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Starting a Multidisciplinary Senior Capstone Design Course

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Abstract

In 2000, George Fox University expanded its engineering program from a 3/2 program to a complete four year engineering program providing a Bachelor of Science in Engineering with concentrations in both electrical and mechanical engineering. 2004 saw the first graduates from the program which became ABET accredited the following year.

Very early in the program development, it was decided that the senior capstone experience would be a multidisciplinary experience. The small class sizes (9-10 seniors in the first three years) also enabled the program to focus on a single project in the initial years and expanded to two projects to accommodate the 17 seniors in the 2006/2007 academic year.

While many senior capstone experiences are constructed to focus on the design experience, we decided to expand this focus. By their senior year, George Fox University engineering students have already experienced a number of significant design experiences. This wealth of prior design practice enables the program to use the capstone experience to help students transition from the mindset of a 'student' to that of an engineer. This desire to imitate "real-life" engineering project experience drives the structure and pace of the capstone experience. Students tend to be surprised at all the "non-technical" issues that must be confronted and addressed.

The project progress is assessed throughout the two semesters and input is frequently provided by the faculty members and the representative from the industry sponsor. Both the complete team and individual students are assessed. This course serves as an excellent place to measure the overall learning and progress of the students as well as the success of the engineering program. Final oral presentations and demonstration of successful prototype functionality are given at the annual Design Project Day and at the client's industrial site.

In this paper we describe the methods used by the George Fox University engineering program to acquire and work with industry sponsors and define the scope of these projects. Additionally, we will describe the specifics of the student group formations and how students have, either effectively or ineffectively, participated in the multidisciplinary experience. We will use the specific examples from the delivered prototypes, using these elements to emphasize those efforts that have worked well and to indicate those areas that have been less successful.

Introduction

In 1995, Todd, et. al.[1] published a survey reviewing capstone engineering courses in North America. A follow-up survey by Howe and Wilbarger was performed in 2005[2,3]. These surveys showed that universities employed a variety of course implementations for a senior capstone experience. While the vast majority of institutions now employ design teams rather than individual projects, there are significant differences in the students that make up the teams, the length of the experience, the source of the experience, and the funding for the experience. It seems clear that any senior capstone experience is not a one-size-fits-all solution. In the original survey, less than one-third of the respondents were providing a multi-disciplinary capstone experience, only 40% required a working prototype, and fewer than one-quarter required production ready hardware. The later survey indicated an approximate 10% increase in the number of multi-disciplinary teams at the expense of a reduction in individual projects. There was no indication in the report of a change in the required delivery item.

In 2000, George Fox University expanded its engineering program from a 3/2 program to a complete four year engineering program providing a Bachelor of Science in Engineering with concentrations in both electrical and mechanical engineering. 2004 saw the first graduates from the program which became ABET accredited the following year. A significant step in making this transition was the development of a senior capstone experience.

Very early in the program development, it was decided that the senior capstone experience would be not only a team-based experience, but one comprised of multi-disciplinary teams. Students at George Fox University take the same curriculum for the first two years and then focus on their specific concentrations in the final two years. As such, the freshman “cornerstone” experience is multi-disciplinary and creating a multi-disciplinary capstone provided a wonderful opportunity to emphasize what is believed to be a strength of the program.

In examining other capstone experiences, some have indicated a struggle with completing significant design projects. One university reported that “few student groups complete the full functionality promised at the outset, and many groups did not even complete working systems, only working subsystems”[4] As a solution, project management was suggested. Another university study stated that “systems-level design tasks require background knowledge. In a one-semester course, there is not enough time to acquire that knowledge” and “students do not have enough design experience to make systems-level tradeoffs.”[5] The solution at this university was to eliminate system-level design and focus on detailed design activities.

Other capstone experiences do not shy away from significant design projects, but instead make the significant design project the primary purpose of the capstone experience. Meyer reports that electrical/computer engineering students at Purdue University are given three options to fulfill the senior design requirement. One of these is the *Digital Systems Design Project* course where each team can design an embedded microcontroller based system of their choice (subject to instructor approval)[6]. This project includes device programming, printed circuit board design, and system packaging.

Due to the small size of the classes at a university like George Fox University, engineering students can often be exposed to in-depth design components early in the curriculum. At George Fox University, the junior level microprocessor course includes a month long project where each student is individually required to do a project similar to the Purdue University project (without the system packaging and documentation deliverables). Through this course and others like it, senior engineering students have had a number of significant design experiences.

Because George Fox University engineering students have experienced significant design projects, it was decided that students in the capstone course *would* not only undertake a significant design, but be required to deliver production ready hardware. Furthermore, the capstone experience is also designed to enable students to transition from an academic setting to a more professional engineering, or “real-world” environment. Other schools have indicated that they wish to provide a “real-world” experience[7,8,9] but this term is often not defined.

Course Structure

The capstone course is offered as a two-semester sequence. During the first semester, teams meet with faculty for an hour once per week. In the second semester, teams are schedule to meet for three hours each week. During this time, the faculty meet with the students twice per month. One of these times is for a formal presentation/design review. This process serves not only as a design review, but as a chance to teach the team better presentation/communication skills. The other monthly meeting is used as a “check-up.” Depending on how the project is progressing, this meeting might be anything from a one minute conversation to another full design review.

Course Beginning

In the initial weeks, students are taken on tours of the industry sponsor’s facility, and the project is described to the students. Typically, students are given a set of requirements for successful completion of the project. These requirements include basic requirements that must be completed, along with advanced requirements that are given number weights based on the degree of importance. Every student group invariably begins with the intention of performing all of the basic and advanced requirements. To date, these have always been met.

The senior capstone is designed to present students with a situation similar to what many might face as entry-level design engineers. To make this transition smoother, the senior design course is structured to run as a design team at a company rather than a class. The company structure is set up with the supervising faculty representing division chiefs in a company, with multiple design teams operating within the division. Each class of students forms a design team responsible for the design, development, and delivery of a product for a customer. Each design team (class) then is organized into a project-specific structure that generally yields a project manager, technical manager, and various subgroups depending on the task to be accomplished. This process happens early in the first semester.

Team Structure

The division chiefs (the faculty advisors) operate much the same as in a “real-world” setting. Early in the project the faculty advisors offer significant instruction in architecting the system. From these initial conversations, a picture of tasks emerges and what subgroups might be required to perform those tasks, along with whatever leadership might be required for the group in general. While students are solicited for thoughts on group structure and to discover individual interest in various positions within the team, it is ultimately the responsibility of the advisors to determine team structure. After notifying the students of the “official” structure for the team, the advisors continue to offer advice in the initial stages of the system design. However, by the middle of the first semester, the design team has basically taken ownership for the project and the faculty advisors become more like traditional division chiefs who are frequently being briefed on the status of the project.

The project manager is responsible for scheduling of the project and budget operations. Typically, the project manager is assigned to employ Microsoft Project to design a project schedule. While this schedule is often not followed perfectly, and often isn’t well maintained in the later stages of the project, it serves as an invaluable aid in showing the students the number of details in the daunting task ahead. The timeline derived from this tool provides a series of significant marker stones that student's target.

The technical manager is responsible for assuring that all of the technical requirements of the project are met. This position is critical in a multi-disciplinary team as the subgroups can rapidly start a "divide-and-conquer" approach. In a relatively short time, a stepper-motor controller will be designed for a system that has a servo-motor. For at least one advisor, the highlight of the entire capstone experience occurred this past year when the project manager was having an "intense negotiation" with the technical manager. The project manager was pushing for release of the design to the machine shop in order to meet a scheduling deadline and the technical manager was demanding that the designs be reviewed by the team for correctness before being released. It was at this juncture that we realized that we had truly achieved a "real-world" experience.

As part of the team structure, it has become almost imperative that an industry liaison be appointed and offered an internship with the project sponsor if the project sponsor maintains purchasing and/or manufacturing control of all parts. This person can be either or none of the above positions, but without this individual in place, getting a timely response from the industry sponsor can prove challenging and can significantly affect product timetables. The liaison was in place for all but one project – and that project suffered significantly as a result.

Finally, subgroups are assigned based on project tasks. Projects have had different structures – some have had individual task groups for each task, others formed an additional control group using representatives from the other task groups. Some groups have had group leaders, most do not. Some teams have created documentation managers, and others have had purchasing managers emerge. One group replicated the "real-world" by doing a mid-semester "re-organization" as the project demands underwent significant change.

Semester Transition

As design activities increase, students are pushed very hard to complete the major portions of the design so that the vast majority of purchasing, especially for critical parts, can be done before the semester break. It has become important to utilize the three week period for shipping of parts with longer lead times. Upon returning from the break, students generally have a pile of parts ready for some assembly.

End of the Project

As the final semester comes to a close, project activity begins to ramp up to a furious pace. One significant challenge has been the inability to vary schedules due to the school year. In a multi-disciplinary experience creating a complete product, product integration must wait until the final part of the project. As this integration generally involves the control of the system, those in the controller groups (generally electrical engineers, but not always) are involved in a furious finish. The rest of the group can help write documentation during this time, but there is generally much more documentation to complete when the integration is finished.

On the last day of classes for the semester, the design team gives a presentation at the annual George Fox University Engineering Design Presentation. At some point during the following week (finals week), a presentation is given at the sponsor company's facility.

The Projects

At George Fox University, obtaining a significant design project is the responsibility of the supervising faculty (this falls in line with the idea of the division manager obtaining work for the division). While some utilize graduate research projects or competitions, utilizing industry sponsors has greatly enhanced the "real-world" quality of the project. The small class sizes (9-10 seniors in the first three years) enabled the program to develop with a single project in the initial years and expanded to two projects to accommodate the 17 seniors in the 2006/2007 academic year.

Year 1 – Drop-on-Drum Imaging System

A relationship was developed early on with contacts at Xerox in Wilsonville, Oregon. Xerox markets solid-ink printers and there is a considerable amount of testing required to produce various kinds of ink and ensure that the ink provides the correct color from the time it leaves the solid-state to the time it cools back into a solid on the paper. The first senior design project was an electromechanical test device to allow ink designers to view ink droplets on the printer drum. The project involved creating a chassis to hold a Xerox printer, mounting a movable camera above the printer that could observe the ink droplets on the drum, and designing a control system to operate the camera and the drum.

Figure 1: Drop-on-Drum Imaging System

Year 2 – Ink Durability Tester

The successful completion of the first year project enabled further projects to be requested by engineers at Xerox. In the second year, Xerox commissioned the capstone design team to develop an "ink durability tester." As part of the ink development process, Xerox engineers desire to see how durable ink on paper is when it has been scratched. Xerox had a simple system to perform this test. To utilize the system, the tester would place a sheet of paper on a tray, set weights on some lever arms, and then press a button to have three metal nubs move across the paper with the desired weights. After moving the paper and performing the test a second time with three other weight selections, the paper could be taken up and moved to an evaluation stage. This process was very time consuming and Xerox wanted to automate the entire system.

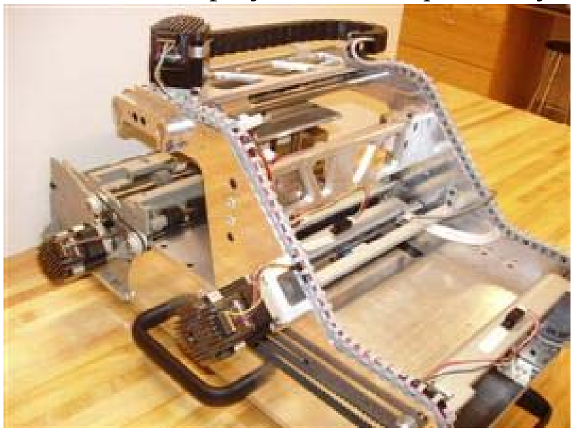

Figure 2: Ink Durability Tester

The second year design team utilized a paper “pick” system from Xerox and built a specialized robot around that “pick” system to automate the entire process. The system involved some specialized circuitry as well as interfaces to off-the-shelf motor drivers. The chassis and “scratch” assembly had to be custom designed by the team and fabricated at the Xerox machine shop. At the end of the year, while giving a project presentation to the team at Xerox, the system was initiated and processed 100 sheets of paper as the students finished giving the presentation. The system has been heavily utilized at Xerox and termed an unqualified success.

Year 3 – Transfix Roller Characterization Fixture

In a different part of the Xerox facility, engineers had heard of the work being done by the design team and requested another test fixture – one to test the qualities of the rubber rollers used in the printing process. This system involved a number of unique tests that had to be integrated into a single chassis with a number of different control systems – electronic, mechanical, and pneumatic. Xerox engineers desired a number of different speed, temperature, and pressure tests to evaluate the roller under different configurations. Design members did a significant amount of working scouring the market for various types of sensors and gauges to serve in the automation process. In this project, National Instruments hardware was purchased to control the various elements and LabView was used to control the system.

Figure 3: Transfix Roller Characterization

Year 4 – Color Robot

Again, Xerox came to George Fox University with a project to update an existing test system. To test color quality on printed paper, Xerox uses a photospectrometer to take hundreds of readings at unique points on a printed sheet of paper. This is replicated on hundreds of sheets of paper at a time. Clearly, this process is too tedious to complete manually. Six years prior, a design team from another university had completed a project to automate this process. The system was a success and has been used very heavily at Xerox. However, as with any engineered system, time revealed some design flaws. Among these, the machine was full of custom parts and difficult to replicate and it was designed for one particular spectrophotometer and could not be easily adapted to a new one or to other measurement devices. Xerox asked the design team to consider retrofitting the system to eliminate these flaws.

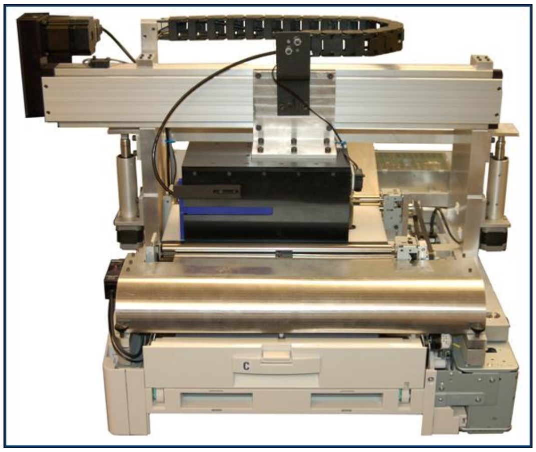

Figure 4: Color Robot

After careful deliberation and consideration of design trade-offs, the team constructed a proposal to Xerox requesting permission to create a new color robot rather than retrofit the old one. Xerox was impressed with the proposal and agreed to sponsor the design of a new robot. The system required the design and development of custom printed circuit boards to allow cost-effective control of all of the system components and was controlled via a single network interface. Again, the system was received with great excitement at Xerox and plans are in place to build several copies of the robot.

Year 4 – Horizontal Motion Conveyor

Prior to the start of the year, verbal agreements had been reached to perform test fixture design for a different company. The final agreement was pending approval from upper management. As Murphy's Law anticipates, the approval was denied shortly before the start of the school year. Fortunately, FMC Food Corporation had inquired asking about senior design opportunities. FMC builds horizontal motion conveyors to service the food industry. Unlike the other projects that had been completed, this company did not ask for a test fixture. Instead, they wanted engineers to contemplate a new way of performing horizontal motion – in essence, to brainstorm about a new way to perform one of the primary tasks of their company.

Figure 5: Horizontal Motion Conveyor

The prospect seemed daunting, and somewhat beyond the reach of a senior team of engineers. However, necessity is the mother of invention (literally), and the offer was accepted. The process was quite different from others in that there wasn't a clear set of requirements, basic or advanced. This was also the first year in which two projects were being conducted – one highly defined and organized, with plenty of experience with the sponsor company, the other more ambitious and new in most every way. The project ran differently with the first semester being reserved for a large amount of brainstorming and exploration of differing technologies. A novel method was devised, and the initial system was successfully tested (the night before the presentation). FMC was extremely pleased with the result and will be pursuing productization of the design.

Industry Relations

Project budgets have run between $5,000 and $10,000 for parts. This has always been completely paid for by the industry sponsor. Additionally, our sponsors have provided unlimited access to their commercial machine shops that have supplied another $2,000 - $5,000 worth of labor. This can be (and has been) considered a bargain for the industry sponsor as student hours calculated with standard intern wages has generally amounted to $55,000 worth of engineering. This figure does not include the time and involvement of the faculty advisors.

Lessons Learned

Test Fixtures as Projects

While working with Xerox has been a great situation for us (and one that we plan on continuing), building electromechanical test fixtures has emerged as a powerful model for providing significant design experiences for the capstone class. Such fixtures are technically challenging and generally capable of being completed by our classes. Perhaps more significant is that test fixtures offer significant value to the sponsor company, yet the device itself is not part of the product chain important to the company. In general, companies tend to put their own engineers to work on challenges of primary importance to the company. In lean operating environments, little engineering time is available to develop a test system to streamline these operations. Capstone design experiences serve as a perfect platform for engineering significant systems that are not critically important to the sponsoring company provides a wealth of opportunity to develop systems that value that test fixtures offer engineers.

Clear Requirements

As the project with FMC progressed, the lack of a clear definition for the project emerged as a significant challenge in providing a quality educational opportunity for the students. This is especially difficult on multi-disciplinary teams. These teams were divided at the very beginning of the year (by the faculty advisors) and each team was given an equal complement of electrical and mechanical engineers. As the FMC design progressed, it became clear that the final solution would be strictly mechanical one. While this was an elegant and very successful solution, the experience for the electrical engineers was not as good as we would have hoped for. Had the system been more clearly defined, a better job could have been done in assigning student teams.

Documentation

Most engineers prefer design to documentation. This “real-world” phenomenon is well replicated in the capstone experience. As most documentation must be written *after* project completion, it has been difficult to get quality documentation from some groups. To counter this, documentation managers have been appointed in the latter groups, however, with little success. Ultimately, the faculty sponsors need to do a better job of providing a document framework and periodic checking of the documentation that can be completed.

Assessment

In general, the projects have been assessed based on the final product and the final presentations. As these projects have been highly successful and most students have performed admirably, this method has been sufficient for those students. However, for those students who fail to do much, little has been done to assess their poor performance. Students are responsible for grading the performance of their peers, and some give the occasional poor performers failing grades. However, as this assessment has come at the end of the project, it has come too late to responsibly give a failing grade to a senior student. As we are working toward a “real-world” model, we plan to introduce some form of performance appraisal system so that students who are underperforming can be placed on a “personnel improvement plan” where their performance either improves, or where their employment can be "terminated" (failing grade) prior to the final week of class.

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