Making the Makers: Building Hands-on Skills to Help Humanity Through First-Year Design

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Abstract
This complete evidence-based practice paper examines structure and student feedback of a pilot offering of “Engineering Design & Society”, a new hands-on first-year course teaching human-centered design to inspire engineering students to become innovators to help humanity. Students are actively engaged in practicing the human-centered design and prototyping process while learning makerspace and hands-on skills (solid modeling, 3D printing, programming, microelectronics, sensors, actuators, basic hand & power tools). Students then practice and incorporate these skills in a multidisciplinary team to research, design, build, document, and present on their functional prototype of a solution to help humanity to meet specific needs. The course is centered on experiential learning for all first-year engineering students through hands-on education in a classroom structured as a makerspace. Students collaborate at worktables in teams, each team with their own tools, with a dedicated class suite of 3D printers and other maker tools to help students not only design, but also physically build and program functional prototypes.

The goals and benefits of the Engineering Design & Society course are to:
1) Promote a culture of making in first-year students through early introduction of solid modeling, programming, sensors, data acquisition, 3D printing, and other maker tools;
2) Help students learn techniques to solve open-ended engineering challenges;
3) Build student self-confidence in their individual making skills (especially for female and minority engineering students) to increase student hands-on participation in engineering societies, innovation challenges, and internships, and
4) Build teamwork and cooperative learning skills through participation in multidisciplinary teams.

This complete evidence-based work outlines the curriculum characteristics of this first-year course. Impact on students is examined both quantitative and qualitatively through student self-reported surveys from the pilot sections of the course. Survey data examines student perceptions on how the structure and content of the course impact student identity as makers and their self-confidence in making skills. Student self-reported data on gender, ethnic background, major, prior programming experience, and prior building experience are included to examine maker-centered impact across a diverse background of first-year engineering students.

Course Development
The study of this work focuses on the course development and course structure based on the integration of a number of successful curriculum characteristics from other researchers into a single-semester active learning course to introduce a first-year human-centered multidisciplinary design course at a large university where no prior similar experience existed. Figure 1 outlines the four categories which were examined in the development of the structure of the course, 1) Maker Skills & Maker Space, 2) Educational Content & Course Structure, 3) Human-Centered Design & Societal Needs, and 4) the integration of 1-3 for course Deliverables & Outcomes to support student success in the larger engineering curriculum.
1) Maker Skills & Maker Space: A makerspace classroom used for the pilot offering in the course is described in [1], it is a room with seating for 20 students with workspace tables for teams of 4 students. The makerspace setting for this class was chosen based on existing research that suggests that these type of settings facilitate student collaboration, communication, design thinking, and creativity. The setting for our class is similar to other existing makerspaces since it includes rapid prototyping tools, low-cost microcontroller components, and several online resources that are common within the makerspace education community [3,4]. For instance, each student team has a rolling tool cart at their table with a number of hand and power tools utilized in prototyping. Students are shown how to safely handle all tools needed for the course, and are encouraged to freely get up and use the tools as needed. The makerspace is structured as an active learning classroom, there is no front or lecture area in the room. All lecture materials are delivered online, and live course time in the makerspace is utilized for active learning and practicing the design & prototyping process. The makerspace is equipped with 3D printers for students to individually learn and use as tools for prototyping. The 3D printers used are Lulzbot TAZ6 models, which were selected by utilizing 3rd year engineering undergraduates to test a variety of PLA based printers to select the model they felt first year students would have the easiest time operating independently. The application of 3D printing across a variety of engineering majors is covered as part of the course curriculum. Students use online tutorials to individually learn solid modeling software. Onshape was selected for the pilot course based on the combination of the software being free for students, exporting files well for 3D printer use, ease of online team collaboration, ease of linking solid modeling files into documents for faculty grading, and being a web based software, so there is no software installation required and it runs the same across various computer types. The course textbook is an Arduino Starter Kit which includes a 170 page book that documents microelectronics, engineering sensors & actuators, and
the coding process through a series of 12 well documented microelectronic builds. Each student individually owns the kit and learns to program the use of a variety of engineering sensors & actuators that have applications across most engineering majors. The Arduino platform was chosen to build individual maker skills using a commonly used hardware in the maker community with a large online repository of open source physical builds & associated code for first-year students to continue making even after the course is over. Arduino electronics are used in some of the second and third year engineering courses at the University of Florida so introduction during first year also benefits those students taking any of the subsequent courses.

2) Educational Content & Course Structure: The format of the course was based on balancing student credit hours and makerspace resources. The University of Florida has an estimated enrollment of 1,600 new engineering students each year. The steady-state goal is to structure the Engineering Design & Society course where all first-year students take the course, so optimization of credit hours and space utilization had to be balanced. To make minimal impact on student credit hours, the course was designed as a one semester, 2 credit hour course. This allows first-year students to take the course in the fall, spring, or summer terms. Fitting that quantity of students into a makerspace and having a meaningful experience resulted in the structure of a 2 hour live meeting once per week for a maximum of 49 students per section. This will result in approximately 33 sections; 14 in the fall, 14 in the spring, and 5 in the summer. A dedicated makerspace classroom and 3D printer room for the Engineering Design & Society course is part of a building currently under construction with an opening date within the next year. To limit the in-makerspace time to 2 laboratory hours, 1 credit hour of online course content is delivered in module videos through the university course management system. These modules cover topics such as human-centered design, tutorials on solid modeling, 3D printing techniques, Arduino build tutorials, engineering memos, engineering design reports, teamwork, elevator pitches, etc. Students are assigned video modules to cover before they attend makerspace class each week [1]. This flipped format, with lectures online, and live time reserved for hands-on activities optimizes makerspace resources, and allows students to engage with faculty and peer mentors during the live active learning sessions. Undergraduate peer mentors, junior and senior students from a variety of majors, are utilized for both in-class help alongside an engineering faculty member and for open build time (currently all day Fridays), where individual students or student teams can come into the makerspace for peer assisted help with any aspect of their projects.

3) Human-Centered Design & Societal Needs: Utilizing human-centered design for societal needs was chosen to engage first-year students through the impact engineering can make to help society. The goal was to engage and excite students by bringing them into being part of the solution for designing and prototyping for the purpose of helping humanity. The 7-step human-centered design process shown in Figure 2 was created for the Engineering Design & Society course [1] to support both integration of human centered design and cover the full curriculum and deliverables of the class.
Students begin practicing the human-centered design process from the first day of class to establish the mindset that engineers have the abilities to solve problems in the world through their skills and human-centered design. As the semester progresses, assignments and makerspace activities increase in complexity along both the “Understanding of the Users” and the “Design Process and Integration” axes of experiential learning [2]. The characteristics balanced in the final group projects for the course include being: a human-centered design topic that students can research and document the impact on society, multidisciplinary in nature, representable by a physical prototype that can fit within a desktop workspace, and a functional prototype that can be designed and built by student teams using a combination of solid-modeling, 3D printing, microcontroller-based electronics, and a limited number or purchased or recycled materials [1]. The engagement in the societal aspect of the engineering design is documented in both the final design reports and presentations to tell the full narrative of how each team’s built prototype is created for specific users to serve a societal need. An example of the pilot semester narrative for the final group human-centered project is included below.
Final Project: Human-Centered Engineering Design for a Societal Need

Your research team has been hired by a prestigious, national consulting firm that contracts with a variety of companies with projects in biomedical, agricultural, and manufacturing fields. Your first project is an ambitious endeavor to design a “Windowsill Self-Watering Planter” for people affected by the Hurricane Maria in Puerto Rico. Your company decides that it will fund the design and manufacture of the self-watering planters that will have the largest societal impact. You will build a small-scale version of a self-watering planter to test out your ideas, to determine the feasibility of your proposal, and to display and present on a prototype for demonstration.

You will need to design and build a functioning prototype product that must:
1. Be a human-centered design (report instructions include research documentation)
2. Fit within a 30-cm x 30-cm x 30-cm volume
3. Use an Arduino Uno microcontroller development board.
   (It must be powered and controlled by no more than 2 Arduino microprocessors.)
4. Receive input from at least one sensor (soil, humidity, sunlight, temperature, etc.)
5. Control at least one actuator based on input from the sensor(s)
6. Incorporate at least one functional 3D printed component designed using Onshape
7. Estimated print time of your 3D printed component should be 8 hours or less
8. Include at least one recycled item
9. Stay within a budget of $10 per team member (these funds are in addition to 3D printer filament which is provided, and the Arduino kits which students own)

4) Deliverables & Outcomes: Integration of the Maker Skills & Maker Space, Educational Content & Course Structure, and Human-Centered Design & Societal Needs results in Deliverables & Outcomes to support student success in the larger engineering curriculum. One major deliverable is the student teams both design and actually have to build a functional prototype using sensors, actuators, programming, solid modeling, and 3D printing for a human-centered societal based need. In some first-year design courses deliverables include design or simulations, but not necessarily students actually building and debugging a physical functional prototype of their own design. Going through the design, build, re-design, and rebuild cyclic process first hand strengthens students’ skills in “failing forward” or the vigor they will need within engineering studies to try again in solving open ended challenged when faced with adversity [4]. The deliverable of an actual physical functional prototype also helps to build self-image as makers and creators because they have gone through a full engineering design process. Some first-year design courses do include physical builds, but most are centered on a robotic challenge (line following, moving balls around, battling robots), without a human-centered research narrative to show engineers serving humanity [6-11]. By integrating the open ended human-centered story, a wider diversity of students can be engaged about how engineers can use their skills to create items to help society. A second major outcome/deliverable are students creating fully documented engineering design reports covering background research, human-centered design, societal needs, technical specifications of their design, costs analysis, solid model drawings, and reflection on their functional prototypes. The third major outcome/deliverable is students have to give a 15 minute presentation on their final functional prototype, with all students in the team contributing in the presentation. Students practice the
skills of technical presentations, team presentation coordination, and the art of conveying information in an elevator-pitch style delivery.

**Student Demographics**

Three sections of “Engineering Design & Society” were piloted in the makerspace classroom. In total, there were 59 students across the 3 sections. From these pilot sections, 48 students (81.4% of class) chose to participate in anonymous pre- and post- surveys related to their demographics and impact of the course on their development as engineering students. Self-reported student demographic data for pilot students is included in Figure 3.

![Figure 3](image-url)

The students examined in this study were primarily freshmen (46/48), and have a diverse mix of self-reported majors covering 9 different engineering majors. One category of engineering major included is “Exploratory Engineering”, which is the major designation for first-year students knowing they want to study engineering, but are unsure of which field within engineering they want to study. One of the goals of offering the new Engineering Design & Society course is to help Exploratory Engineering students pick an engineering field through hands-on participation in activities that cover a variety of engineering majors so they can try activities first-hand instead of just touring departments to see what field might suit their personal interest the most.

As shown in Figure 4, students examined in this study self-reported as 58.3% male, 34.1% female, and 6.25% “other or prefer not to answer”. Self-reported ethnic background percentages are 56.25% white, 20.8% Hispanic/Latino/Spanish Origin, 12.5% Asian, 6.25% “no response or prefer not to answer”, and 4.17% Black or African American.
Prior Experience Level

In examining the impact of a hands-on makerspace based curriculum covering aspects of building, solid modeling, 3D printing, Arduino electronics, and programming; it is important to understand the experience level of students in these areas prior to participating the course. Figure 5 examines student self-reported data on prior building, solid modeling, and programming experience, with the vast majority of students participating in the study having little or no experience with hands-on building, solid modeling, and programming.

Quantitative Results

Student surveys in this work focus on impacts of participation in a human-centered design course structured in a makerspace environment. Makerspace engagement is related to student motivation and persistence, knowledge of engineering, belongingness & social interactions, and professional identity [12]. This work expands just makerspace impact to include the integration of makerspaces with human-centered design, and full-project prototyping to see if the combination of the 1) Maker Skills & Maker Space, 2) Educational Content & Course Structure, 3) Human-Centered Design & Societal Needs, and 4) the integrations of 1-3 for course Deliverables & Outcomes support student self-perception, confidence, and skills needed in engineering.
Self-Perception as Makers: Two main questions were asked of the students at the beginning of the course and the end of the course to examine their self-perception of their maker and building skills. The first question was a Likert scale response to how students agreed with the statement “I View Myself as a Maker”. Figure 6 compares both before course participation (orange) responses to post course participation (blue) responses.

Confidence: The second question focused on student confidence in building and making skills, again a Likert scale, but now on the statement “I am Confident in My Building & Making Skills”. Figure 7 compares both before course participation (orange) responses to post course participation (blue) responses.
Skills: A third Likert survey question was asked only as part of the post participation survey to examine students’ perceptions of the course on building skills to help them in their engineering studies or personal growth as makers. Figure 8 shows student responses to “Participation in this course helped me to gain skills that I will use in other engineering courses or personal projects”

Figure 7: Student responses pre- and post- participation on building skills confidence.

Figure 8: Student responses relating to participation impact on skills development.
Qualitative Results
At the end of the course, students were asked for feedback to the open ended question of: “What aspect(s) of the course do you feel were most relevant to your personal development as a maker and future engineer?” Select representative student narrative responses are included below to tell the story directly from student words on the impact of the course in this area.

“The human-centered design process made me feel most relevant towards personal development as an engineer. We were designing products in the class with real-world applications.”

“Being able to create a prototype for a human centered design project.”

“This course allowed me to experience fields of engineering I had never encountered and broadened my view of what kind of engineering I might be interested in doing. Also, the skills of fabrication, rapid prototyping, and solving design issues have allowed me to believe that I have the capacity to make and design projects. Those same skills have allowed me to further believe I have the capacity to become a good engineer, and confirmed what I thought I would enjoy about engineering.”

“I believe that all aspects were important. The class offered a good mix of both personable and technical skills. The 3D modeling skills will definitely be of use in the future, particularly in internships. The skills used for writing reports and preparing presentations are also very important and useful in both upper level courses and future careers.”

“Actually working on the design process and learning how to do engineering memos and design reports felt so important to me. Those are skills that I know I will carry with me for years and that I will actually use. Also, I went from being very shy and not voicing my opinions to feeling like I can speak intelligently. This class has given me my voice and my confidence.”

“I felt most like a maker/future engineer when I was in peer mentor hours or meeting with my group outside of class hours. Being able to talk about design with my group members in a less structured environment helped us brainstorm more freely and allowed us fall into the group dynamic (vs that of individual students in a classroom). Also, being able to drop in for peer mentor hours either to use the 3D printers or use the workshop tools and ask for advice or assistance with a few things independently made me feel more like a maker.”

“The introduction to the design process I feel will be the most beneficial. It was nice having a smaller scale project to work on, as opposed to a real project that must be completed in a certain time. I learned how it will almost always fail a few times, which means there will be lots of trial and error.”

“Diving into Arduino builds and learning how to use tools like the Dremel helped me build confidence in my abilities and knowledge.”
“Everything! The Arduinos, 3D printing, 3D modeling, and actual manufacturing were all enjoyable and will be relevant in my future endeavors.”

“I think the teamwork and the parts where we learned about modeling, circuitry, etc. and bringing them all together were the most relevant.”

“The online designing and use of the 3D printing felt very relevant and made me realize I was interested in those aspects.”

“I learned some coding, but mainly how to go about the design process. Engineering is all about designing for the betterment of society, and I feel I built a good foundation on how to do so in this course.”

“Opened my eyes to the true difficulty of a good design and that there are very often mishaps and corrections that must be made throughout.”

“I learned a lot of problem-solving skills while working on the self-watering planter, since we had to fix so many things when something broke or did not go according to plan. It taught me that yes, it is absolutely important to plan ahead and understand your design goals, but you also need backup plans or other ways of getting to your end result.”

Pilot students were also asked for feedback to improve future offerings of the course with the question “What suggestions do you have to improve this course for future students?” Select representative student narrative responses are included below to tell the story directly from student words on the impact of the course in this area.

“Focusing more on programming experience and practice. Allowing groups to pick from a list of human centered design problems for the final project.”

“The course could be improved with more focus on coding, and perhaps more than one design project.”

“Start the final design project earlier, giving more time for it. Maybe get a bigger and less cramped room : )”

“My main suggestion is just to work on how to teach some of the coding and circuit information. In addition, maybe having different prompts for the final project would help teams take the project in a direction that suits what they want to learn the best. Otherwise, please keep this course going. Please give other students this opportunity that I have had, it really has changed me and given me the confidence in my major that I needed.”

“More sections, my advisor had to squeeze me into this class and I went to the first orientation date.”
“I think the course was very helpful and that not much can be improved as it was already very well done.”

“Future students should fully research any motors/parts that are not part of the kits to make sure they have everything they need to complete their build. We were behind on our timeline due to thinking we had the correct parts and example build researched.”

“More emphasis on learning to code.”

“For some students, it might be helpful to learn more about wiring. The wiring is fairly easy, and students could always learn the information outside of class, but it might be easier for them if there was some kind of lecture that just gave a basic introduction.”

“I thought it was really great! I would stress to students that you really don't need any prior experience to take the class. That was what made me nervous about taking the course originally.”

“Better selection of a final project, something more applicable to the Arduino.”

“I think spending more time learning the programs would help novices get a better feel for how to use them.”

Discussion & Conclusions

For statistical analysis of the data, a value of 1 was assigned to “strongly disagree”, 2 assigned to “disagree”, 3 assigned to “somewhat disagree”, 4 assigned to “somewhat agree”, 5 assigned to “agree”, and 6 assigned to “strongly agree” to find average numeric values of student responses.

Self-perception of students as makers examined in the Figure 5 survey question of “I View Myself as a Maker” pre- and post- course participation shows a measurable shift towards students strongly agreeing that they perceive themselves as makers following participation in the course. Using the numeric point assignment scale above, the average values pre- course were 4.56, and post- course 5.17.

Student confidence in their building and making skills examined in Figure 6 survey question of “I am Confident in My Building & Making Skills” pre- and post- course participation also shows a measurable shift towards students strongly agreeing that they are confident in their building and making skills following participation in the course. Using the numeric point assignment scale above, the average values pre- course were 4.21, and post- course 5.33.

Student value of participation in the course examined in Figure 7 survey question “Participation in this course helped me to gain skills that I will use in other engineering courses or personal projects” shows the majority of students strongly agreed with the statement. Using the numeric point assignment scale above, the average value was a 5.55.
Examining the qualitative open ended student response to the question of “What aspect(s) of the course do you feel were most relevant to your personal development as a maker and future engineer?” returns a wide variety of aspects of the course related to all four categories examined in the goals behind the development of the course, 1) Maker Skills & Maker Space, 2) Educational Content & Course Structure, 3) Human-Centered Design & Societal Needs, and 4) the integrations of 1-3 for course Deliverables & Outcomes to support student success in the larger engineering curriculum.

Examining the qualitative open ended student response question of “What suggestions do you have to improve this course for future students?” returns a few main areas that are being incorporated for improvement to the pilot. These main areas include: 1) Additional modules on introductory programming for getting started within the Arduino environment, 2) Additional resources on selecting and wiring Arduino compatible sensors and actuators, and 3) More variety in human-centered design final project topics for teams to choose from.

Conclusions drawn from this complete evidence-based practice work is the first pilot offering of “Engineering Design & Society” was successful in increasing student self-perceptions as makers, self-confidence in their building skills, and in developing skills students can use in future hands-on projects. The use of human-centered design for a societal based project qualitatively received positive feedback from students about being able to fully design and build a prototype to serve humanity. Engineering Design & Society is currently running additional pilot sections, and the future developments on the course will include student and faculty feedback to continually improve course outcomes, for planned expansion from pilot sections of 20 students, to the full-scale sections of 49 students in the new dedicated makerspace classroom in the next year.

References


