Capstone Design Course with Industry Collaboration

Cecelia M. Wigal[1], Ph.D., Robert T. Bailey[1], Ph.D., and Ronald U. Goulet[1], Ph.D., P.E.

Abstract

Transitioning from the traditional classroom study of engineering to real life industrial practice can be challenging for the graduating engineer. Making ties between what has been learned and its application in industry is not always easy or apparent to the student; nor are the application examples and problems always easily accessible to the instructors. This paper describes the senior capstone design course developed at the University of Tennessee at Chattanooga (UTC) that collaborates with local industrial firms and engineers (industrial partners) to help bring the application of engineering into the classroom. Course instructional goals, objectives, and structure, industrial partner contribution, and industrial partner and project team selection processes are discussed. In addition, reflections on triumphs and shortcomings are mentioned as well as a list of past and current projects.

Introduction

At the University of Tennessee at Chattanooga (UTC) the senior engineering capstone design course (affectionately called the "Senior Design Experience" (SDE)) bridges the gap between the traditional classroom study of engineering and industry practice through partnerships with industrial firms. The industrial partners provide real-life and open-ended, multidiscipline, design problems and furnish most of the materials, funds, facilities, and/or equipment required to bring the projects to fruition. More importantly, however, the industrial partners commit experienced engineers to serve as key contacts and mentors.

All senior engineering students take the two-semester capstone design course sequence. Prior to the first semester of the course sequence, faculty solicit and obtain several project/collaboration commitments from local industry firms. Following plant tours, students are placed on project teams consisting of six to eight students from various engineering disciplines.

This paper describes the process for selecting the industry partners, projects and student project teams as well as the course mission, goals, objectives, and structure.

Course Mission, Goal, and Objectives

The UTC SDE course mission is

> *to provide a design experience that requires the senior engineering students to apply the technical skills they have developed during their formal education within the*

---

[1] College of Engineering and Computer Science, University of Tennessee at Chattanooga, 615 McCallie Avenue, Chattanooga, TN 37403.

context of what is expected of them technically, relationally, and managerially in the industrial work environment.

UTC's engineering faculty believe that the best way to meet the above mission is to provide the students real-world design projects. In addition, they recognize that most work environments require some type of collaboration between several engineering disciplines to bring a project from the problem definition phase to the prototype phase (and onward).

Based on the above, the primary goal of UTC's SDE is to

expose students to real-world, problem-based multidisciplinary analysis, evaluation, and design in the engineering environment utilizing the participation of industrial partners.

The Course Objectives

SDE, being a design course, requires that students perform the tasks of the design process (problem definition, requirements and specification definition, alternative generation, design analysis and/or modeling, concept testing and/or evaluation, design refinement, prototyping and/or build, project communication, and design documentation [1]). Also, it necessitates that students become acquainted with the interfacing and communication skills and knowledge needs required to have successful real-world projects. In addition, students should have the opportunity to experience and understand how practices of the various disciplines integrate in a diverse project team. In essence, the classroom needs to physically as well as figuratively move to the industrial environment. To this end, the faculty advisors have established the following student outcome and faculty instructional objectives.

After completing the two-semesters of SDE, the <u>students</u> should

- have experienced the processes of problem solving, project management, project life cycle, and multidisciplinary teamwork.
- have developed teamwork and communication skills.
- be able to break a project into components for design and planning purposes.
- know how to develop plans to meet objectives and provide leadership to accomplish the plans.
- know there are factors other than technical aspects that influence the design and the design decision-making.
- understand the necessity for and difficulties of tradeoffs and compromises in the design process.

The course <u>instructors</u> must

- provide the structure necessary for the students to apply the discipline specific tools learned in previous courses.
- provide the structure and resources necessary for the students to apply the concepts of design in a real-world application.
- bring the industrial experience onto the campus and into the classroom.
- get the students out into industrial facilities, communicating with practicing engineers.
- provide a means for the students to practice their written and oral communications skills as applicable to industry needs and multidisciplinary project teams.
- provide advisement to each of the project teams with respect to technical, communication, and management needs.

Industry's Role

Currently, there is a trend to use case studies of past industry projects as tools for learning design concepts and the technical, relational, and managerial aspects of real-world projects [2]. However, as outlined in the objectives, we want SDE to provide a design experience that is relevant and applicable to today's industries so students have the opportunity to participate in the design process and its real-time application. These present day industry projects are best defined and supported by those presently practicing as engineers in the various industries. These individuals and their associated firms have a constant flow of problems that need to be solved, some of which can be used as learning opportunities for senior level engineering students.

With respect to SDE, individual industrial firms sponsor the real-world design projects, providing not only the projects but also the projects' key technical contacts (the industry partners (IPs)). The IPs mentor the UTC student project teams, provide the industrial perspective often not found within the university, monitor team progress, and participate with the course faculty instructors (faculty advisors) in project assessment. In addition, the sponsoring project firms provide any special equipment, facility, space, and technical expertise needed to complete the projects.

Figure 1 illustrates the relationship between the IPs, the project teams, and the faculty advisors. The faculty advisors, as instructors, provide the structure for the course as well as the initial and follow-up team interface with the IPs. The IPs act as independent project sources and mentors for their project teams. Their technical and financial support remain independent of the other teams. The teams work as single entities, deriving guidance from either the faculty advisors or the IPs, or both. In addition, the project teams learn from the experiences of each other.

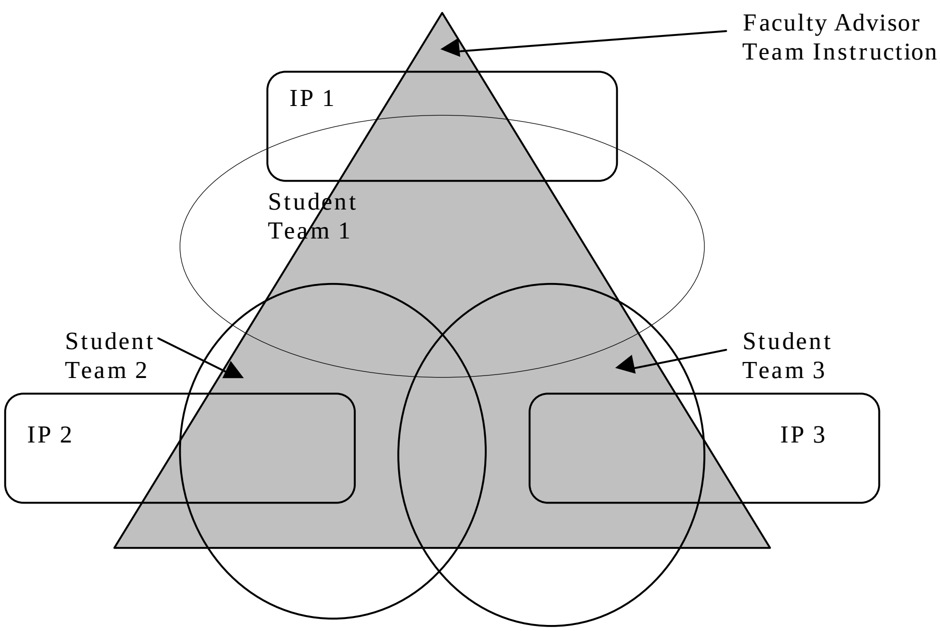

Figure 1: SDE Collaboration with Industry Model

Industry Partner Selection/Project Selection

The Project

Based on the course goal and objectives, an *ideal* SDE project should have (1) multidisciplinary elements and be (2) important but not critical to the industry, (3) challenging for senior-level engineering students, (4) sufficiently complex to require project management, (5) substantial enough to support two-semesters of work by the student team, and (6) likely to conclude in prototype construction. When first reading these requirements it appears that the number of possible projects is limited. However, this is not so. Local industry has a variety of problems of varying complexity that need to be solved and, due to their application, most require knowledge from at least three of UTC's engineering disciplines. In addition, most firms have been willing to add or subtract from the project descriptions to meet the two-semester project length requirement.

Project Sponsor Solicitation

Industry participation in SDE is solicited from a variety of sources—for example, the Chattanooga Manufactures Association, the Advisory Board of the College of Engineering and Computer Science, the Chattanooga Engineers Club, graduates from the College, and faculty contacts. Solicitation techniques include (1) presentations by faculty advisors and/or students about SDE and present project activity, (2) formal letters describing SDE and requesting project ideas and participation, and (3) informal phone calls discussing SDE and the benefit of industry participation (the most successful technique). The solicitation process begins approximately six months prior to the start of the course.

Once a prospective project sponsor expresses interest, the faculty advisors visit the potential IP at his/her facility and discuss in-depth the project requirements, the responsibilities of the industry project sponsor, and the structure of the course. In addition, the faculty advisors request the IP to provide a high-level description of the proposed project(s). The visit consummates with a tour of the facility, including areas directly relating to the proposed projects. Optimally, these visits occur about three months before the beginning of the SDE sequence.

Project Selection/Team Selection

When there is a list of at least five possible projects (based on an average class size of 40), the IPs, whose projects appear to meet the criteria discussed above, are asked to submit a one to two page project proposal for each project they are interested in supporting. These proposals include a short discussion of the background of the problem, a concise project description, a list of the disciplines that may be supported by the project, a statement of expected results, and a statement of capital needs. The faculty advisors use the proposals to ensure the projects meet the criteria and to aid in student team selection. Table 1 provides project descriptions of previous and present SDE industry sponsored projects.

At the onset of the SDE sequence, three to four class periods are dedicated to visiting the various industry sponsors' facilities. Each student selects three (or four) locations to visit based on the project descriptions and problem background statements provided in the IPs' proposals. Following the plant visits, the students apply to work on a specific project via a cover letter and resume. They discuss why they are interested in the project and how they will contribute to the team. In addition, they rank the remaining projects in order of preference. If the number of students enrolled in the course is insufficient to support all projects, the project or projects with least student interest are postponed until the following semester or year. The IPs are aware of this possibility prior to submitting their proposals.

Table 1: SDE Past and Present Industry-Sponsored Projects

Industry Project Sponsor	**Project Description**
Astec Industries	Design and build a scaled device that can be used to predict the overall heat transfer coefficient for full-scale thermal soil remediation systems. (The device will be used to optimize the performance of the full-scale systems.)
AVS, Inc.	Design, build, and test a mobile, versatile test system that will acquire and display data from a hybrid electric/gas turbine bus and batteries using the data acquisition program (LabVIEW).
E.I. DuPont de Nemurs & Co.	Propose an alternative for disposal of the plant's coal ash due to the expected loss of the plant's ash landfill in three years.
Roadtec, Inc.	Design and build an apparatus for testing the hydraulic and electrical functions of an asphalt paver screed. The test stand will simulate the body of a Roadtec paver and will provide electrical and hydraulic power and appropriate connections for screed mounting and testing.
Steward, Inc.	Design a means to test the performance of a specific high-tec electromagnetic part effectively, efficiently, and quickly following production.
Synthetic Industries	Propose a solution to counteract the loss in profit due to errors in manufacturing, handling, and rolling of non-woven fabric that result in wasted product.

The faculty advisors use the student resumes and cover letters to select the project teams. Team selection is based on the desires of the students, the discipline participation suggested by the IPs in their proposals, and the need for discipline diversity and project leaders within projects. Most students receive their first choice, and some their second. It is rare that students receive their third choice, and they have never received their fourth or greater choice. Teams consist of six to eight students, including one who acts as the project manager. (Team sizes of ten and eleven students were initially tried but students found it too easy to "hide" and be noncontributing team members.)

Three individuals per team have the opportunity to act in the role of project manager. The faculty advisors select the initial team project managers based on (1) whether the students indicated in their cover letters an interest in being a project manager, and (2) the students' participation and performance in other courses and/or activities. Team members choose subsequent project managers at approximately one-third and two-thirds through the course sequence.

Course Structure

SDE meets twice a week (Tuesdays and Thursdays) for 1.5 hours each day. The Tuesday class times are reserved for team meetings at which the IPs are asked to participate. The Thursday meetings are reserved for faculty advisor instructional sessions (workshops) and student oral presentations.

Tuesdays – "Team Time"

At the Tuesday team meetings project status is discussed, although the bulk of the time is for accomplishing objectives and creating and assigning action items. The teams create meeting agendas prior to the meetings (to which the faculty advisors may respond) and meeting minutes following each meeting. Each team is visited by at least one faculty advisor during the meeting time. The faculty advisor's role is as observer—he/she allows the meeting to be run by the team project manager and comments only for clarification or if called upon.

Thursdays – "Workshops and Briefings"

The Thursday instructional sessions (affectionately called "workshops") address such topics as "Defining the Design Cycle," " Defining Project Goals and Objectives," "Using Scheduling & Planning Tools," "Managing the Project," "Effective Technical Writing," and "Creative Thinking." In addition, the workshops address concerns the faculty advisors may have following the Tuesday team meetings such as requirements definition stumbling blocks and team/industry partner interaction. The faculty advisors lead some of these workshops; experts from the UTC and local industry communities lead others.

The Thursday student oral presentations are of three varieties—(1) formal team based, (2) individual impromptu, and (3) informal technical briefing. For the first semester, the students are randomly placed on three member teams (unrelated to their project teams.) The teams select a topic to present to the class from an approved list of topics related to design, project management, and industry practice issues. Each team is required to research the given topic and present their findings formally in a 30-minute Power Point presentation. Many of the project teams, such as the "patent" and "six-sigma" presentation teams, are provided a topic expert from the UTC or industry community as a resource.

During the second semester of SDE, both impromptu presentations and technical briefings are used as communication learning tools. Impromptu presentations are approximately three minutes in length and are prompted by questions from the faculty advisors about the industry-sponsored projects. Students may use the chalkboard to illustrate or may refer to their design notebooks to support their responses. The SDE classmates critique the presentations as to how well the speakers answered the questions and presented themselves. Depending on the class size, each student can have multiple opportunities to participate.

The Technical briefings partner two or three project team members to informally discuss a technical aspect of their project. There is no limit on the length of the presentation or the media chosen to aid in the presentation (chalkboard, Power Point, overhead slides, or handouts). However, each briefing team must state clearly what they are hoping to accomplish with their presentation. The class critiques the presenter's abilities to realize this goal. Each project team has three technical briefings; an individual student participates in only one of these presentations.

The Course Project Assignments

In addition to the individual student classroom activities and requirements, the project teams are required to complete project specific activities and assignments. For example, the student teams must organize, schedule, lead, and monitor their projects whose scopes include research, analysis, problem solving, design, testing, and, in some cases, prototype construction. They also are required to present periodic oral and written reports at applicable milestones. The report requirements are structured with respect to the progress and application of the individual teams. For example, one team may be asked to report on the specifics of their test of concept, while another team will be asked to report on the specifics of their design selection. The final report presentation each semester is given to an audience of the students' peers, the IPs, the faculty advisors, and other engineering faculty.

The team assignments are intended to simulate what an engineer may experience in the real-world, industrial environment. Table 2 illustrates the general format of the project course assignments.

Table 2: SDE Project Course Assignment Schedule

	SDE Semester	
Task - Team	**1st**	**2nd**
Memorandum and *oral presentation* (10 minutes)—Project history, problem statement, project definition, goals, and objectives descriptions	X (3rd wk)	
Memorandum and *oral presentation* (10 minutes)—revised project goals and objectives, project/team work breakdown structure (WBS), task assignments, and detailed project schedule.	X (4th/5th wk)	X (2nd wk)
0ral presentation (15 – 20 minutes)—status and progress toward goals and objectives, and updated WBS and schedule.	X (9th wk)	X (7th wk)
Report—status and progress toward goals and objectives, and updated WBS and schedule.		X (7th wk)
Report and *oral presentation* (30 minutes)—requirements and specification definitions, test descriptions, and drawings etc. of the preliminary design. May include results of concept testing.	X (Finals wk)	
Report and *oral presentation* (30 minutes)—final product of project. Define, describe and include in appendix all documentation necessary for smooth transfer of knowledge to the IP such as specifications, test procedures, operations manual, and design drawings.		X (Finals wk)
Meeting agendas and *minutes*—respectively prior to and immediately following each team meeting.	X	X
Task - Individual		
Plant tour attendance	X (1st 1.5 wks)	
Project team application *cover letter* and *resume*	X (1st class after plant tours)	
Project notebook—record of individual work on project.	X (Periodically)	X (Periodically)
Monthly Activity Report (Memorandum) to the instructors and the respective project manager (PM)—Individual's activities for the past month, any project problem issues the individual is facing, and the individual's plans for the next month. (PM is exempt)	X (last Thurs. of month)	X (last Thurs. of month)
PM Monthly Progress Report (Letter) to the instructors and the IP—the team's major activities of the past month, any problems the team is facing with respect to the project, and the team's plans for the next month.	X (1st Thurs of month)	X (1st Thurs of month)

SDE Triumphs and Shortcomings

The SDE sequence has shown some specific triumphs that are relatively pleasing; but it has also shown some shortcomings that require continued attention. With respect to triumphs, the oral presentation skills of the students have been greatly enhanced. Having to speak in front of a large group of peers, faculty, and practicing engineers seems to create enthusiasm for preparation. Other triumphs include

- enhancement of student technical writing skills.
- illustration to the students of a variety of engineering experiences in the workplace.
- enhanced technical communication skills with respect to customer relations.

The shortcomings are varied and are relative to the students, faculty advisors, projects, and IPs. These shortcomings include:

- Some team members are unproductive when teams are too large.
- Some projects do not reach a successful completion with respect to meeting initial goals.
- Some project teams have difficulty setting usable and/or realizable goals and objectives resulting in a project that is a moving target.
- Some IPs are more involved with the project teams than others making it difficult to provide equal experiences for all project teams.
- Some IPs insist on providing more structure to the team than the faculty advisors would like making it difficult for the students to drive the project and create the outcome.
- Some of the students, even after completing the course, have difficulty understanding the usefulness of following a design process.

Conclusions

Even though SDE has some shortcomings that will hopefully be resolved as the course evolves, we believe that SDE is meeting the course goal. We also feel SDE benefits the students, the institution, and the industry project sponsors. For example, for the students, it (1) ensures that the design projects are of the sort practicing engineers face regularly and the solutions devised are satisfactory in practice as well as in theory and (2) provides other experiences that are excellent preparation for students starting their careers. SDE also provides faculty the opportunity to mingle with various industries, to receive immediate feedback with respect to student preparation and course applicability, and to create means to remain current with respect to the needs of local industry. Also, the faculty advisors have a window for viewing possible research opportunities and expert knowledge applications. And last, participation in SDE offers a variety of benefits for industry firms, including

- an opportunity to recruit exceptional engineering graduates,
- an avenue to directly impact the engineering curriculum at UTC to ensure that graduates gain the skills valuable to the industry, and
- a solid relationship with the UTC Engineering Program.

SDE also addresses a number of concerns of the ABET 2000 criteria. These criteria call for the students to have a demonstrated ability to design systems and components; function on multidisciplinary teams; identify, formulate, and solve engineering problems; understand professional and ethical responsibility; and communicate effectively [3]. SDE maintains an important role in providing the students an opportunity to develop and demonstrate these competencies.

References

1. Dym, Clive L. and Patrick Little, (2000), *Engineering Design: A Project-Based Introduction*, John Wiley & Sons, New York, NY.

2. Naumes, William and Margaret J. Naumes, "Case Writing: A Tool for Teaching and Research", *Journal of SMET Education: Innovations and Research*, January – April 2000, pp. 24.

3. Criteria for Accrediting Engineering Programs: 2000 – 2001 Accreditation Cycle, November 1, 1999, *http://www.abet.org/eac/eac.htm*.

Cecelia M. Wigal

Dr. Wigal is an assistant professor of engineering at the University of Tennessee at Chattanooga (UTC). She received her B.S. degree (electrical engineering) from Ohio Northern University (1985), her M.S. degree (electrical engineering) from Illinois Institute of Technology (1991), and her Ph.D. degree (industrial engineering and management science) from Northwestern University (1998). Before coming to UTC in 1999 and before undertaking her Ph.D. work in 1993, she worked in industry for over 8 years as a Project Engineer and Senior Project Engineer in the Aerospace Electrical Systems Division of Sundstrand Corporation (now Hamilton-Sundstrand). Dr. Wigal's primary areas of interest and expertise include complex process and system analysis (ensuring representativeness while minimizing bias and data overload), quality process analysis with respect to fast-paced growth, and information system analysis with respect to usability and effectivity.

Robert T. Bailey

Dr. Bailey is an assistant professor of engineering at the University of Tennessee at Chattanooga (UTC). He received his B.S., M.S., and Ph.D. degrees in mechanical engineering from University of Florida, the latter in 1991. Before coming to UTC in 1999, he worked in industry for over 8 years, serving as a Senior Program Officer for the National Research Council, as a Senior Engineer and Branch Manager for Science Applications International Corporation (SAIC), and as a Senior Engineer with Westinghouse Savannah River Company. His primary areas of interest and expertise include thermal/fluid system analysis (predicting behavior under off-normal, transient conditions), quantitative risk assessment (QRA) and safety enhancement of engineered systems and industrial processes, computational fluid dynamics (CFD), and application of computer technology to engineering education.

Ron U. Goulet

Dr. Goulet is an assistant professor of mechanical engineering at the University of Tennessee at Chattanooga (UTC). He received his B.S. in civil engineering from Northwestern University (1976) and his Ph.D. in Engineering (in the field of fracture mechanics) from the University of New Hampshire (1997). He joined the UTC engineering faculty in 1998 with over 20 years of professional experience serving the power, legal, and insurance industries in Chicago and Pittsburgh. Dr. Goulet's primary research interest includes the application of 3D vision based displacement measurement techniques in experimental mechanics. As director of UTC Biomechanics lab, Dr. Goulet coordinates experimental research of implanted orthopaedic constructs in collaboration with the Dept. of Orthopaedic Surgery, Chattanooga unit of the UT College of Medicine.