Work in Progress: Measuring the Effects of a Making-Based Senior Design Project in Engineering Technology

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Abstract
In a pilot corresponding with the founding of the university-wide maker space at Texas State University, the Engineering Technology senior design class completed a making-based senior design project. This pilot semester also represented the first semester of a formal senior design experience for Engineering Technology majors at Texas State University rather than culminating their college experience with a capstone-style industrial internship. This change was the result of feedback from the department’s Industry Advisory Board, which requested that the internship program to be converted to an early, cornerstone-style experience for the students. The objective of the new senior design course was to provide students with the working knowledge of systematic product development process covering all major design phases including product planning, conceptual design, embodiment design, and detail design. One major distinctive feature of the new senior design course is its multidisciplinary nature in the sense that students within design teams come from different Engineering Technology concentrations, namely, mechanical, manufacturing, electrical, and environmental engineering technology. Interdisciplinary teamwork is increasingly becoming prevalent in today’s global market and the new senior design course is intended to prepare students for working in environments where crossing traditional professional boundaries is a necessity for promoting innovation and critical thinking.

For the study, the students in the course took the Engineering Design Self-Efficacy measurement tool at the start of their senior design project and then again at the end of the semester to try to measure the change in their self-efficacy, or their belief in their own ability to conduct engineering design, over the course of the senior project class. The construction of the prototypes for the senior design project occurred in Bobcat Made, the new maker space. This paper will describe the structure of this new senior design course, the project completed during this first semester, and the results of the pre- versus post-project surveys. In future semesters the projects available to the students in this senior design course will be a mixture of ones requiring use of the maker space and those where it would be optional to use in order to assess to what extent does the use of a maker space while completing the senior design project have on students’ Engineering Design Self-Efficacy.

Introduction
A senior design class was recently added to the Engineering Technology curriculum at Texas State University in lieu of having a capstone-style industrial internship. This change came about at the suggestion of the Department of Engineering Technology’s combined Industrial Advisory Board. All students still have a required internship as a part of their degree programs, but those internships are now early, cornerstone-style experiences. The resulting new senior design program is cross-disciplinary as all of the concentrations in Engineering Technology share the same senior design course. The introduction of this new course also coincided with the founding of the university-wide maker space, Bobcat Made. For the pilot semester reported in this paper, the students in this new senior design course created their prototype in the maker space, providing the opportunity to examine changes in their Engineering Design Self-Efficacy (EDSE). This paper describes this new course, the prototype created in the maker space during this pilot semester and the preliminary pre- versus post-project results from the EDSE tool.
Course Description
The senior design course (TECH 4398) in the Department of Engineering Technology is the culmination of four years of engineering technology education where students bring together their technical and non-technical knowledge towards the completion of a product development project. One unique aspect of the TECH 4398 is that it is a required course for all ET specializations. Therefore, the instructor has the opportunity to form multidisciplinary design teams composed of students from different disciplines including Mechanical, Manufacturing, Environmental, and Electrical Engineering Technology based on the nature of each project. It should be noted that this course was developed from the outset based upon using multidisciplinary teams and, therefore, there is no prior experience available to compare these experiences to working with single discipline senior design teams in the Department of Engineering Technology.

Since manufacturing knowledge is the common thread that goes through all ET specializations, the design teams are expected to create high-quality functional prototypes at the end. The projects are solicited from external sponsors who can act as both potential customers for the project and project advisors. The design projects involve designing a product per customer requirements, fabricating a functional prototype, and testing the fabricated prototype. The design teams are expected to follow the systematic product development process including requirements planning, conceptual design, embodiment design, and detail design. The instructed design methodology is generic enough to be applicable to a wide range of products.

The class meets once per week and is composed of lecture and lab sections. The lecture section, which is limited to the first six weeks of the semester, is focused on providing information about design tools, design process, and design terminology. The underlying goal is to familiarize students with the structured design thinking and curb the deficiencies induced by ill-structured and open-ended nature of design projects. The design methodology taught in this course is based on Pahl and Beitz theory of systematic design and Ulrich and Eppinger methodology for product design and development (Pahl et al, 2007 and Dieter and Schmidt, 2009). After the midterm presentation, wherein the teams present their conceptual designs and receive approval from their sponsors, the entire class time is dedicated to modeling, fabrication, and design documentation. The details of each phase of design, together with the deliverables of each phase, are described below. The four phases of the product development process described below define the four phases of the course as well.

Product Planning (Week 1-2): In this phase, design teams are expected to understand the underlying problem that is intended to be addressed by the final product and develop the projects mission statement. The mission statement of the project contains the broad description of the product, the main assumptions, the key business goals, the primary and secondary markets for the product, and the main stakeholders of the product. The design teams are cautioned that the product description that is created in the product planning phase should only identify the product’s basic functions and it should avoid implying any specific concept. The mission statement serves as the project contract that defines the scope of the project and its main constraints. Also, the design teams are expected to create a project work plan represented as a Gantt chart in this phase.
**Conceptual Design (Week 3-6):** Conceptual design is the most demanding phase of the project in TECH 4398 in terms of the variety and the depth of design activities. In the early stages of the conceptual design phase, the design teams are expected to work closely with the customer to identify the design requirements and categorize and prioritize them as constraints and criteria. Design teams are provided with special guidelines for properly formulating customer requirements in order to improve the clarity and completeness of requirement statements. The identified requirements are then translated into engineering specifications using Quality Function Deployment (QFD) method. Multiple concepts are created guided by brainstorming tools such as C-Sketching and 6-3-5 method and then combined using Morph Charts. The generated concepts are evaluated using concept evaluation matrix in order to arrive at one or two final concepts to be carried over to the Embodiment Design phase. At the end of the conceptual design phase, the design teams are expected to develop proof-of-concept prototypes that only convey form-related information.

**Embodiment Design (Week 7-10):** In this phase, the selected concepts are further developed into a product that delivers the required functions and can be produced. The main focus in this phase is on architecture design, configuration design, and parametric design. Design for assembly, manufacturing, and environment rules are also applied to the design artifacts at this stage. The design teams are expected to develop functional prototypes by the end of this phase. The design teams are also expected to develop the CAD model of their products in this phase.

**Detail Design (Week 9-14):** At this stage, the focus is on generation of design documentation including detailed drawings, assembly charts, bill of material, and operation process charts. Design teams also conduct economic analysis in order to estimate the direct and indirect manufacturing costs of the final design.

**Course Evaluation**

Students are evaluated based on five criteria, namely, presentation and communication, teamwork, design product, design process, and design knowledge with different relative weights. The instructor and the project sponsor participate in the evaluation process.

**Design Knowledge:** The lecture session focuses on providing information about design tools, design process, and design terminology. Student’s knowledge of systematic design process is tested through a single midterm exam. There is no final exam for this course. **Presentation:** Presentation involves both written and oral communication. There is one interim report and one final report. There are multiple design review meetings throughout the semester in which the design teams provide updates about their progress. There is one midterm presentation and one final presentation per project and the sponsor attends both presentations. **People:** Peer evaluations is critical in evaluating the team and individual performance. Teamwork is monitored throughout the project with the expectation that each member be able to identify a specific deliverable for which they are primarily responsible. **Product:** The final solution is evaluated from a technical and economic viewpoint. The solution should be well justified through supporting documentation and analysis. **Process:** The design process is evaluated based on the appropriate application of design tools and whether or not the design team would be able to successfully apply the process to a different design problem. An important learning outcome from this course is the realization that
engineering design is not accidental, but can be a controlled process that yields higher quality solutions.

Case 1: Development of Wrist Device for Triangular Fibro-Cartilage Complex (TFCC) Injuries

In the first semester of offering TECH 4398, a professor in the Department of Physical Therapy sponsored a project related to developing a wrist device for the triangular fibrocartilage complex (TFCC) injuries. TFCC is a group of ligaments located on the side of the wrist below the small finger. An injury or tear to TFCC can cause chronic wrist pain. There are few devices available in the market that provide partial stability for TFCC injuries. The objective of this senior design project was to design, prototype, and test a wrist device that provides both sagittal and frontal plane stability to the ulnar side of the wrist with minimal or no restriction of wrist and forearm motion. One of the requirements of the designed device was that it should reduce or abolish pain during pain producing maneuvers. Apart from providing its core function, the device was required to be low profile, easy to wear, washable, and made of non-elastic, breathable, and recyclable material and fit a wide range of hand sizes for adults.

Both design teams in TECH 4398 worked on the same project to create their own prototypes. These teams followed the systematic design process, including interviewing the project sponsor and potential users to develop a detailed listing of design constraints and criteria. Multiple concepts were generated by both teams during idea generation; two of which shown in Figure 1. The design teams developed two different wrist devices while working independently.

For prototyping, the design teams used the maker space. Neoprene and Velcro were the main materials used for prototyping. After generating the 2D CAD model of various pieces of the brace they were cut using VLS 3.60 laser cutter and then assembled together through stitching and sewing using Bernina B580 sewing machine as can be seen in Figure 3. Simple hand tools were used for final cleaning. Since sufficient instructions were provided for operating the machines available in the maker space, the teams were able to use them efficiently and create and test multiple prototypes in a short period of time and make the necessary adjustment to their design such that it better meets the identified requirements. As shown in Figure 3, the
performance of the final prototypes for both teams was tested using *press test* method and it was observed that both designs increase the weight-bearing limit of the patient as much as 12-15 pounds.

Figure 2: Prototyping in the maker space

Figure 3: The final prototype was tested using press test method

**Survey Instrument**
The Engineering Design Self-Efficacy tool (Carberry et al, 2010) was used to measure any changes in the students’ self-efficacy from the beginning to the end of the semester. Specifically, this instrument evaluates self-efficacy of four attitudes towards engineering design: confidence, motivation, expectation of success, and anxiety. Self-efficacy is defined as an individual’s confidence in their own ability to complete a certain task (Bandura, 1977). High self-efficacy is associated with higher retention rates in college and with a stronger identification as being part of a group (Bandura, 1977; Lent et al, 1984; Multon et al, 1991; and Marra et al, 2012). As such, increasing students’ engineering design self-efficacy could have positive influences on retention and graduation rates as well as increasing students’ persistence in
engineering and engineering technology as career fields. This survey instrument was chosen for this study as the instrument is currently being used to examine effects of makerspaces and making projects on engineering students (Morocz et al, 2015; Morocz et al, 2016: and Talley et al, 2016). These other ongoing studies allow comparisons of this preliminary data to those of other student groups in future work. As the students in this study were in a senior design course, it was expected that their engineering design self-efficacy would increase as a result of the course and project as observed by Miskioglu (2016) in a similar study of engineering design self-efficacy in a senior design course. This preliminary data was collected to compare to future semesters, when not all students would use the maker space to create their prototypes. Therefore, the future work of this project will provide the opportunity to compare gains in self-efficacy between types of senior design experiences. Further, future work could compare these differing gains in self-efficacy with responses to the students’ responses about their subsequent career paths in future alumni surveys.

**Preliminary Survey Results**

This initial offering of the Engineering Technology senior design course had a small enrollment: seven (7) students. As completing the survey was voluntary, the pre-semester survey had four (4) responses and the post-semester survey had six (6) responses. Of these responses, only three (3) students complete both the pre- and post-semester surveys. As the number of participants was so small, it would be challenging to draw generalizable conclusions about the results. Therefore, the class average pre- and post-semester Engineering Design score from the four assessment categories of the Engineering Design Self-Efficacy tool are reported as preliminary results in Figure 4. As both design groups worked on the same project, it seemed reasonable to group the entire class together to present these preliminary results. Figure 4 shows that there was a trend of increasing student confidence, motivation, and expectation of success in conducting engineering design from the beginning to the end of the semester. Further, the students’ anxiety about conducting engineering design was largely unchanged from the beginning to the end of the semester. The standard error bars included in this figure suggest that the increases in student confidence, motivation, and expectation of success in conducting engineering design are statistically significant. Note that the number of participants in this study was very small, and that there were only three students who took both the pre- and post-project surveys. The average of all of the student responses is presented here to show preliminary trends, but additional data would need to be collected before drawing conclusions. As well, the students’ self-reported demographics are presented in Table 1 to provide context for their responses. All of the students were seniors who took this course. No further analysis was attempted at this time because the sample size was too small to draw meaningful results. In future work, these results could be aggregate with other senior design students who complete making-based senior design projects to compare to students who did not utilize a makerspace for their senior design projects.
Table 1: Participant Reported Demographics

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<th>Survey Question</th>
<th>Pre-Survey</th>
<th>Post-Survey</th>
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**Future Work**

In future offerings of this course, the Engineering Design Self-Efficacy tool will continue to be used pre- and post-semester to measure changes in the students’ self-efficacy. It is expected that some groups will utilize the makerspace more than others owing to their project scope. By correlating the changes in the four areas of self-efficacy to the types of projects and the use of the makerspace, this future work will allow the exploration of what, if any, additional benefit the students receive by creating their prototypes in the makerspace. Further, this future examination of increases and levels of engineering design self-efficacy can be compared over time with students’ responses on future alumni surveys, such as correlating self-efficacy to pursuing careers in engineering and engineering technology.

**References**


