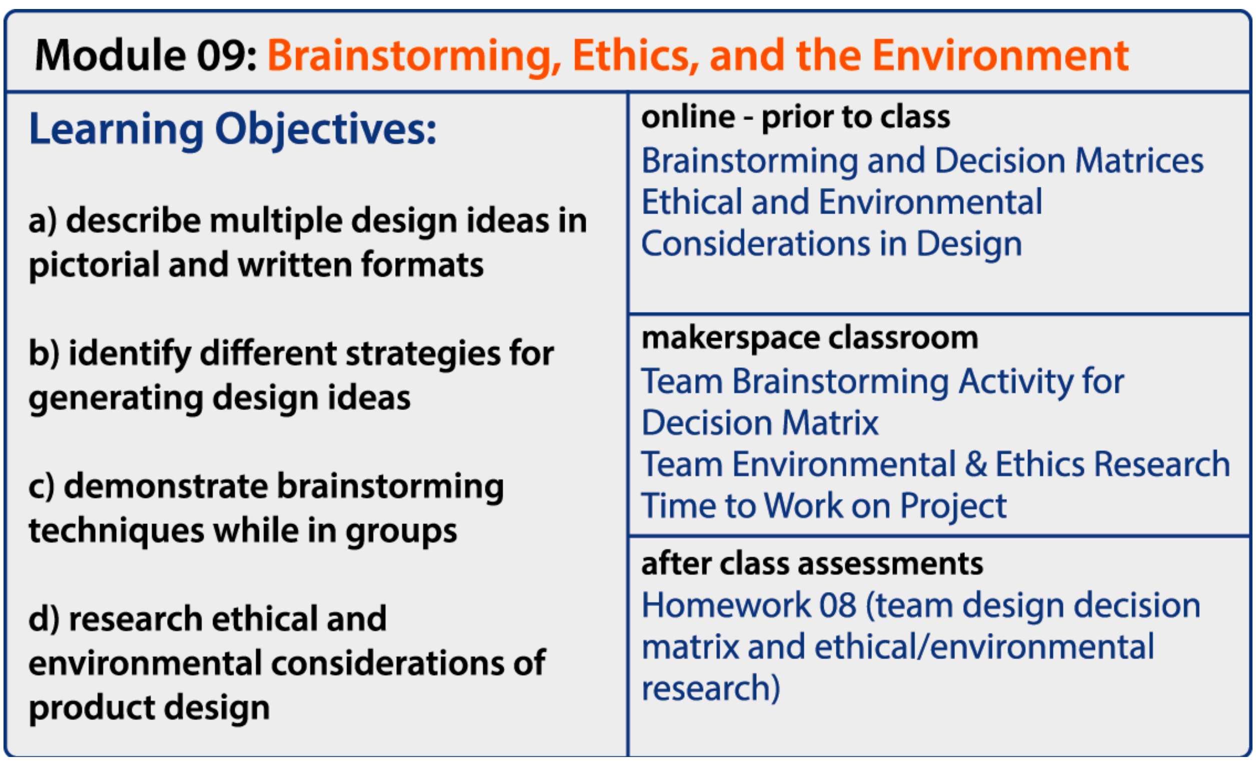

Figure 10: Module 09: Brainstorming, Ethics, and the Environment

Module 10: Design Reports & Functional Prototypes

Learning Objectives:	
a) identify key features of a functional engineering prototype b) review and outline sections of a human-centered engineering design report c) develop both technical and non-technical written communication skills d) work on open-ended challenge	**online - prior to class** Engineering Design Reports Functional Prototypes **makerspace classroom** Engineering Design Report Sections Functional Prototype Expectations "Electronic Guts" Timeline Time to Work on Project **after class assessments** Continue Work on Final Project Order any Necessary Parts

Figure 11: Module 10: Design Reports & Functional Prototypes

Module 11: Pictorial Communication and Presentations

Learning Objectives:	
a) illustrate effective use of pictorial communication for both teamwork and presenting to audiences b) examine guidelines for producing charts, graphs, plots, drawings, etc. c) communicate engineering design process and results d) demonstrate use of elevator pitches for communication	**online - prior to class** Pictorial Communication Verbal Communication Elevator Pitches **makerspace classroom** Characteristics of a Good Presentation Grading Rubric for Presentations Time to Work on Projects **after class assessments** Continue Work on Final Project Begin Work on Final Presentation

Figure 12: Module 11: Pictorial Communication and Presentations

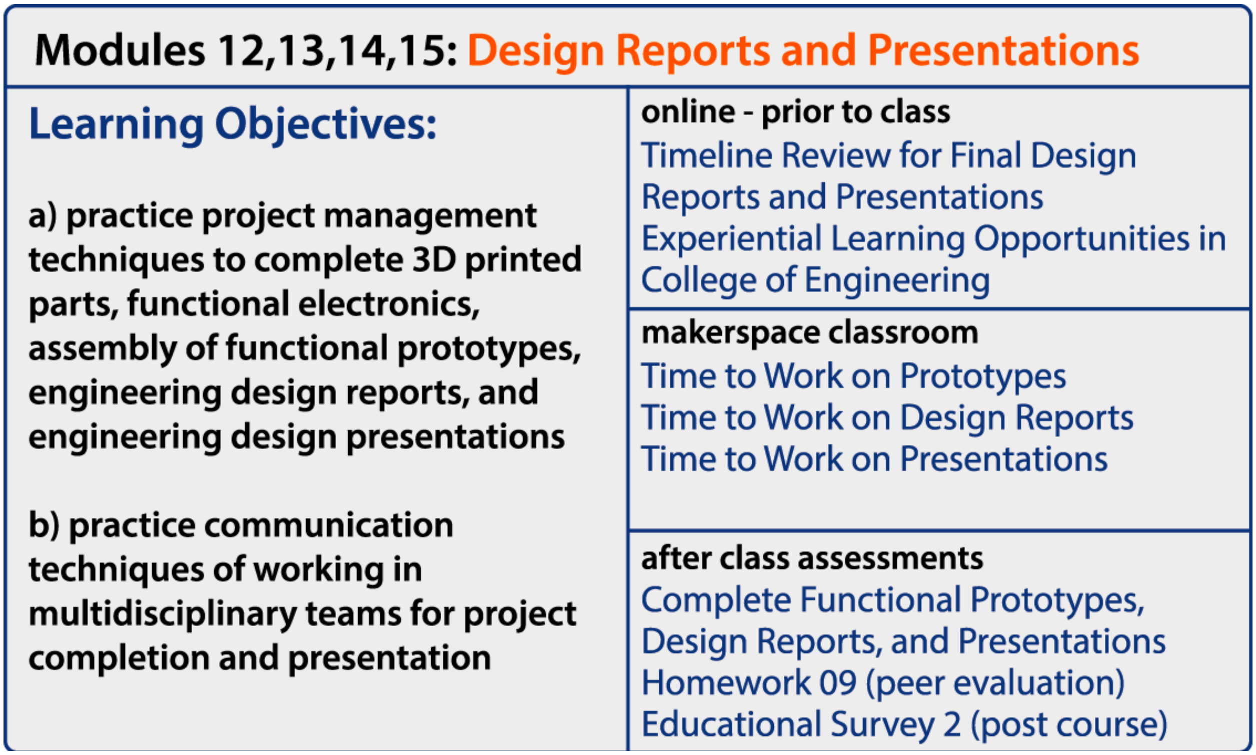

Figure 13: Modules 12, 13, 14, 15: Design Reports and Presentations

The narrative associated with the overall story of the progression of course modules is that the class starts with two weeks examining human-centered engineering and how engineers can have impact on society, including environmental and ethical considerations. Then there are about four weeks of technical makerspace skills including solid modeling, 3D printing, Arduino kits (with microcontrollers, sensors & actuators), introductory programming, and hand/power tools common to makerspaces. The last six weeks are focused on working as a team to create a functional prototype of their own invention using the makerspace and human-centered process to solve a societal need. Each team has to research, design, 3D print parts, create electronics, build, program, and assemble their functional prototypes. Students document their work in both a formal engineering design report and in team presentations to the class where they demonstrate their prototypes in action.

Relation to ABET Program Outcomes

Given the structure of the course, the relation of the course content to the current ABET Outcomes is as described in Table 1.

Outcome	Coverage
1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	Low

2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	High
3. An ability to communicate effectively with a range of audiences	Low
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	Medium
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	High
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	Low
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies	Low

Table 1: Relation of course content to ABET Program Outcomes

Student Makers Skills and Course Reflection

While the majority of this paper is on the structure and content of the course, a one-question, pre- and post-survey relating to makerspace skills is included to initially reflect upon the impact on student confidence from participation in the course. Students were asked at the start of the semester their level of agreement with the statement: **"I am confident in my building and making skills, and I feel I could handle the hands-on portion of a group project"**. Sixty-nine students agreed to participate in the anonymous survey for the particular semester this data was taken. Weighing each the responses of "Strongly Disagree" as a 1, "Disagree" as a 2, "Somewhat Disagree" as a 3, "Somewhat Agree" as a 4, "Agree" as a 5 and "Strongly Agree" as a 6, the average response at the start of the semester was a numerical value of 4.12, so between "Somewhat Agree" and "Agree". Figure 14 presents the distribution of student responses at the beginning of the semester related to the survey question on student confidence.

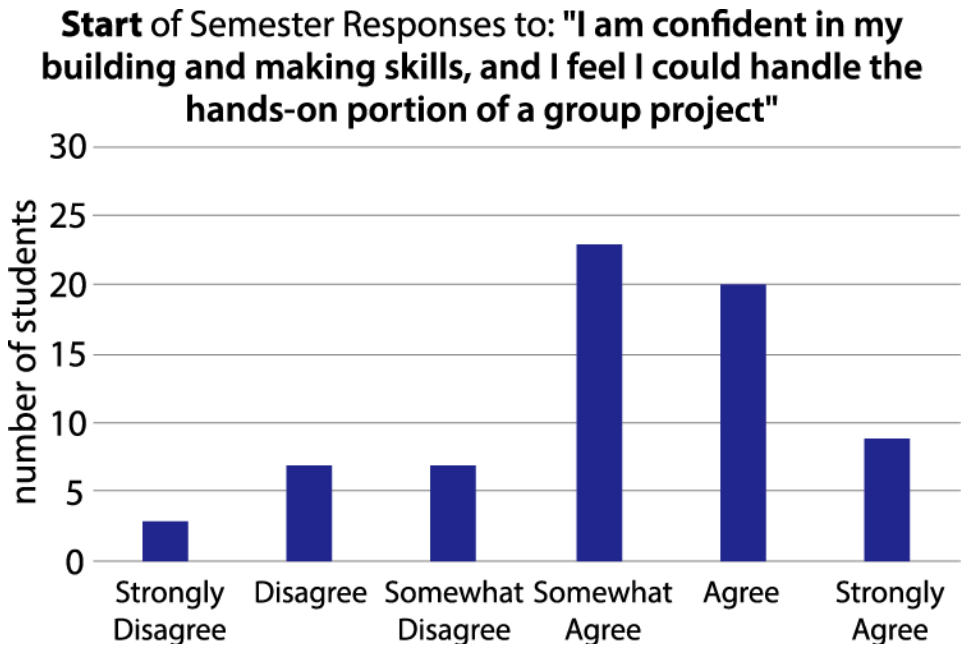

Figure 14: Start of Course Survey Data Related to Student Building Confidence.

Students were asked the same question regarding their agreement with the statement at the end of the semester following the Engineering Design & Society course. At the end of the term, using the same numerical weightings, the average response was a score of 5.17, over a full point higher than at the beginning of the semester, rising to in between "Agree" and "Strongly Agree". Figure 15 presents the distribution of responses from the survey given at the end of the semester.

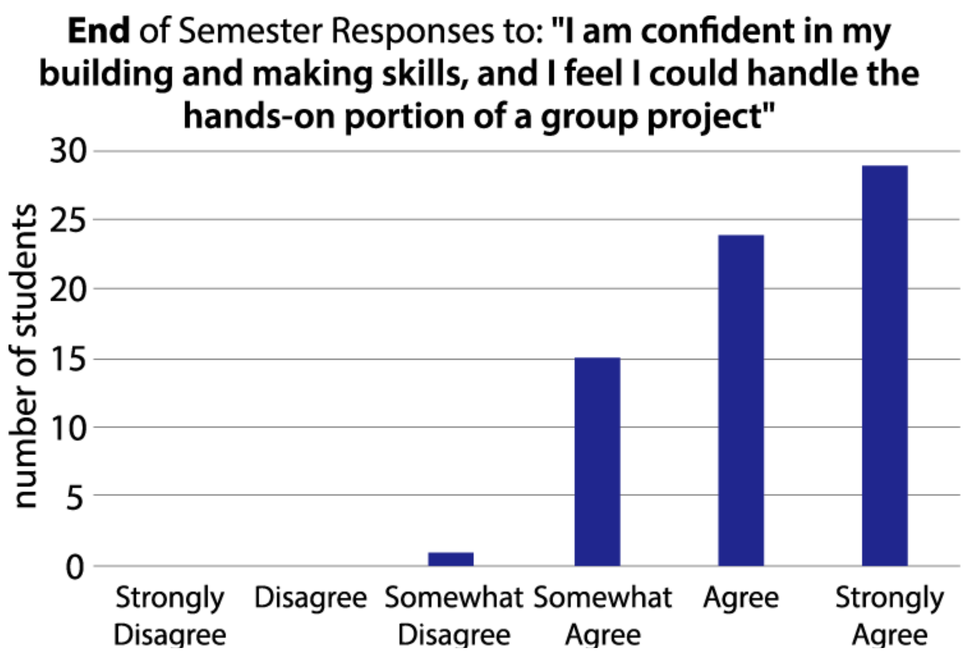

Figure 15: End of Course Survey Data Related to Student Building Confidence.

The results from the pre- and post- course survey question regarding student confidence in building and making skills for participating in group design projects showed a measurable improvement following participation in the first-year human-centered engineering design course.

The post-course survey included an open-response question for students to qualitatively reflect on their perspective on the overall impact of the structure of this hands-on, human-centered first-year design course. Students provided written responses to the question, **"What Did You Find Most Interesting About the Course?"** We found that most responses fell into five defined categories around the human centered design process, the hands-on nature of the course, engineering software applied in the course, the integrative nature of the design project and/or course, and exposure to engineering disciplines. Examples of student responses are provided below.

The Human Centered Design Process: Students who found the human centered design process aspect of the course as the most interesting highlighted the approach to the design project, which allowed them to focus on creating "helpful" projects and designing something they "care about." These types of responses illustrate how some students perceived contextualizing human centered design and user needs in engineering as impactful. The human centered design process category of responses is related to learning goals, 1) Understand and practice the human-centered engineering design process for a societal based project, and 2) Learn techniques to solve open-ended engineering challenges.

"I found the focus on human-centered design most interesting, as it gave me a new perspective on how to engineer helpful projects."

"The heavy focus on user centered design and emphasis on the design process."

"There was so much that I found interesting about this course, but my favorite part was definitely the final project. It's not often that a class gives you almost free reign to design something you care about while being given all the tools to succeed in it. It was so fun getting to learn about engineering in a hands-on environment and then getting to show off what we learned."

"I found the 3-D modeling in Onshape to me the most interesting aspect of the entire course. But I also understand that the exposure to power tools, 3-d modeling, circuits, coding, and <u>human-centered needs will be beneficial in the long run to my education and career.</u>"

Hands-On Nature of the Course: Students who found that the hands-on nature of the course as the most interesting differentiated the course from "traditional courses," e.g. lecture-based courses, included the opportunity to build prototypes, and learning and applying skills related to modeling, building, programming, and circuitry. This category is most closely related to learning goals, 3) Promote a culture of making by introducing solid modeling, programming, sensors, data acquisition, 3D printing, and other maker tools, and 4) Build teamwork and cooperative learning skills through participation in multidisciplinary teams and active engineering project management.

"What I found most interesting about this course was that it was not like a traditional class. Doing things hands-on and being limited by our own creativity was really cool."

"I found making the prototypes the most interesting about this course. We were able to get hands on experience on how to use different tools and equipment. Our skills were really tested for this project."

"I found this course to be especially interesting because it allowed me to have a hands-on experience with engineering as a freshman, and it provided a good introduction to the design process. I liked being able to learn a bit of coding and circuits with the Arduino and solid modeling with Onshape. It was fun to have a workspace with so many tools and supplies on hand, since it inspired creativity."

"I found that the hands-on experience this class emphasized was very interesting. As a freshman who is considering an engineering major, this course truly opened my eyes to a future possibility. I learned many new skills such as 3D modeling and printing, circuits, and more. Also, it was wonderful to have a class that was group based rather than lecture. It definitely enhanced my learning experience and truly made the class fun and something to look forward to each week."

Makerspace Skills & Engineering Software/Hardware: Students who found the technical makerspace skills and engineering software/hardware knowledge the most interesting aspect, highlighted the 3D modeling and printing, and Arduino based activities. Some students perceived using the engineering software or hardware as an opportunity to gain skills in engineering, even if they came into the course with less experience in these areas. This category mainly relates to course learning goal, 3) Promote a culture of making by introducing solid modeling, programming, sensors, data acquisition, 3D printing, and other maker tools.

"I thought it was most interesting to learn how to use solid modeling software. I think solid modeling is quite different from other software applications and requires a more engineering mind set to use effectively."

"<u>I found the 3-D modeling in Onshape to me the most interesting aspect of the entire course. But I also understand that the exposure to power tools, 3-d modeling, circuits, coding,</u> and human-centered needs will be beneficial in the long run to my education and career."

"I found the interactions with 3D modeling and printing most interesting in this course. The course does a good job at introducing students to the hands-on aspects of engineering that don't involve high levels of experience. Introducing 3D printing, coding, and wiring were all things that I liked being able to explore."

"Coding with the Arduino and seeing how versatile such a seemingly simple device is."

"I found the Arduino kit most interesting about this course because it is the perfect beginner's kit for circuitry while it could also be used to build much more complex circuits."

Integrative Nature of the Design Project and/or Course: Students who found integrative nature of the design project and/ or course as the most interesting, stated how they were able to make functional designs from the integration of software used in the course, and how the design project necessitated them to use "everything they learned in design and coding." This category of response relates to course learning goals, 2) Learn techniques to solve open-ended engineering challenges, and 4) Build teamwork and cooperative learning skills through participation in multidisciplinary teams and active engineering project management.

"The thing I found most interesting about this course is the relationship between CAD, such as Onshape, and Arduino and coding. In particularly, how you can combine the three and make functional designs."

"I loved the final design project. I was able to use everything that I had learned in design, coding, and Onshape and put an actual product together."

"The life cycle of developing a product from beginning to end. Also learning how to use 3-D printing."

Exposure to Engineering Disciplines: At least one student response focused on how the course allowed them to learn about the different fields of engineering, and then translate that to possible career decisions or applications. This category directly relates to course learning goals, 7) Introduce engineering students to the various engineering majors and their roles within society, and 8) Inform students of opportunities for experiential learning related to their majors throughout the college of engineering and community.

"I liked learning about the different fields of engineering that I could potentially work in and gained actual experience in each of those fields."

Conclusions and Future Work

The quantitative results regarding student confidence in building and making skills showed a measurable improvement following participation in the first-year human-centered engineering design course. The student narrative responses reinforce that the structure and content of the course supports student excitement and engagement in the content (module) areas that are part of the overall learning objectives and goals proposed in the creation of the course. Initial qualitative student perspectives about what was most interesting to them following participation in the course did map to a number of course learning goals. However, a limitation of the survey question presented was that the question did not directly ask students to reflect on, or address, their perspectives on all the specific learning goals of the course. Future studies conducted by the authors of this paper will include an analysis of comprehensive student design work and survey data to investigate more directly the impact of the course as it relates to the course learning goals. Additional future work on the Engineering Design & Society course includes a number of parallel studies in-progress specifically about the student educational impact related to human-centered design, makerspace skills, and student retention in engineering disciplines through participation in early hands-on multidisciplinary design experiences.

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