Human-Centered Design Incorporated in the Freshman Year through an Active Learning Engineering Design Lab: Best Practices, Lessons Learned, and Proposed Improvements

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Abstract

Engineering and design have been given new broader definitions in recent years to include terms such as client-centered, sustainability, and global from organizations like ABET and ASME [1-2]. Additionally, engineering companies seek more than just a high GPA, but rather interpersonal skills and real-world project experience. Engineering faculty at Lipscomb University recognize the present and coming changes in the field and are seeking ways to improve the curriculum to address these changes. In 2017, the faculty initiated the redesign of the freshman Introduction to Engineering lab course to include key elements of human-centered design throughout an engineering design process experience. One of the unique aspects of the redesigned course is the utilization of partnerships with the Peugeot Center and Engineering for Change to ensure these key elements were implemented properly and sufficiently supported. The long-term goal of this research is to produce a freshman engineering course for Lipscomb University that effectively prepares students for an engineering career through exposure to humanitarian projects with the aid of these partnering organizations. This redesigned course may also serve as an example for other universities that wish to introduce human-centered design and service-learning projects for improved student outcomes with respect to ABET standards. In this paper, best practices and lessons learned are presented from the first iteration of the redesigned course from fall 2017 as well as proposed improvements for the second iteration of the course for fall 2018. Preliminary data and observations from the first iteration of the course are utilized to improve for the second iteration. Highlights from the first iteration include student interactions with clients as well as an understanding of how engineering translates to improving the lives of others. Areas of improvement will involve integrating the lecture period with the lab and providing opportunities for student exposure to disciplines outside their own lab section.

Introduction

Before 2017, the Introduction to Engineering freshman course at Lipscomb University focused on introducing students to different disciplines within engineering through completion of various hands-on activities. The activities were fun and educational for freshmen and included water-bottle rocket design, robotic maze-following, LED circuit design, and bridge truss design. In fall 2016, a humanitarian engineering section was included as the fourth rotation (Figure 1) and focused on using mechanical, civil, or electrical engineering skills in a humanitarian setting. This was a commendable step toward improving the course and addressing broader impacts of engineering, but something was still lacking. While these activities provided a glance into some typical laboratory exercises in the various engineering disciplines and kept students engaged, the course did not emphasize human-centered design concepts that are vital for solving real-world

challenges. Additionally, faculty in the Raymond B. Jones College of Engineering have identified critical areas of improvement for upper-level students that could be addressed early in their career. Specifically, students lack experience in designing a solution to fit a human need. Though this is a natural inclination of many engineering programs, the college has a desire to produce engineers that have a better understanding of how their career affects the public. More details on the purpose of the redesign of the course, specifically the inclusion of human-centered design and humanitarian projects, can be found in [3].

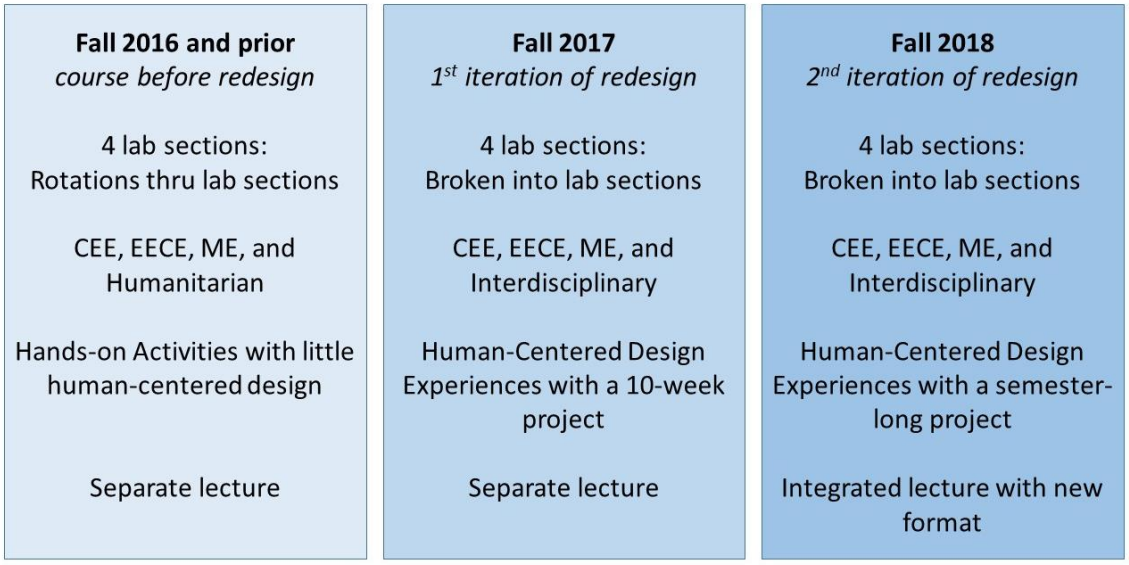

Figure 1 Major changes from the original course taught in the years prior to fall 2017 to the first iteration in fall 2017 and the second iteration in fall 2018

In the 2011 ASME 2030 Vision Report, recommendations were made to engineering education institutes to strengthen curricula [2]. While intended for undergraduate mechanical engineering programs, the objectives translate directly to any engineering major. Four of the six major recommendations in the report were considered in the lab course redesign effort, including the use of open-ended solutions and iterative design, working directly with clients, a strong hands-on component to the lab work, and a focus on humanitarian projects as a means to improve lives around the world. In response to these recommendations, the college faculty hope to encourage innovation and creativity, professional teamwork including client relationships, and preparation for a future in engineering practice in the freshman course. In the first iteration of the redesigned lab course, a wide variety of design concept experiences were utilized such as client interactions through role-playing, decision-making processes through brainstorming exercises, and sustainable design techniques through hands-on prototyping and testing. To increase opportunities for real-world design experiences, the college partnered with the Peugeot Center for Engineering Service in Developing Communities and the non-profit organization Engineering for Change (E4C) [4]. Through these partnerships, the course design incorporates human-centered design techniques and a five-step engineering design process through humanitarian engineering projects. The Peugeot Center, as an entity within the college, has completed over fifty humanitarian engineering projects through its fourteen year lifespan. The partnership with the Peugeot Center provides the

opportunity for students to work on real-world humanitarian projects that may be fully implemented at a later date by the Peugeot Center. The partnership with E4C provides faculty with human-centered tools and techniques used in the course as well as the five-step engineering design process (Plan – Learn – Design – Realize – Sustain). Until this course, the five-step engineering design process produced by E4C had not been utilized in a freshman engineering course anywhere. Until fall 2017, the Introduction to Engineering course at Lipscomb had not specifically utilized human-centered design tools, thus the benefit of partnering with E4C. Another benefit to partnering with the Peugeot Center for humanitarian-based projects was the possibility for increased diversity within the student population. As documented by multiple authors, an emphasis on human-centered engineering projects is particularly attractive to women and minorities which could lead to an increase in diversity [5-8]. The college views an increase in diversity as positive growth and thus is supportive of this opportunity. Overall, these partnerships provide much needed support to faculty leading the course as well as ideas for improving the course and its primary goals. In some ways, these partnerships are symbiotic as students and faculty utilize the resources provided by the Peugeot Center and E4C while the Peugeot Center and E4C benefit from the work completed by the students and research by the faculty.

During the fall semester of 2017, the four freshman lab sections adopted the first iteration of the redesigned course for a total of about sixty students. Three lab sections focused on a single discipline – mechanical, electrical, and civil – while the fourth provided an interdisciplinary experience by combining the three disciplines. Faculty were provided with a teaching assistant to facilitate the lab through typical TA duties like grading or lab support, but were also given the opportunity to role-play as the client that would receive the students' design. To prepare for the lab, TAs and faculty participated in an online training course through E4C called Introduction to Engineering for Global Development. Each professor then chose a humanitarian engineering project as their design focus and prepared the immersive experience with help from the Peugeot Center. Throughout the semester, the professors, TAs, and the course director met regularly to discuss best practices, lessons learned, and future opportunities for the course. This work-in-progress paper will provide some conclusions from this first iteration of the redesigned course as well as some of the preliminary data collected. From the data collected, proposed improvements to the course are presented as well. Some of the major changes through the first two redesigned iterations of the course compared to the original course are shown in Figure 1. During the first iteration, three assessment methods were utilized including CATME Peer Evaluations [9-10], faculty observations, and audio-recorded focus group sessions to better analyze student improvements in key areas. The CATME Peer Evaluations and audio-recorded focus group sessions were approved by the Institutional Review Board for the course.

First Iteration of the Course Design – Fall 2017

Details of the first iteration of the redesigned freshman course can be reviewed in [3], but a brief outline will be given here to provide a better view of the course and its objectives. The Introduction to Engineering course was redesigned to incorporate improvements in the following areas: client interactions, decision-making processes, holistic critical-thinking, and sustainable design. The

goal of the redesign of the course was to improve student outcomes relative to ABET criteria, specifically student outcomes (c), (e), (g), and (h) [1], and faculty recommendations and requests. To achieve improvements in these critical areas, students worked in groups on a semester-long project to design a solution to fit a human need. A five-step engineering design process, originally developed by E4C [4], was used to guide students through the project starting with a community and the challenges it faces all the way to ensuring sustainability of the project. Throughout the project, students worked with one another to brainstorm ideas, develop concepts, communicate with a client, and think critically about their solution. Across the four sections of the course, the community and the challenges differed to provide opportunities for the instructors to customize the projects. The Peugeot Center, a non-profit organization that functions within the college, provided expertise and guidance for instructors to build a simulated community and realistic challenges for the students to face. Note that the lab provides two credit hours and is taught alongside a one credit hour lecture. During discussions as a college, only the lab was chosen for redesign whereas the lecture would be kept the same as it had been taught in past years.

The format of the course was apportioned into four phases, each delving deeper into the engineering design process in a different way. Phase 1, which was held during a single lab period, encouraged the students to dive into hands-on design-thinking by completing a full design cycle including prototyping with a fellow classmate as the client. Phase 2, which was spread over the course of five lab periods, incorporated the design process through analysis and discussion of multiple case studies of completed projects from various organizations. The third and longest phase, Phase 3, taking about twenty lab periods total, presented student teams with the opportunity to complete the entire five-step design process and find a solution to a challenge with guidance from the instructor. Throughout this phase, students worked as teams, communicated with a client, tested prototypes, and learned basic engineering concepts through hands-on labs. The fourth and final phase, Phase 4, over two lab periods gave students the opportunity to present their solution to other classmates and learn about how others developed their own solutions to the different challenges.

Data Collection

During the first iteration of the redesigned course, preliminary data was collected formally through focus group sessions and informally through observation. Note that this paper only details one completed semester of the redesigned course, thus only preliminary data is presented. Future iterations of the course design will utilize further assessments and evaluations once the final design is complete. Focus group sessions with students in the course were held at the end of the semester while observations were recorded from instructors throughout the semester during regular meetings. During the three focus group sessions, a total of 22 students voluntarily participated of the 63 that registered for the course. At least one student from each of the four sections participated in the focus group sessions. To better facilitate the focus group sessions with limited time, students were asked to respond to one another with phrases like ‘I agree’ if they had a similar experience or ‘My experience was different because…’ This not only allowed for a greater amount of responses in a short time period, but also for easier analysis. The meetings between instructors

typically involved all four lab instructors and the lecture instructor and occasionally other faculty with an interest in the course. Observations from faculty were recorded by taking notes during the meetings and follow-up emails. The audio recordings for the focus group sessions and the notes from instructor meetings were analyzed to determine relative success or failure for various parts of the course. If a part of the course received multiple (at least 7 instances) complaints or critiques from faculty and students, it was deemed as an area requiring major improvement. On the other hand, if part of the course was praised (at least 7 instances) by both faculty and staff, it was deemed as satisfactory. Additionally, 3 positive or negative responses from faculty observations provided a quick indicator of the parts of the course requiring the least or most attention for change. This rating of relative success or failure was utilized to determine areas of improvements from the first iteration to the second iteration of the course. Note that these levels of success and failure were determined based on the amount of responses given and provide a threshold of at least a quarter of the 27 total participants of faculty and students.

The data collected from CATME Peer Evaluations was used primarily to provide students with feedback on their teamwork performance and was not utilized as a tool for educational research for the first iteration. Though the data was not analyzed for this iteration, the responses may be used by instructors to better facilitate building teams and encouraging healthy teamwork practices in the future. Additionally, the responses have been stored and may be used in the future once enough data has been collected. The university Institutional Review Board approved these research tools for the course prior to collecting the data and all participants provided informed consent.

Best Practices and Lessons Learned

Throughout the semester, the lab instructors met regularly to discuss best practices and lessons learned from the first iteration of the course. Additionally, students were invited to participate in audio-recorded focus groups which met at the end of the semester. During the focus groups, participants were invited to share their thoughts on two main aspects of the course: their understanding of the engineering profession and design processes as well as their response to the lab course. The responses from both the faculty and student focus group participants are summarized here.

Phase 1

Faculty and students responded with praise for the Phase 1 ‘Wallet Activity’ [11] and it was deemed satisfactory. Both groups enjoyed the fact that there were no technical engineering skills required to complete a design. Additionally, faculty appreciated the idea that designing a wallet translates well from requirements given by a user to a solution that fits for the user. Another positive outcome noted by the faculty was the activity gave students the expectation that they would experience active learning throughout the lab course. There were a few minor glitches during the activity that could be improved with practice. For example, many of the students accidentally left parts of the worksheets blank, especially if the facilitator did not instruct them to

write down specific things. Based on these responses, the Phase 1 activity will only require minor improvements.

Phase 2

Despite Phase 1 being fairly successful, Phase 2 was the low point of the semester for both faculty and students and was found to need major improvements. Both parties noted that these lab periods felt more like a lecture and were missing primary components of a typical lab period, like hands-on activities. Though group discussion was encouraged by faculty to facilitate understanding of the design process content, students were hesitant to speak up so faculty tended to fill the gaps with their own thoughts. On the other hand, students responded well to real-world designs and enjoyed seeing the full process of design in professional work through the case studies. Because this phase was the least well-received, it will be one of the primary focuses for planning changes for the second iteration of the course.

Phase 3

The longest and possibly most difficult phase (Phase 3) also proved to be the most varied and enjoyed among the four sections. Students in the focus groups gave high praise for the opportunity to design a real-world solution to improve another person's wellbeing (Figure 2).

"The focus on holistic engineering was my favorite part of the class. The fact that it focused on that gave me a better idea of engineering… I'm going to be able to actually find a way to help people and better their lives"

"We came up with an idea that will actually help somebody… I get to see that idea actually come to life"

"In the future, we can help out a lot of people with our skills… people who otherwise wouldn't have what we could give them"

Figure 2 Direct quotes from student focus group participants in response to the question 'What was the most meaningful part of your project?'

The wide variation in Phase 3 was primarily due to different instructors teaching the different sections of the lab course. Each instructor had their own idea for a design project as well as the structure for completion of the project. For example, one instructor focused heavily on preparation of design reports to communicate the project whereas another instructor focused on oral presentations instead. Additionally, due to the variation of projects, an idea that worked for one instructor might not have been appropriate for another. During the focus group sessions, students expressed frustrations with the variations among the lab sections and the teaching styles of the instructors when they learned about the other lab sections. Despite the varying projects and

instructing styles, Phase 3 seemed to be the most well-received part of the course by the students. Students showed strong appreciation in designing a solution for a specific client, and faculty found that this encouraged accountability as the students strove for a design that would really work rather than just give them a good grade. It was also apparent from the responses that students and faculty both enjoyed the hands-on activities and demonstrations that not only provided significant engagement with the project, but also active learning. Figure 3 shows a few of the hands-on experiences and results of prototyping from three different sections of the lab. With these responses in mind, the second iteration of the course will focus on streamlining the different sections without taking academic freedom away from each instructor as well as continuing to improve the projects with real clients and active learning. Improvements to the projects themselves will utilize the partnerships with the Peugeot Center and E4C. Opportunities for assessing the various projects are under investigation and will be utilized in the second iteration of the course.

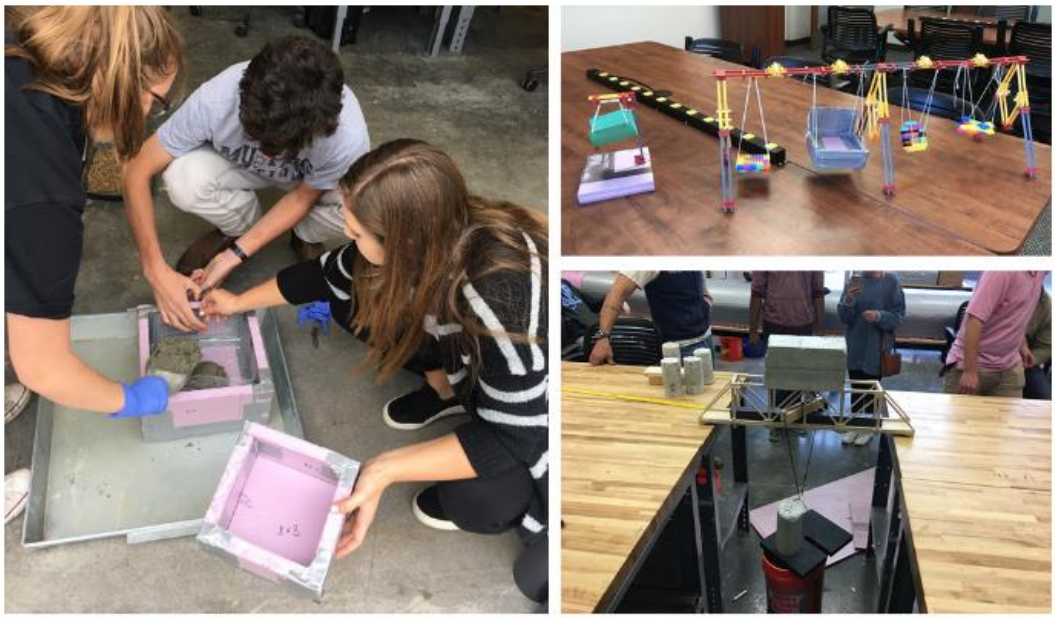

Figure 3 Left: Students building a prototype spring box to test concrete slump and rodding, Upper Right: A low-fidelity prototype of a swing set for a therapeutic playground in Honduras, Lower Right: A prototype balsawood bridge being tested for strength under extreme loading conditions

Phase 4

The last phase of the lab course, though short, was also a positive outcome from the semester. Students and faculty responded with support for this phase, thus it was deemed satisfactory. In response to Phase 4, students stated that they enjoyed seeing the projects completed by another section, but wanted more opportunities to see other sections' progress. Faculty also found merit in providing the opportunity for students to present their design solution in front of a group who are fairly unfamiliar with their work. For future courses, this phase will primarily be expanded to encompass more presentations instead of the final presentation only.

Proposed Improvements to the Course Design for Fall 2018

Overall, from student and faculty responses, proposed improvements to the course will focus on three main areas: improving consistency so that students and faculty in different sections do not have widely varied experiences, continuing to encourage innovation, creativity, and thoughtful, holistic design, and tackling the corresponding lecture period to streamline the entire course. These main areas of improvement reflect the best practices and lessons learned from faculty and student responses. Minor improvements will be made to Phases 1 and 4 while major improvements will be made to Phases 2 and 3. Due to the major changes and consolidation of various parts of the course, the terminology of Phase 1-4 is removed from the course and will be replaced with new terminology. Though the lecture period was kept off-limits during the first iteration of the redesigned course, it has been opened up for redesign and integration with the lab for the second iteration during the fall 2018 semester. This opportunity to redesign the lecture and lab together will allow for a more streamlined approach with learning objectives that align throughout the course.

First Day of Lab

For the first day of lab, students will be led through a hands-on design process activity very similar to Phase 1 from the first iteration. But the as-built activity fell short of client-engineer co-creation, a concept where the client actively participates in the design process. While the 'Wallet Activity' [11] utilizes interviewing to understand the client's needs, the engineer is not encouraged to prototype with the client's feedback due to the time limit of the activity. Some studies suggest that when clients are given the opportunity to participate more fully in the design process, the end-product gives higher value to the client [12-13]. Companies and businesses around the world are already inviting consumers to participate in designing their own product, like Nike and numerous vendors on Etsy. To improve the activity, the backbone of the 'Wallet Activity' will be used and customized to improve upon the current design principles by incorporating co-creation techniques.

Semester-Long Lab Project

After the first day of lab, the students will move directly into the design process experience and begin their semester-long project, an expansion on Phase 3 from the first iteration. Phase 2 and the concepts presented during those lab periods will be moved into the lecture period in response to the criticism from the focus groups and faculty meetings. Similarly, the presentations from Phase 4 will be expanded and adjusted to three poster-type presentation sessions throughout the semester as 30, 60, and 90% design reviews. Student groups will present their work in poster format during a communal lab period where all sections meet together. With three opportunities throughout the semester, students from each section will be given ample opportunity to see the different designs from all sections. Teams across sections will also be required to complete the same design documents during the semester to provide more consistency across sections. These design reviews and required design documents at designated intervals will give instructors the opportunity to provide feedback on repetitive tasks so students can improve throughout the semester.

Last Day of Lab

At the end of the semester, after completing the 90% design review presentations, students from all four sections will be gathered and given time to socialize with the collegiate professional societies offered by Lipscomb University (ASME, ASCE, SWE, and IEEE). Since this will be the conclusion of the fall semester, the professional societies will participate in hosting a holiday party for the freshman class. While this idea does not necessarily contribute directly to design, the party will provide an opportunity for freshmen to integrate with their fellow students and experience the culture of the Lipscomb engineering program. An added benefit of the social time with fellow classmates may be a higher retention rate that may come with a feeling of inclusion in the college.

Lecture Period

To better streamline the course as a whole, the lecture period will also be redesigned for the second iteration of the course. The lecture period meets once a week for 50 minutes throughout the semester for a total of about 14 sessions. This part of the course will be used to expose students to a wide variety of engineering disciplines as well as reflection and discussion about the design process. Six of the fourteen lecture sessions will be taught by individual faculty and professionals while the remaining eight will be taught by the lecture instructor. Faculty in the engineering college will be invited to participate in the lecture sessions or find an interested local engineering professional to teach their lecture session. The faculty (or professional) will be provided with basic guidelines for their lecture period as follows:

- Introduce yourself and give some background on your experiences as an engineer
- Expose students to a unique topic within your field that interests you (possibly research-related)
- Present on a topic or skill that has allowed you to succeed in your career, for example, time management, life-long learning, or professional communication
- Provide time for questions so that students can learn more about you, your field of engineering, or how to succeed in an engineering career

The anticipated benefits from these lecture sessions are as follows: exposure to specific fields within a discipline to engage higher interest levels (i.e. HVAC systems within mechanical engineering), introduction of faculty to the freshman class to build familiarity, and an opportunity for students to learn skills that will boost their experiences in college and in their engineering career. The lecture instructor will use the remainder of the lecture sessions to coordinate reflection and discussion time about the design process and related concepts. These will be dispersed throughout the semester and positioned at strategic intervals to coincide with the projects completed during lab.

Conclusion

In conclusion, the first iteration of the course proved to be an insightful learning experience with highs and lows in different areas. Various parts of the course were designated for major improvements after the first iteration while other parts provided encouragement to faculty that they

were indeed headed in the right direction. Students gained hands-on experience working in teams with a client to produce a full design solution. In general, faculty were pleased with the results of the course and are committed to continued improvement toward the long-term goal. The partnerships with the Peugeot Center and E4C were found to be vital for success and will continue to grow as the course improves. The second iteration of the course for fall 2018 will focus largely on streamlining the course and addressing issues from the first iteration, but the same general objectives will still be central to the course. Assessment and evaluation methods for the second iteration have yet to be finalized, but CATME tools [9-10, 14-15] and focus groups will remain. The proposed design review periods and design documents consistent across all sections of the lab may be used as an evaluation method. Other methods will be developed in the coming months to ensure student success and provide opportunities for future improvements to the course.

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