Design, Build, Install: An Experiential Implementation of Freshman Engineering Design

Louie Elliott and Cecelia Wigal
Mechanical Engineering Department, University of Tennessee at Chattanooga

Abstract

This paper reports on an experiential-learning team-based implementation of a freshman engineering design class for mechanical engineers with a focus on assistive technology devices. This course is unique in that the students design for real-world clients which are often students at regional elementary schools with a variety of physical and mental disabilities. The University of Tennessee at Chattanooga partners with Signal Centers, Inc., a local non-profit organization with a stated mission of "helping all individuals with disabilities strive for a life of independence" to identify the clients and projects. Each team meets with their client to identify the scope of the design and understand the user needs. When the fabrication and testing are complete, the teams work with local facility planners to deliver and install the prototype devices at the clients' locations. After a brief history, several pedagogical aspects of the course are discussed.

Keywords

K-12, experiential learning, assistive technology, freshman design, outreach

Background

The Introduction to Engineering Design (hereafter referred to as Freshman Design) experience at the University of Tennessee at Chattanooga has been a course or combination of courses in the college's engineering curriculum for over 30 years. During this time it has evolved from a 5 credit hour group of 3 separate courses to its present format of a 2 credit hour design laboratory course that meets 4 hours per week. The experience also evolved from one that emphasizes computer aided design (CAD) drawing as design to one that emphasizes the process of engineering design and its various components including the practice of solid modeling (which is now taught in a separate laboratory course). The experience also evolved from being a core course for all engineering majors in the college to one that is now required by only the mechanical engineering and mechatronics engineering technology students. The course also added a learning outcome addressing the ability to technically communicate information in written and oral formats.

In 2006, the course instructors obtained a grant from the state Department of Education, Special Education Division, to develop small scale solutions to help children (ages three to six) with disabilities to be more independent. The course team projects began to center on designing, building, and delivering assistive technology devices for this population group. Later, the grant was expanded to K-12 students as well as young adults. In 2011, the course instructors again expanded their clientele to any persons with a disability and to partners outside of the state. The instructors also began partnering with the University's Art department to specifically create solutions that will help persons with disabilities create art products.

Course and Project Participation

The Freshman Design course is offered in both spring and fall semesters most often as two sections. It is desired that each section be limited to 30 students; however, some sections have been as large as 40, and three sections were needed per semester when all engineering programs required the course.

Presently the course uses a single virtual project that the students address individually to learn the basics of the engineering design process. This takes a little less than half of the semester. During the remainder of the semester, the students work in teams of 4 to 6 students to apply what they learned of the design process and address the needs of an actual customer and clients. This project most often addresses the needs of persons with disabilities. However, some projects may address other needs such as those of a junior – senior level competition project or a project proposed by a regional entrepreneur. Typically, 7 to 12 projects are addressed each semester. Through the grants obtained and College and Departmental funding, projects have been supported with $300 to $600 each. A minimum of 2/3rds of these projects focus on persons with disabilities.

Clients

Most project customers and clients are based within a two hour drive of the University. The customers include regional elementary, middle, and high schools as well as preschools. Clients also come from local nonprofit organizations that seek to improve the lives of persons with disabilities such as Signal Centers, Inc., Open Arms Care, Orange Grove, Therapeutic Riding Centers, and the Special Olympics of Tennessee and Georgia.

The clients are included in the project definition and understanding. It is important that the students meet with the customer and the clients to clearly understand the project needs, the clients, and environmental constraints.

Project Variations

The projects have evolved over the years sometimes due to changes in the funding or funding source and sometimes due to recognition of need from the community. The emphasis on producing products to help persons with disabilities create art came from a local art gallery that serves the veteran community. They recognized that creating art is a form of therapy for veterans, but that some veterans have difficulty participating in creating art due to their disabilities. Thus the "Art for All" project was born[1]. This project teamed engineering students with art students to design and build tools to help persons with disabilities create art. One such device is the paint egg toss art tool shown in Figure 1. This collaboration project continued formally through spring 2017 and culminated in a showcase featuring the art generated by the clients with the assistive devices (Figure 2).

Figure 1: Paint Egg Toss Art Tool

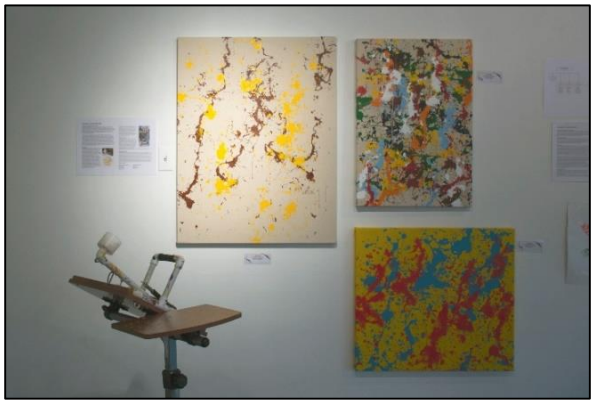

Figure 2: Paint Egg Toss Artwork

The next collaborative project is for the engineering students to team with students in the newly created program in music therapy at the University. This program needs tools that can be used in the teaching of the curriculum as well as for use in therapy sessions. This collaborative project is proposed for spring 2020.

Experiential Learning Designation – Beyond the Classroom

The University has emphasized experiential learning as a means for students to create confidence in creative and critical thinking especially with respect to experiences outside of the classroom. Experiential Learning course designations are becoming more important as the University moves toward requiring all students to have at least one experiential learning experience. After the 2017-2018 academic year, 1,996 unique students have participated in 62 different UTC experiential learning courses[2]. The Freshman Design course was the first in the College of Engineering to achieve "Beyond the Classroom" experiential learning designation. Requirements include that the course is project-based and requires the students to work with clients and customers within the regional community to solve a real world problem.

The component of experiential learning that sets it apart from hands-on learning is its use of reflection. Reflections, used in various forms, link the students' education to their world experiences and impacts on their own development. This course uses a leading question form of journaling to help the students reflect. There are three opportunities for reflection: once at the beginning of the team project, once during the team project, and once at the end of the semester. The leading questions for each phase are provided in Table 1 below:

Table 1: Freshman Design Reflection Leading Questions

Reflection Phase	Question
Prior	Describe what existing knowledge or skills you bring to a team engineering project.
	Describe your experience so far with people with physical disabilities.
	Describe your beliefs on how individuals should contribute to a team project for it to be successful.
During	Describe how you are contributing to the success of your team and project.
	Describe what you have learned during this project about persons with disabilities.
	Describe how your team is progressing and what changes may help the team be more productive.
Post	Describe what you believe you learned about yourself as a team member on the team project.
	Identify what aspect of your team you believe, that if improved, would have helped create a better project outcome. Explain why you believe this is so.
	Describe what you believe it means to give back to your community and why it is or is not important.

When the reflections were added to the course the instructor thought the students would think they are just busy work and not seriously complete them. However, the instructor was pleasantly surprised that most students spent more than the minimum required number of words to respond to each question. Most students completed all three reflections. Many students expressed in some way something that they learned from the experience and how it may affect them in the future.

Freshman Engineering Design is certified as a Beyond the Classroom course, therefore students can use this course to meet requirements toward their ThinkAchieve Graduate status. Students who graduate as a ThinkAchieve student have accumulated a required amount of experiential learning experiences and completed an experience synthesis (most often a website reflecting on their experiential learning path).

Pedagogy

The Freshman Design course is structured to help students reach to the top of the Bloom's Taxonomy Pyramid. To do this, the courses uses various creative thinking and communication tools, group learning strategies, and a qualitative grading scheme.

Reaching the top of Bloom's Taxonomy

Bloom's Taxonomy is simply a hierarchy of learning levels where the lowest level "Remember" is merely rote memorization and recalling facts from memory. At this level one is not even able to put information in their own words. As a student climbs the ladder, higher levels skills are built on lower levels. In the next levels, one can explain concepts, then use this info in new situations, then draw connections, make and justify a decision, and finally produce a new or original work[3]. Most educators use the Revised Bloom's Taxonomy (Figure 3) where the levels have been modified to be more process oriented and the top tiers have been switched. By requiring the students to fabricate a new design they ascend the learning pyramid, performing tasks at all learning levels: define, describe, sketch, compare, select, and assemble.

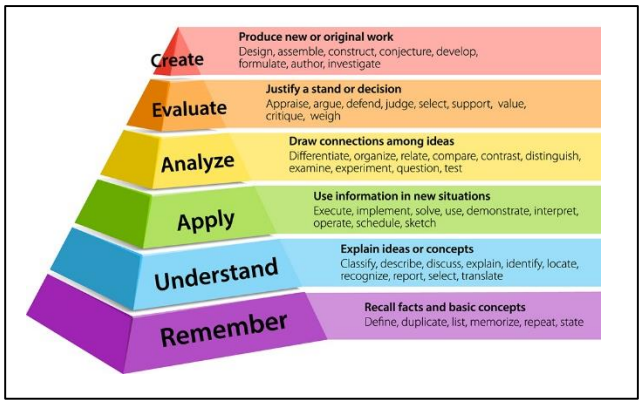

Figure 3: Bloom's Taxonomy Revised [4]

Meta-cognition methods for creative thinking

As part of the engineering design process, the students engage in activities that promote creative thinking for generation of possible design solutions. One such activity is the use of rich pictures which evolved from Peter Checkland's Soft Systems Methodology (SSM)[5]. Rich pictures provide a way to create a preliminary mental model of a complex issue through the use of diagrams, symbols, and words and help to open discussion and come to a shared understanding of a situation[6]. The teams are given a large sheet of paper and colored markers and half an hour to generate a rich picture. In the current semester the students were given the topic of "Global Warming". Several team generated rich pictures on the topic are shown in Figure 4.

Figure 4: Team generated Rich Pictures on topic of Global Warming

In addition to rich pictures, morphological charts are utilized for alternative solution generation. In this method which is based on functional analysis, the attributes, functions, or characteristics of the design are listed in a single column. For each entry, the options associated with it or possible means of implementation are listed horizontally in that row. Additional attributes are accommodated by adding another row to the chart, while additional options are handled by adding further columns to the chart[7]. Design solutions are created by choosing one entry from each row. In this way multiple solutions can be created with different means of achieving each attribute or design criteria.

Group learning strategies

Some of the activities for group learning include [8]

- Brainstorming – In this activity, the teams generate a list of possible uses for a paper clip. They are encouraged to think outside the box. Some examples include: fish hook, lock pick, jewelry, tweezers, key ring, and zipper pull.

- Myers-Briggs Type Indicator (MBTI) – as part of the discussion of balanced team dynamics, the students all take the personality type indicator test in which four dichotomies are assessed: Extravert/Introvert, Sensing/Intuition, Thinking/Feeling, and Judging/Perceiving[9]. The students discuss their results and compare with their group members and the instructor.

- Survival Game – In this activity the teams take a survival training test developed by the U.S. Army in which their group has crashed in an airplane in Canada in winter time[10]. 12 items are salvaged and must be ranked in order of importance for survivability: steel wool, ax, loaded pistol, can of Crisco, newspapers, cigarette lighter (without fluid), shirt and pants, heavy-duty canvas, air map, quart of whiskey, compass, and chocolate bars. The teams must come to a group consensus. Not all teams survive.

Technical Writing

Two student learning outcomes of the course focus on effective communication in written and oral formats. These outcomes state that students, upon completion of the course, will

- know, understand, and be able to use the principles of good oral communications to effectively communicate major ideas
- know and be able to use principles of good technical writing to effectively communicate major ideas

To help the students learn effective communication, the students are responsible for one individual oral presentation and two team oral presentations. The individual presentation summarizes a design solution with the goal of selling the design idea to management for future investment. This presentation is the culminating activity of the class virtual project exercise. The first team presentation is a design proposal for the team project. The second team presentation is a design solution demonstrative in either a poster session or a formal slide presentation in which the team must showcase the project's physical solution and operation.

The students are also responsible for three written documents – two individually written documents for the class virtual project and one team composed document for the team project. The individual documents are a short format memorandum that summarizes the understanding of project need and a long format memorandum that describes proposed project solution as well as the basis for the solution. The team document is a formal design report summarizing the solution design as well as need definition, cost, build instructions, and design specifics.

All assignments in the course support the creation of the written and oral presentations. The first memorandum is used as a draft for the second memorandum. Students receive in class instruction on how to compose effective technical documents using lecture material as well as examples. Students also receive instruction on giving effective oral presentations. They also critique their peers on their presentations in a forum format to acknowledge effective practices that others should duplicate and identify ineffective practices that need improvement.

The instruction and practice on communication has been successful. The students have won college and regional poster presentation sessions. Specifically last spring one of the freshman projects won second place in the mechanical engineering department's poster presentation division at the College's Technology Symposium.

5 point grading scale

The Freshman Design course uses a standards-based grading scheme from outcome based education theory as opposed to rank based grading which does not measure the actual achievements of a given student[11]. The instructors use a 5 point grading scale to assess student work as they learn and practice the elements of the design process. This scale is used because it is difficult to equate quantitative values to a qualitative work product. Also, this scale allows the instructor to communicate how well the student is meeting the requirements of the assignment or activity. As illustrated in Table 2 below, three points indicates the student is work is adequate – the student is responding to the assignment as the instructor expects for a typical freshman level student learning and applying the design process or communication practices. Four points indicates that the student work Is commendable and exemplifies some critical thinking. Five points indicates the work is superior and exemplifies a higher level of critical thinking.

Table 2: 5 point grading scale definition

Points	Performance Level
5	superior performance (exceeds expectations in most areas)
4	commendable performance
3	adequate performance
2	marginal performance (below university standards)
1	far below expectations

The students most often want to equate this scale to the typical letter scale of A, B, C, D and F (3 points mathematically equating to 60% makes them nervous). The students are told that (1) 3 points is a low B – every student should be capable of being adequate in this course, (2) 4 is a low A, and (3) 5 is the highest possible score – it is very difficult to get a 5 since no one is perfect. They are also told that if they receive a 2, they are performing below university expectations as a 2 is just below the lowest C, and a 1 is failing. Most students work to get scores at or above the 4 scale.

Web-based learning management system (LMS)

The course makes extensive use of a LMS. In this semester we have switched from Blackboard to Canvas as our online system, which is representative of the market share and national deployment of these respective systems[12]. In addition to the lecture material which is made available online, student and group assignments are uploaded to the LMS. Group sites are made for each team, where they are able to post the results of their team design process, including supporting documentation, and meeting minutes.

Design Results - Fall 2019

The Fall 2019 projects represent typical projects for the course. There were seven projects and all were completed and delivered to their associated customer by the end of the semester (see Table 3). The project customers vary across the Chattanooga community, as is true for projects for all semesters.

Table 3: Fall 2019 Projects and Customers

Project	Customer
Wheelchair Oscillator	Red Bank Elementary
Hammock Rocker	Spring Creek Elementary
Climbing Wall	Tri-State Therapeutic Riding Center
Sensory Box	East Lake Academy
Big Lite Brite	Wolftever Creek Academy
Activity Gate	Spring Creek Elementary
Therapy Stairs	Calvin Donaldson Elementary

As a requirement for successful completion of the course, the teams must document their final project installation. Typical documentation is by photo. However, some teams video record the installation and delivery. In their post reflections many students mention that the final delivery of the project strongly affects them, because at that moment they realize that their work can positively affect another's life. Two team installations from the fall 2019 semester are shown in Figure 5.

Figure 5: Sensory Box and Wheelchair Oscillator installation.

Conclusion

This paper reports on an on-going project-based experiential learning implementation of a freshman engineering design course at the University of Tennessee at Chattanooga. Through partnerships with local schools and non-profit groups the students work in teams to develop assistive technology devices for clients with physical and mental disabilities. Several pedagogical aspects of the course were discussed including its experential learning designation, meta-cognition methods, group learning activities, and a five point grading scale. Learning outcomes for technical writing are achieved through individual and group written documents and oral presentations. Through reflections the students have expressed that the experience has had a profound impact on them.

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Dr. Louie Elliott

Louie is an Assistant Professor in the Mechanical Engineering Department at the University of Tennessee at Chattanooga with degrees in physics and computational engineering. His primary research interest is the simulation and modeling of complex systems with a focus on numerical design optimization. Louie accumulated 10 years of industry experience in sensor design, prototype development, electromagnetics, and fuel cells. He performs funded research with students in additive manufacturing and sheet metal forming as well as outreach programs with local middle and high schools. He is currently Chair of the Software Engineering division and Secretary of the K-12 division for the ASEE Southeastern section.

Dr. Cecelia Wigal

Cecelia is a Professor in the Mechanical Engineering Department at the University of Tennessee at Chattanooga with degrees in electrical and industrial engineering. She teaches engineering design courses, project-based instruction courses, information systems courses, and systems modeling courses. Cecelia's primary areas of research include complex system analysis and quality process analysis with respect to nontraditional applications such as service systems. Cecelia is particularly interested in improving the lives of those with physical and mental disabilities. She is currently Secretary and member of the Executive Board for the ASEE Southeastern section as well as Vice-Chair of the Industrial Engineering division.