3-Course Capstone Sequence

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The Engineering programs at Liberty University consist of Electrical, Computer, and Industrial & Systems Engineering. All programs funnel through a multidisciplinary two-semester senior capstone design sequence. However, the two-course sequence is preceded by an introductory engineering design course intended to prepare and evaluate students prior to assigning them to project teams. This design course is offered during the spring semester prior to the fall/spring semester capstone sequence, in effect serving as a third course in the capstone design sequence or alternatively, a pre-capstone course.

Prior to the 2011/2012 academic year, this introductory design course was used to simply introduce design and project management principles to juniors prior to enrolling into a discipline-specific, two-semester capstone sequence. However, the potential for forming multidisciplinary project teams resulted in the replacement of discipline-specific capstone course sequences with a single multidisciplinary capstone sequence. In addition to this change, the junior level introductory engineering design course was tailored to prepare students for their capstone project (as well as assess individual students to identify those who exhibit good leadership qualities, and assess the team dynamics of different combinations of students.) This article is written to highlight the benefits and challenges of this three course approach.

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Background

As with many engineering programs, Liberty University School of Engineering and Computational Sciences (SECS) utilizes a two-semester capstone design sequence to serve as a means for students to apply their discipline specific training and demonstrate competency by working on a team project in their senior year. The capstone sequence begins in the fall semester and concludes in the spring semester. The first semester focuses on developing a design solution for a client, while the second semester focuses on implementing the design by building and testing a prototype or process. The project client may be an external industry partner, or internal where the client is one of the departments within the university campus. The project teams are typically made up of 3-5 students. Teams may be composed of one discipline or many disciplines depending on the nature of the project. To ensure that each team is making the most of each member's skillsets, a set of project ground rules has been established, requiring each student to demonstrate application of engineering science and design strategies, methods, and means pertaining to their respective disciplines. A three-phase design process model is used (1. Conceptual, 2. Preliminary, 3. Detailed) to identify stages in the design process.

At the very beginning of the first semester the students are notified of their team assignments and issued a solicitation that includes a brief description of the client's needs and contact information. At this point the students are expected to initiate contact with the client and begin the conceptual design stage of their respective capstone projects. This involves a kick-off meeting with the client to develop a design problem statement and project framework. Each team is required to deliver a series of interim reports (both oral and written) over the course of the semester, as well as a midterm and final report. The main deliverables at the end of the first semester are a detailed design solution, a digital prototype or process demonstration, and an implementation plan to be carried out the following semester. Other than successfully meeting the deliverables at the end of the semester, the project teams are free to work through each phase of the design process at their own pace (often iterating back and forth between phases based on new information or setbacks). At the end of the course the student evaluation is based upon the process by which they develop the solution to their client's needs. The instructors will review how effectively the strategies, methods and means covered in the pre-capstone course were utilized in the execution of the design. Criteria measured include: Are teams using the strategies, methods, and means? Are they using them properly? Do the analyses performed follow a clear and meaningful structure? Has the client's problem been fully synthesized (i.e. how does the client's need fit within real world constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability?) Are teams managing their time effectively? Are tasks sufficiently documented? Are responsibilities effectively delegated? Does every member of the team add value to the project?

The spring semester follows the same format as the fall semester, except that the objective is to implement the design solution by building and testing a physical prototype or implementing a process solution. The main deliverables at the end of the semester are a final design document, a physical prototype or process demonstration, and an operating guide for utilizing the prototype or process solution. During this semester, the teams are expected to not only produce a working prototype of a product or process for the client; they must also demonstrate how and why the prototype meets the client's requirements. In addition, the prototype must be usable such that the client (or intended users) is able to use it with minimal training. The supporting documentation should include any refinements to the detailed design as a result of modifications made while building the prototype. It must also provide sufficient information about how to utilize the prototype.

Pre-Capstone Engineering Design Course

All engineering students are required to complete a general engineering course called *Introduction to Engineering* during their freshman year. As with many other programs this course serves as a snapshot of what engineering is about. For example, it covers introductory topics such as engineering professions and societies, engineering ethics, engineering standards and units, and engineering design. The role of this course has gradually expanded over the last three years to also serve as a cornerstone design course[1] by incorporating more project-based design projects using Solidworks solid modeling software and Arduino hardware kits to get students acquainted with the design process. Over the subsequent 6 semesters, students concentrate on completing courses within their respective engineering programs. During the spring semester of their junior year, they enroll in a general engineering course called *Engineering Design Introduction*. This course precedes the two-semester capstone design sequence that occurs during their senior year. The course was originally intended to simply introduce design and project management best practices to juniors prior to enrolling into a discipline specific two-semester capstone sequence. But, after replacing the discipline specific capstone sequences with a single multidisciplinary general engineering capstone sequence, this course has focused more specifically on preparing and evaluating students prior to assigning them to capstone projects. As a result, this course is considered the first course in three-course design sequence leading to the completion of a physical prototype or demonstrable process solution for a client. The motivation for this change was to better satisfy ABET criteria d. "Ability to function on multidisciplinary teams."[2]

The course introduces students to a collection of strategies, methods, and means for carrying out the engineering design process and managing the design project[3]. The rationale for this course is to introduce students to engineering design principles geared toward successful application in senior capstone projects. It introduces basic engineering steps, concepts, tools, and methodologies used successfully in engineering design projects. This course also emphasizes the importance of ethics in engineering. Communication skills are evaluated in terms of writing technical reports, group discussions, and oral presentations. Students are also evaluated on their ability to identify and formulate engineering problems, and logically solve both well-defined and ill-defined problems. The course learning outcomes are shown below.

Learning Outcomes for Pre-Capstone Course:

1. Utilize formal design methods.
2. Manage small projects with hard deadlines.
3. Recognize the aspects of group dynamics.
4. Utilize software for digital prototyping, data analysis, planning, and budgeting.
5. Apply communication skills in terms of writing technical reports or memos, and giving oral presentations.
6. Describe the code of ethics in the engineering profession in dealing with social and technical issues.

Students are assessed individually on conceptual knowledge, but primarily work in teams to accomplish a series of in-class assignments and three major projects. The practice of teaching concepts through application during in-class exercises supports a "*learn by doing*" philosophy; fostering both theoretical knowledge and practical skill building during the exercise. A secondary goal of the in-class exercise is to evaluate how effectively students perform under time constraints with newly formed team members.

The three major projects address three design aspects: Literature Reviews, Reverse Engineering, and New Product Development. The goal of the first project is to develop research skills. Each team is assigned a technology topic for which they are to thoroughly research and deliver a technical assessment of the technology based on the following criteria[4]:

- Purpose and Function
- Current Stage of Development and Work Required for Commercialization
- Barriers to Imitation
- Ethical, Regulatory, or Legal Concerns

- Implementation or Production of Technology

The second project centers around understanding design intent and uses of reverse engineering. During this exercise each team is given an ordinary object that possesses both mechanical and electronic functionality. Their first task is make a clear hypothesis about the items functionality, based on their observations. The teams must then dissect the object and perform a functional analysis. From this exercise they will produce a function-means tree consisting of a table of engineering functions that the product appears to have, and the means by which the function is performed. In addition to a functional analysis of how the product works, teams must also generate a list of alternative means by which the functions of the product could have been carried out.

The goal of the third project is to learn how to effectively use digital prototyping tools to design a useful product. The digital prototype produced can be used by teams to perform kinematic and thermal studies prior to fabrication. It is also used to generate detailed design drawings and a bill-of-materials (BOM). The end result is a 3D printed prototype of the new product that is generated from the digital prototype solid model. The student design team is able to make comparisons between the digital and physical prototypes to see how fabrication tools can impact a design. Having a practical understanding of how things are made can help them to make better designs for manufacturing, as well as making better decisions about what to purchase off-the-shelf and what to custom make.

Each of these projects is framed by the application of project management tools for managing cost, schedule, and project scope. The application of these tools is reinforced through the projects as well as the in-class exercises. Technical communication in the form of oral and written reports is also a major part of this framework. Students are given multiple opportunities to develop their oral and written communication skills.

At the conclusion of the course, the students are expected to be able to apply these same tools and techniques during their capstone projects. Having prerequisite knowledge of the assessment process is expected to help project teams invest more time in understanding the client's needs.

Benefits and Challenges of this Approach

A key benefit of utilizing a pre-capstone design course in our programs is a far more effective distribution of instruction and class time during the actual capstone sequence. Shifting the instruction of design principles, project management and documentation practices to a pre-capstone course allows students entering the first sequence of the capstone course to immediately begin working with their capstone clients on their projects, thus providing more class time to *"learn by doing"*. Progress reports are required and scheduled during class time periodically; otherwise students are free to utilize class time to collaborate with teammates in the labs, design their projects and develop their individual and collective skillsets. The second benefit is that the students are trained to a common set of design and process management tools so that their reports are more structured. This facilitates measurement of learning outcomes performed by instructors. A third benefit is that the pre-capstone course is used to assess student performance both individually and within groups prior to assigning teams. Since the course serves as a prerequisite for the two-semester capstone sequence, the distribution of students is known prior to the fall semester (allowing teams to be assembled and assigned to a client by the capstone coordinator during the interim between the end of the pre-capstone design course and the first capstone course, again, allowing teams to immediately begin the design portion of their projects in the first days of the capstone course).

The main challenge of this approach has been aligning all engineering program course sequences to fit what is effectively a three-course capstone sequence. SECS has a single engineering department made up of three engineering programs; Electrical Engineering, Computer Engineering, and Industrial & Systems Engineering. Each discipline has its own set of core competencies to develop students. Our goal is to ensure that the students have reached a desirable level of competency within their respective disciplines prior to entering the capstone sequence. Since our capstone projects are largely client driven, students are expected to already possess a minimum level of training in their area of study. Although many of our clients are themselves engineers and do serve as a resource for students, the burden is on each student to effectively contribute their acquired skills towards prototype development. Therefore, along with course sequence alignments, the pre-capstone course prerequisites had to be adjusted to verify that each student obtained this level of competency.

An additional challenge has been the integration of non-engineering disciplines into the capstone sequence. Some multidisciplinary projects require skillsets that extend beyond the discipline-specific training of the engineering students. In particular, we are seeing more and more projects requiring software application development along with engineering design. Under our current structure this skill set is better suited to computer science. This has prompted more collaboration between our computational sciences and engineering departments. Unlike engineering students, computer science (CS) students complete a traditional two-course discipline-specific capstone sequence. Students spend the first semester in the classroom studying the software engineering design process in preparation for working with a client during the second semester. The learning outcomes for computer science are as follows:

Learning Outcomes for CS 1st Semester Course:

1. Identify and analyze the advantages and disadvantages of several popular life cycle models.
2. Use standard tools, methods, and practices to plan schedule, and complete a team-oriented software development project.

At the beginning of the second semester the computer science students are formed into teams of 3-4 persons, and are assigned to work on a project submitted by a ministry, some component of the university, or an associated business organization that emphasizes the software development process.

During the 2013/2014 academic year, the engineering department invited a computer science student to participate as a member of an engineering project team. The computer science student provided much needed software engineering support to the project, and has also played a role as consultant to another project team. The computer science student is a member of the team but her individual performance is evaluated by a computer science capstone instructor in the course for which she is registered. Whereas, most of the computer science students do not begin actual work on their capstone projects until the spring semester, she is already assigned to a project and will receive credit for her performance on the engineering team.

Conclusion

Utilizing a design course that specifically prepares engineering students to operate within a common framework for capstone (1) team design, (2) project management, and (3) technical communication enabled our student teams to focus on the design problem on day-one of a two-semester capstone design sequence. This facilitates measurement of learning outcomes performed by instructors during the capstone sequence. The pre-capstone course gives instructors an opportunity to assess group dynamics prior to assigning students to project teams. The aim is to increase the likelihood of good team synergy which plays a vital role in project success. In addition, students have an opportunity to engage with students that they may be working with on their capstone project, building relationships without the immediate pressure of deliverables and time constraints. Consequently, when the capstone projects begin, team members will be more familiar with each personality and skillset of their teammates, allowing team structure to develop prior to their project assignments. The main disadvantage of this approach is our need to align all engineering program curricula to funnel through a single 3-course design sequence. When incorporating non-engineering students (computer science students for example), we need to work collaboratively with the respective programs to ensure that the students involved are able to satisfy their own program criteria for graduation. Thus far we have benefitted from both computer science and engineering being within the same school. We hope to incorporate more non-engineering students into engineering capstone teams, for example, collaborating with the School of Business to add an entrepreneurial element to the projects. This may help our engineering students see the broader marketability of their design solutions and formulate better business plans.

The implementation of the pre-capstone course has been more of an evolution of our program structure rather than our attempt to follow a specific, documented model. As we continue this structure we will begin to compile specific measurement data to evaluate our success.

References

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