The Capstone Design Experience Modeled as a Small Business Enterprise

Tristan J. Tayag
Texas Christian University

The capstone design experience offers the greatest academic opportunity for experiential learning before undergraduate students embark on their professional engineering careers. Industrial-sponsored engineering projects typically require a team of engineers with multidisciplinary skill sets. Success of the project is based on the team satisfying the technical specification within the allotted budget and time frame. Each individual team member's performance on the project is evaluated by the project manager and his/her raise is taken from a fixed pool of funds. Texas Christian University's capstone design program strives to incorporate each of these facets of engineering into the students' design experience by having a large team of 15-20 students function as a small business enterprise. In this paper, the team structure, project schedule and individual assessment process are presented.

Keywords: multidisciplinary, experiential learning, assessment, industry model

Corresponding Author: Tristan J. Tayag, t.tayag@tcu.edu

Background

Texas Christian University (TCU) offers its students an interdisciplinary program in electrical and mechanical engineering based on both classroom instruction and experiential learning. The capstone design program is a significant aspect of their learning experience. Currently, about 40 students graduate each year from TCU with bachelor's degrees in engineering. Two capstone design projects are offered each year with about 20 students per project.

TCU's capstone design program was founded by Dr. Patrick Walter in 1995.[1] Dr. Walter came to TCU after a 30 year career at Sandia National Laboratories, the last 18 years of which he spent in the management of large-scale weapons and test systems. To help TCU's engineering students transition for academia to industry, Dr. Walter established a continuous 3-semester design sequence beginning the spring semester of their junior year. Teamwork is emphasized in this junior-level course through group exercises involving topics including, but not limited to the following:

- engineering economic analysis,
- budgeting,
- fault tree analysis,
- project planning/scheduling/tracking,
- engineering report and memo writing,
- decision making, and
- engineering presentations.

During their senior year, a team of about 20 students operates as if they were a small engineering business contracted to produce a product for a customer. Similarly, the team could be considered a separate business entity within a larger engineering organization. The objective is to give the students the experience of managing and executing an engineering project for a real customer.

The large size of the team (about 20 students) and their interdisciplinary skill sets (electrical and mechanical engineering) provides the opportunity to engage industrial customers with a broad range of technical specifications. Typical capstone design projects in North America involve 4-6 students with a project budget of under $1,000.[2] Over the 21 year history of TCU's engineering program, there have been 24 sponsored projects.[3] Industrial customer funding for these projects ranges from $5,000 to $69,000 with an average of $21,000 per project.

In this paper, I present how TCU's capstone design program is structured as a small business enterprise, our assessment process which is based on the industry model and the student learning objectives. Specific examples from the past 2 years of customer-sponsored projects are included:

2011–2012 Customer: Bell Helicopter Textron, Inc.
Title: Helicopter Cockpit Synthetic Display System
This project was to design, build, and test a prototype "augmented-reality" display system for a helicopter cockpit. The system allowed imagery and flight data to be super-imposed on the pilot's view outside the

cockpit. The purpose of the system is to provide aircraft pilots with synthetic visual cues of sufficient fidelity to allow safe flight operations in lieu of real world visual information (for example, aircraft flight in fog or sandstorm).

2012–2013 Customer: Corning Cable Systems
Title: Fiber Assembly Positioning and Curing System
This project was to design, build, and test a system to cure a heat-cure-epoxy in various types of fiber optic cable assemblies. Key technical specifications included the requirement that the system must ensure the fiber is fully seated in the ceramic ferrule and that the system must cost under $5k.

Structure of the Capstone Design Program

TCU's capstone design program provides its students with a real-world engineering experience through a customer-based project. The students are responsible for the management and execution of the project. On the first day of class their senior year, the student team is notified who their customer is and they are handed the Statement of Work (SoW) detailing the specifications of the project.

Organization of the Team

The student team elects a project manager (PM) from the team. The PM and faculty mentor meet weekly during the senior year. The PM manages the team meetings and will invite suggestions from the faculty mentor at the end of each meeting. To encourage ownership of the project by the team, the faculty mentor's comments are prefaced with the reminder that these suggestions are not mandates. Not surprisingly, the team typically learns through their experience more so than through advice offered by the faculty mentor.

A common mistake is that students neglect to use the tools they have learned to help guide their design decisions. Instead, they rely on their intuition, which is based on limited experience. As an example, the 2011-2012 team designed a transparent display screen which would wrap around the interior of a helicopter cockpit. They chose ¼"-thick lexan for the screen substrate. A slot was cut in the center of the lexan sheet for mounting to the windshield frame. The stress concentration points at the corners of the slot caused the lexan to fracture when the sheet was bent (see Fig. 1). Finite element analysis simulation revealed that a 1/16"-thick lexan sheet and a slot with rounded corners significantly reduced the stress concentration.

Typically, the PM will divide the team into groups appropriate to the needs of the project (for example, hardware design, signal processing, sensor integration). Each group will have a leader who reports to the PM. The more successful PMs invite their teammates to volunteer for leadership roles and group assignments.

Other roles include the budget manager (some PMs elect to perform this role), equipment manager, and documentation manager. Each role contributes to the success of the overall project and activity within a role varies throughout the course of the project. This year, the equipment manager set up an efficient survey system through SharePoint to track equipment loaned by faculty to the team during the research phase of the project early in the fall semester.

Contract with the Customer

The team enters into a formal contract with the customer; however, the team is not given the opportunity to select the project nor do they contribute to the negotiation of the technical specification. The faculty mentor and the customer define the project's SoW (technical specifications, budget and milestones).

A key consideration in the selection of a project is that it must be of value to the customer. This is necessary since the student team must have access to a technical point of contact at the customer's company. Equally important is that the project's technical specifications be sufficiently quantified to allow both the customer and the student team to assess the project's success.

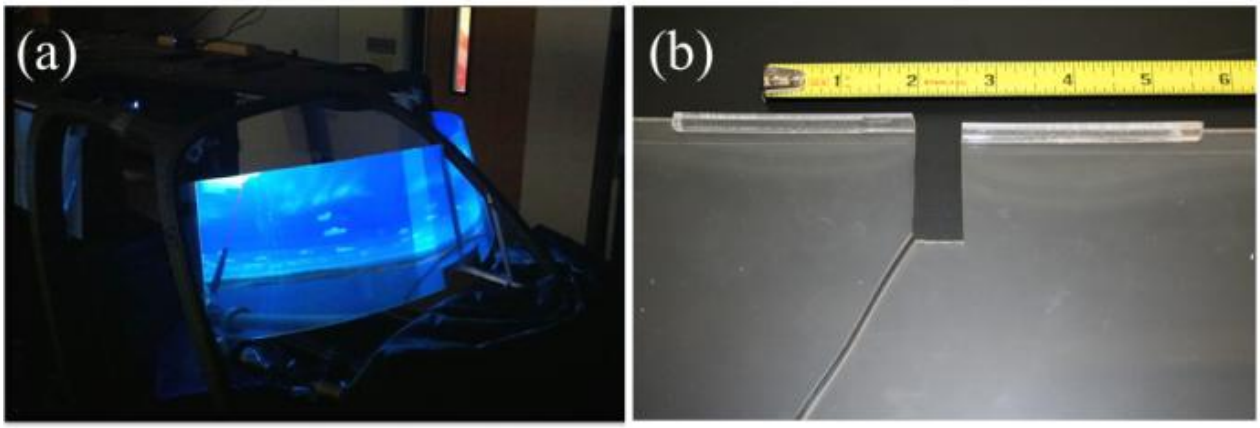

Figure 1: 2011-2012 Helicopter Cockpit Synthetic Display System Project (a) imagery displayed on the transparent front screen within the helicopter cockpit and (b) fractured lexan substrate of the front screen.

Other requirements which TCU places on the selection of a project are as follows:

- Project must include a hardware deliverable.
- Project must include both electrical and mechanical engineering aspects.
- Project must be of sufficient scope to engage 20 engineering students for 1 academic year.
- Project must be sufficiently funded for materials, equipment, and printing (no charges are made for salaries, wages, and overhead).

Key milestones which are consistent with industry-run projects are defined within the SoW. These milestones are critical to insure interation between the student team and their technical points of contact at the customer's company:

- Project Kick-off: On the first day of class, the SoW is distributed to the team.
- Systems Requirement Review (SRR): Within 2 weeks of the project kick-off in August, an SRR meeting is held. At this meeting, the customer is given the opportunity to make a presentation to the team and the team is given the opportunity to ask detailed questions on the specification.
- Preliminary Design Review (PDR): At the end of October, the team presents its design concepts with associated budgets to the customer. Trade-offs among the design concepts are discussed. The customer down selects to the preferred design.
- Critical Design Review (CDR): At the end of November, the team presents its final design to the customer. Following approval of the design, CAD drawings are finalized with the machine shop and purchase orders are prepared.
- Demonstration of the Product: In mid-April, the team demonstrates its final product to the customer in a closed-door presentation.
- Final Presentation: In late April, the team makes a formal public presentation to the customer, faculty and staff, family and friends.
- Product Delivery: In early May, the team delivers the product, final report, operating manual, and any other associated documentation and equipment to the customer.

Available Resources

In addition to the funding provided by the customer, the student team is provided with resources similar to a business enterprise within a larger engineering organization. The team has a 24/7 access to a dedicated lab which is over 1300 square feet (see Fig. 2). This meeting and work space is equipped with wireless access, computers, a projector, a stocked tool chest, long distance phone access, a printer, storage cabinets and electronic instrumentation (o-scope, power supplies, waveform generators, etc.)

Figure 2: 2012-2013 Fiber Assembly Positioning and Curing System Project. Meeting with the customer in the dedicated senior design lab.

Just as engineers may consult with technical area experts within a large company, the student team typically seeks the advice and guidance from vendors, faculty and staff. Due to the hardware nature of the design projects, the team has close interaction with TCU's 3 machinists. At TCU, the senior design lab is adjacent to the machine shop.

Assessment Process

The assignment of grades for TCU's 2-semester design course is based on the merit raise process in industry. At the end of the semester, each team member is asked to perform a "Self-Assessment" in which they describe their 2-3 most significant contributions to the project. These documents are made available to the entire team.

The students are then asked to evaluate the performance of each of their teammates in a "Peer Evaluation" process. In the business setting, a fixed amount of funds are available to distribute among the employees for merit raises. In large organizations, each engineer is allocated a raise amount based on their grade and tenure in the organization. From those funds, the manager of a team may award a higher raise to those team members who "exceeded expectations" with exceptional performance for that period; as a result, team members who "did not meet expectations" must have a raise amount less than originally allocated.

In TCU's peer evaluation process, each team member is considered at the same level so the raise allocations are the same amounts. For a team of 20 students, each team member is allocated $3000 for a total raise pool of $60,000. Each team member is required to assign raises to the other members of the team, except to him/herself and to the PM; therefore the total raise pool for a 20 student team is actually $54,000.

These raise distributions are averaged for each team member with the PM's raise distribution being weighted 25% of the total. The students are provided with the scale of how dollar raise amounts correspond to letter grades. For example, an average raise of $3,000 corresponds to a semester grade of B.

The students are also required to comment briefly on the work habits of each teammate. These must be constructive comments intended to help their teammates grow professionally. It might reinforce good performance or point out some manner in which it would be beneficial if their performance changed or improved. The comments must be consistent with the assigned raise amount.

The PM is removed from the peer evaluation process since contentions inevitably arise and the PM is given the decision making authority. The PM's semester grade is assigned by the faculty mentor and based on the percentage of the specification which his/her team is able to achieve.

In industry, the manager typically has a "close-out meeting" with his/her direct reports to discuss their merit raise for that period and set goals for the next performance period. At the end of the semester, the faculty mentor holds a close-out meeting with each team member. The faculty mentor provides the team member with his/her letter grade for the semester and the anonymous peer evaluation comments. These comments are discussed and specific goals set for professional development during the next semester.

Learning Objectives

The capstone design experience modeled as a small business enterprise lends itself to the following learning objectives:

1. Listen to the voice of the customer:[4,5] During the 2012-2013 project, the student team designed a heating system to cure the epoxy in a connectorized optical fiber cable. Their initial design was largely based on their intuition. During the PDR, the customer shared his design ideas with the students. In their subsequent meetings with the customer, the students insisted that their design was better. The team spent January and February of the spring semester conducting experiments in hopes of validating their initial design choices. In the end, the final design was very similar in key respects to the customer's original suggestions.
2. Be project-oriented, not task oriented: 2 common comments in the peer evaluation process are (1) that a particular team member did only those tasks assigned and (2) that team members not within his/her specific group were not aware of his/her contributions. Team members who take a more project-oriented approach not only complete their assigned tasks, but also maintain awareness of the overall project and contribute suggestions to other groups for overall project success.
3. Don't "plan for success": Inexperienced engineers typically do not budget sufficient time to adapt to unanticipated events.[6]
4. Hold effective meetings: Effective meetings have well-defined objectives where the participants prepare for the meeting in advance and arrive on time. Peer evaluation comments clearly indicate that students recognize when their peers arrive unprepared for group meetings.

Summary

TCU's senior design program is modeled as a small business enterprise wherein the student team enters into a formal contract with an industrial sponsor. Due to the large team size and interdisciplinary nature of the design team, industries like Bell Helicopter and Corning Cable Systems can propose projects of sufficient scope that they are of real value to the customer. Success of the overall project is based on satisfying the same 3 basic criteria as in the real world: (1) a technical specification, (2) a budget and (3) a schedule of deliverables.

TCU has established a grading scheme based on the basic performance evaluation process used in industry. Individual close-out meetings between each team member and the faculty mentor are used to discuss peer evaluation comments and set goals for professional development.

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