A Three-Semester Capstone Design Sequence: Advantages and Disadvantages

Kenneth J. Fischer, Christopher D. Depcik, Lorin P. Maletsky, Robert M. Sorem, Ronald L. Dougherty
University of Kansas, Mechanical Engineering

Abstract

Engineering departments have many possibilities when it comes to the organization of the capstone design experience. This experience is generally packaged in one or two semesters in the Senior year of engineering students. Curricula include varying levels of content related to the design process and tools that facilitate the process, in addition to the actual performance of the design project. In addition, the outcomes of the design process vary considerably, depending on engineering discipline and department preference, from detailed designs with no physical realization to required functional prototypes and design evaluation. Certainly, there is no approach that fits all disciplines and all departments.

The purpose of this paper is to describe and discuss the advantages and disadvantages of a three-semester capstone design course sequence. We believe this approach provides students with a more complete and thorough capstone design experience allowing for fabrication and testing of functional prototypes. While it is especially advantageous for Mechanical Engineering departments where a physical prototype is often the ultimate goal, it can also be advantageous for other disciplines, especially where production of a functional prototype is desired.

Primary advantages include 1) students learning the design process and related tools and building teamwork skills without the pressure of their capstone project, 2) more time for students to focus on their capstone projects and to fabricate/test a prototype, and 3) reinforcement of the design process steps and tools, as they are applied to the capstone project. Primary disadvantages are 1) that it moves the design process course content back into the busy Junior year, and 2) it creates more work for students using conceptual projects in which they may not be strongly invested.

Introduction

The capstone design curriculum can take many forms to fit a particular discipline and/or the needs and expectations of a particular department. As such, capstone design curriculum has been the subject of engineering education research and experimentation. Research has focused on such topics as the key elements needed for a successful capstone design experience[1], the effect of design team size and the duration of the project[2], and various approaches in order to reach a diverse set of learning styles.[3] In addition, some studies have focused on providing unique capstone design experiences by choosing engaging design topics.[4-5]

The basic dilemma for any capstone design course (as in many courses) is how to pack all the instructional and experiential aspects desired for the course into a given timeline. Most programs attempt to teach the design process including related tools (methodology), project

management, engineering communications, and professional ethics within a comprehensive design project. However, the span of capstone design curricula can be as short as one semester. In addition, some curricula require the fabrication of a functional prototype, while others merely require a complete detailed design package. Clearly, the size and requirements of the project, as well as the level of instruction on methodology, management, communications, economics, and ethics, are limited within a one-semester capstone experience. Yet, a review of programs showed that this was the most common length of the capstone design experience.[6] Two semester capstone design experiences were second most common. These programs are more likely to attempt to teach the design process and related topics in the first semester, while introducing projects and working on (at least) a conceptual design. The second semester is then dedicated to reaching the goal of a detailed design, fabrication of a prototype and/or testing/evaluation of the prototype (and, thus, the design). Whatever approach is adopted, the problem is that there is substantial content to teach, along with a relatively large amount of work for the students to complete the project, within the limited time.

Consider the typical problems with a two semester capstone curriculum. The instructor and students have to balance the instruction on the design process and related tools with actually assigning and initiating the capstone design projects. The front end of the course tends to be heavy on design didactics, as the projects are first getting organized. The concepts they are learning about the design process are not always applicable to their current stage in the capstone project, nor can it always be when projects proceed at different paces. In some cases, it is difficult to teach student design tools before they actually need to use them on their capstone design projects (the design process and related material lags the actual capstone projects). While instructors may attempt to integrate this material and related assignments with the capstone design project, the progress of some projects can be slowed because of the pace of instruction. If assignments related to the design process instruction are not integrated with the stages of the capstone project (i.e. are ad hoc assignments just to teach the principles/tools), then the students are burdened with doing the work twice—once for the ad hoc assignment and once for the project. Again, this latter approach cannot assure that the project and instruction are coordinated.

The difficulty of teaching the design process simultaneously with the initiation of capstone projects was part of the impetus for our department to implement a change in curriculum that amounts to a three semester capstone design experience. While three-quarter capstone design experiences are used by a small percentage of departments, no three-semester capstone design experiences have been previously reported.[6] However, that fact may partly be due to how programs define the capstone experience. Our basic approach is to teach the design process portion of the capstone curriculum in the Spring of the Junior year, so that Seniors starting their capstone design projects would already be armed with knowledge and experience with the design process and related tools. Although teaching the design process is not simultaneous with the capstone project, it is considered part of the capstone design sequence. Our approach is described in detail below.

Description of the 3-Semester Capstone Design Experience

Semester 1

The first semester is taught in the Spring of the Junior year, essentially removing the design process instruction from the actual capstone project and teaching it as a separate course. In this 3-credit hour course, the design process and related tools are taught using two smaller conceptual design projects. The source of topics for the projects has varied from addressing published design competitions, to using design goals from former actual capstone projects. Students generally have multiple project topics to choose from for both projects. This allows the instructor to focus on the design process, methodology, project management, communications, economics and ethics, without the concern about progress on the actual capstone projects. Clearly, more time can be spent covering steps in the design process and analytical tools in order to assist with appropriate design decisions. The instruction can be more directly applied to the conceptual design projects. Students get experience with intense project teamwork, without the pressure of performing for an external client. Moreover, students can practice what they are learning on two different projects with two dissimilar teams. This facilitates different levels of peer interaction, often found to be the driving factor in the difference between a successful project and an unsuccessful one. Hence, this tends to prepare them well for working in teams on the actual capstone design projects in the following semesters.

Semester 2

The second semester in the sequence is in the Fall semester at the beginning of the Senior year, when the capstone design projects are selected by or assigned to teams and initiated. During this semester, there are two paths depending on the capstone design track.

For tracks that do not require a related Senior-level elective, the students take a 1-credit hour capstone design course. The instructor acts primarily as a facilitator and guide for the teams in the design process. The students are reminded of the design process steps and held accountable for making progress throughout the semester. They use the design and project management tools that they learned in the previous semester. This reinforces the materials previously taught in the two conceptual designs. In fact, this is the third time that they use some of these tools.

The other path involves two of the design track choices in Mechanical Engineering at the University of Kansas that require students to take a related Senior-level technical elective class. For these tracks, the students enroll in the elective, and the design project is incorporated into the class syllabus. For example, in order to participate in the formula car capstone design project that involves designing and manufacturing a functional Society of Automotive Engineering (SAE) formula car for a competition in the following semester, students must take an Automotive Design elective in the Fall semester of their Senior year. Also, students who wish to work on biomechanical design projects are required to enroll in the Basic Biomechanics class in the Fall semester of their Senior year. These classes assure an appropriate level of working knowledge in the area of specialization, while beginning work on the capstone design project in that field. With the 3-semester approach, this specialized instruction can complement the

capstone design project without students being burdened by also learning the design process at the same time.

The goal of the second semester can vary, depending on the capstone track and even the project within a track, but generally requires a minimum of a preliminary design proposal presentation and report. The preferred goal is completion of a full (detailed) design review. The latter level of progress provides the team with the best chance of successful completion in the final semester.

Semester 3

The third semester of the capstone design sequence is in the Spring of the Senior year. During this semester, the instructor solely acts as a facilitator for the teams in all tracks. The students begin by finalizing their design and making any revisions requested at the design review. Then, the emphasis shifts to ordering materials and fabricating a functional prototype. In particular, a detailed budget is presented at the design review, with the students ordering parts (after instructor review and approval or modification) early in the third semester. With respect to manufacturing, students are expected to perform as much of the fabrication themselves as possible with departmental resources while taking advantage of the Engineering machine shop. In addition, they must plan and complete testing of their prototype in order to evaluate its functionality. Of course, the students must also generate a final oral presentation and written report for their client and the instructor.

Discussion of Advantages and Disadvantages of the 3-Semester Approach

Advantages

One of the most important advantages is that students initially learn the design process and related tools while building teamwork skills without the pressure of their capstone project. This provides them the opportunity to fail, without letting down an external client or affecting graduation requirements. As Sitkin elucidates, failure is an essential precursor to success and is an important concept from which to learn.[7] In addition, the pace of teaching the design process and related tools is not influenced by pressure to provide information before it is needed for the capstone design projects.

The 3-semester approach allows students to focus more fully on their capstone project in their Senior year. Students can put their efforts toward *applying* what they learned about the design process to their capstone project (instead of trying to learn it along the way), especially at the beginning of the capstone project. Because students use what they were previously taught, this approach provides opportunities for students to revisit and reinforce aspects of the design process and related tools. Moreover, previous interactions with peers on a conceptual design project introduce students to working with others who have dissimilar backgrounds and skills. Communicating well is an important hurdle that students must overcome in order for their capstone design project to be successful. The more the curriculum can introduce team projects with students working together, the less chance there is that these issues will arise later.

This approach also assists the faculty teaching the courses to deliver a straightforward design message by allowing them to focus students' attention on major aspects of design in each semester: design process, design deliverables, and product [or prototype] fabrication/testing/evaluation.

Finally, because the students have already learned design process, they can focus more on their capstone projects in their Senior year. Teams are more likely to make faster progress on the design. This, in turn, provides more time for fabrication (where problems and design revisions tend to arise) and allows time for testing and evaluation of the design at the end of the project.

Disadvantages

Clearly, the 3-semester approach is not without its disadvantages. It moves the design process course content back into the Junior year, which is generally packed with required courses already. So, another heavy-workload required project course in the second semester of the Junior year may not be welcomed by students. Clearly, this course creates more work for students, overall, with the conceptual projects, versus simultaneously learning and applying design process knowledge and tools to the capstone project. However, they should learn the material in more depth and practice using it more thoroughly.

In addition, some students have indicated that the Junior-level conceptual design projects are "too theoretical". They see the lack of a physical, hands-on outcome making the design process too abstract and unrealistic. It is important for the students to 'buy into' the Junior-level course; otherwise, concerns with work load and 'too much theory' can adversely affect the beneficial gains of this three-semester process. In order to alleviate student concerns, efforts are underway to tie these conceptual projects to research efforts on going with different faculty members. Illustrating the use of the project and providing an "outside mentor" via another faculty member help remove some abstractedness of the project and reinforces outcomes.

Moreover, adding a course in the Junior year may create scheduling and/or prerequisite problems for some of the students. Lastly, the design process course is separated from the actual capstone project by a Summer semester, when many students may forget some of what was learned in the Spring.

Summary

Clearly, each program must adopt a solution for the capstone design experience that fits its curriculum and is accepted by the majority of faculty. We believe the advantages of the 3-semester approach outweigh the disadvantages. Opportunities to revisit and reinforce the concepts and tools taught in the design process course and a greater likelihood of successful design, fabrication and testing are the most compelling benefits of this approach. We encourage other departments to consider this capstone design experience option.

Bibliography

1. Marin, J.A.; Armstrong J.E.; Kays, J.L., *Elements of an Optimal Capstone Design Experience.* Journal of Engineering Education, January, 1999: p. 19-22.
2. Griffin, P.M.; Griffin, S.O.; Llewellyn, D.C., *The Impact of Group Size and Project Duration on Capstone Design.* Journal of Engineering Education, July, 2004: p. 185-93.
3. Pimmel, R., *Cooperative Learning Instructional Activities in a Capstone Design Course.* Journal of Engineering Education, July, 2001: p. 413-21.
4. Catalano, G.D.; Wray, P.; Cornelio, S., *Compassion Practicum: A Capstone Design Experience at the United States Military Academy.* Journal of Engineering Education, October, 2000: p. 471-4.
5. Latcha, M.; Oakley, B., *Toying with a Capstone Design Course.* Journal of Engineering Education, October, 2001: p. 627-9.
6. Dutson, A.J.; Todd, R.H.; Magleby, S.P.; Sorensen, C.D., *A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses.* Journal of Engineering Education, January, 1997: p. 17-28.
7. Sitkin, S.B., 1996. Learning through failure: The strategy of small losses. In Cohen, M.D. & Sproull, L.S. eds. Organizational learning. Thousand Oaks, CA: Sage.

Bibliographic Information

KENNETH FISCHER
Dr. Fischer is an Associate Professor in Mechanical Engineering at the University of Kansas. He received his B.S. in Mechanical Engineering from Oregon State University and his M.S. and Ph.D. in Mechanical Engineering from Stanford University.

CHRISTOPHER D. DEPCIK
Dr. Depcik is an Assistant Professor in Mechanical Engineering at the University of Kansas. He received his B.S. in Mechanical Engineering from the University of Florida, an M.S. in Aerospace Engineering and an M.S. in Mechanical Engineering from the University of Michigan and a Ph.D. in Mechanical Engineering from the University of Michigan.

LORIN P. MALETSKY
Dr. Maletsky Assistant Professor in Mechanical Engineering at the University of Kansas. He received his B.S. in Mechanical Engineering from Rutgers University, and his M.S. and Ph.D. in Mechanical Engineering from the Purdue University.

ROBERT M. SOREM
Dr. Sorem is an Associate Professor in Mechanical Engineering and Associate Dean for Undergraduates at the University of Kansas. He received his B.S, M.S., and Ph.D. in Mechanical Engineering from the University of Kansas.

RONALD L. DOUGHERTY
Dr. Dougherty is a Professor and Chair of Mechanical Engineering at the University of Kansas. He received his B.S, M.S., and Ph.D. in Mechanical Engineering from the University of Missouri-Rolla.