Involving Industry in Capstone Design Courses: Enhancing Projects, Addressing ABET Issues, and Supporting Undergraduate Engineering Practice

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Industry can influence and actively participate in capstone design courses in a variety of ways. Recent research indicates that situating design projects within corporate scenarios enhances students' undergraduate experience by forcing them to think about larger issues beyond traditional numeric calculations, thus better preparing them for the demands and issues of their future professional work. Active participation by industry can include providing topics for projects, working with faculty to shape the technical content of assignments, and allowing students to make on-site visits to collect real world data. Practicing engineers and managers may also act as project mentors, review written or oral project reports, and provide feedback to academic faculty and students. Because the capstone design course is typically the location for communication-intensive activities, as well as addressing teamwork, ethics, and the societal contexts of engineering work, situating these activities within an industry setting gives meaning and motivation to assignments.

This paper reports on the structure and mechanisms by which industry has influenced and participated in a chemical engineering capstone design course. The need for such participation, the goals and structure of the design project, and the benefits realized by both students and industry, will be discussed. Findings on how effectively such a collaboration can address ABET EC2000 criteria are presented.

The Need to Involve Industry and Practice in Design

A number of researchers use activity theory—that learning happens through immersion in a community's activities—to account for the ways in which newcomers to any environment become full participants in that community. Some argue that participation in academic environments—the classroom—merely teaches students to learn to be students; only genuine immersion in a professional environment can lead to learning to be a professional.[1,2]
While an increasing number of students gain some experience in summer internships or co-op placements, such temporary positions often have a narrow focus, may not engage students in

genuine professional work, and may not provide sufficient feedback. Capstone design represents the straddling of academic and industry worlds, the ideal setting for learning outcomes perceived as important by both. The interaction between university faculty and practicing engineers provides opportunity for learning and direction from both, for the agendas of both environments to be addressed, and for students to recognize themselves as both learners and practitioners.

Capstone Design as a Site for Addressing EC2000 Criteria

The capstone design course continues to be the predominant mechanism for incorporating ABET EC2000 criteria, including communication activities and multi-disciplinary teamwork, into the undergraduate engineering curriculum. Typically, the design course is designated as communication-intensive; such is the case with the design course reviewed here. Other non-technical issues these courses often address are engineering professionalism, awareness of social issues, engineering ethics, and global awareness. Addressing these topics in design projects with knowledge of industry needs and opportunities for direct application in corporate settings provides motivation, reinforces learning, and demonstrates the integration of these crucial issues within genuine professional practice.

In capstone design courses, communication activities are usually presented in some industry-like scenario. While this may provide a more interesting context within which students demonstrate design knowledge, students recognize the *faux* nature of these assignments.[3, 4, 5] Numerous studies have concluded that students execute communication activities with greater motivation and meaning when situated in actual industry settings.[2, 4, 5, 6, 7, 8] Further, recent quantitative research on the actual writing practices and values of working engineers suggests that the types and nature of documents most often assigned in typical design courses—proposals and reports—do not accurately reflect current industry practice, and do not fully prepare students for their writing tasks after graduation.[9] Thus, both the writing contexts and the writing assignments are substantially different in the design course reviewed, and include summaries, meeting minutes, progress reports, and short reports.

Similarly, teamwork dynamics and division of labor in the classroom setting differs substantially from team activities in the workplace.[10] Setting design projects within the workplace allows students to observe, and emulate, the wide variety of group roles, contributions, and conflicts that they will encounter as professionals. Finally, allowing students to see the societal impacts of design decisions and processes, and perhaps participate in ethical decision-making, allows students to understand that these concepts are integral to engineering work, rather than a tangential add-on.

Current Chemical Engineering Student Design Problem

The chemical engineering student project involves a scoping study comparing technologies or methods to treat, reduce, or dispose of a mixed solvent stream from a pharmaceutical manufacturing site. Chemicals currently in the waste stream are a variety of hydrocarbons, including methanol, acetone, toluene, and tetrahydrofuran (THF). The average composition of the waste stream varies widely over a period of time depending on the production cycles of the company. Currently, the mixed solvent stream goes through several batch distillation operations to recover and recycle solvents. When solvent recovery is no longer feasible due to purity constraints mandated by Food and Drug Administration (FDA) requirements, the mixed solvents are sold as a waste stream and used as a fuel source for industrial scale cement kilns. The waste solvents are mixed with other liquid and solid industrial and municipal waste and incinerated. The total flow rate of waste materials has been increasing at a rate of 200,000 gallons per year, while the cost of disposal of the mixed waste stream has increased 10% per gallon per year for the last several years. The total amount of materials disposed of during the 2001 fiscal year were 8.4 million gallons, at an annual cost of over $5.3 million. Reducing the potential legal liability associated with the on-site collection and storage of the waste solvents, transportation to the cement kiln for incineration, and possible human exposure are also a company concern. By reducing the overall flow rate of the waste stream that needs to be transported for incineration, these potential liabilities and the annual disposal cost would be reduced. The manufacturing site also pays over $4.4 million annually to produce 170# steam for use within the various production processes. The current boilers at the plant site that produce steam are already operating at over 90% of their rated capacity. If an economically viable process can be designed to produce steam using the current waste stream, the company would realize even greater savings beyond the current $5.3 million in disposal costs.

Capstone Design Course Structure for the Interaction with Industry

As a part of the ongoing design project, students regularly meet with their faculty advisor and practicing engineers working for the project sponsor. The faculty and company engineers act as "managers" for the student design projects, giving input where needed, questioning the students on the technical knowledge behind their design decisions, and acting on student recommendations or requests. These meetings are structured to allow the students to drive the agenda in order to review their progress to date, and to gain needed information or opinions to advance their projects. Students themselves prepare meeting agendas, are responsible for recording and distributing meeting minutes, reviewing the success or failure of past work assignments, and setting forth the proposed work schedule and topics of interest for the near-term work period. The role of the "managers" is to question students and force them to defend their method of arriving at a solution for the design problem, as well as provide technical advice and guidance as the project progresses.

An integral part of these meetings' activities is the student design group's preparation and presentation of technical material to their peers and to their "managers" in the form of both written documents and oral presentations. Although doing some review of written materials, the meetings concentrate primarily on reviewing and critiquing the materials presented orally by the students. This allows the practicing engineers from the sponsoring company an opportunity to have input on a regular basis, but with a minimum of interference with their regular work duties.

As noted earlier, current research suggests that the traditional formal proposals and lengthy reports are no longer the standard means of communication and documentation in industry. In light of this, other means of reviewing written technical material are being used in the current capstone design course. Each individual student documents progress and contribution to group activities and goals every two weeks by producing a short written progress report using a memorandum format with supporting appendix materials. The progress reports are graded by the faculty advisor for technical correctness, clarity, organization, style, format, grammar, and an overall ability to transmit useful and needed information, and are returned to the students. These individual writing assignments serve as a mechanism for fulfilling the communication-intensive design course activities mandated by the University to fulfill each student's baccalaureate writing requirements. Although not graded by the faculty, the review and use of student-produced meeting minutes and agendas also supports this trend of shorter, more concise written documents from capstone design activities.

At the end of the semester, the students will have completed a formal design report extensively documenting the design options they worked on, including their reasoning for options that were analyzed and discarded as not viable, the methods and pathways they followed to reach a final recommendation, and the final recommendations themselves. This large report includes supporting appendix materials, including hand calculations and summarized results from process simulator software programs, and is a major tool used by the faculty for course grading purposes. The sponsoring company receives a written report that is a shorter subset of the graded report, allowing students to practice summarization of crucial information for a busy audience in the workplace. This shorter report contains final recommendations to the company, and the student group's method of solution, reasoning, and supporting calculations that led to the recommendations. Students also present a one-hour seminar at the sponsoring company detailing their design solution, and a 30-minute oral presentation at a University-sponsored senior design colloquium. As a part of the evaluation and assessment activities required to meet ABET EC2000 criteria, a panel of practicing engineers from the sponsoring company will return to the faculty advisor written comments and suggestions about the strengths and weaknesses of both the written report and oral presentations made by the student groups from a corporate engineering viewpoint. Changes in the structure of how the interaction between industry and the capstone design courses were handled, or changes in the content, style, or format of the student design reports or oral presentations may then be implemented as part of the continuing review and self-improvement process encouraged by ABET.

A continual focus of the capstone design course is to encourage students to choose between several "correct" options at various points in the engineering design process, based on the use of comparison criteria that they themselves have devised. The comparison criteria are drawn from their understanding of the overall goals of the project, their own engineering knowledge, and background information about a particular piece of process equipment or production process. A common denominator in formulating the comparison criteria that we have tried to instill in students is an appreciation and consideration of the profit motive aspects of engineering activities. A project design coming out of the capstone experience must not only be technically feasible and correct, but it must also enhance the overall "bottom line" for the company, by increasing sales revenues, reducing operating expenses, or lowering the per unit cost of production. Students must be aware that the ultimate goal of their work is to increase the overall profitability of the company, while producing final products or services in a safe and socially responsible manner.

How Students Benefit from Industrial Interaction with Capstone Design Courses

Industrial participation in undergraduate capstone design can be beneficial to engineering students in a number of ways. Students receive the opportunity to interact with practicing engineers to reach solutions to open-ended engineering problems, where more than one correct solution is possible. Students must decide the types of data or other information needed to advance their project, and either physically make measurements or request needed information from other company employees. The use of real world data gives students an opportunity to analyze the data to support their final design solution, or use it to disprove design options that were not the final recommended course of action. For many students, this is their first exercise in handling data in a decision-making mode, where their interpretation of the data is one of the driving forces behind the design pathway that is followed. In most cases, other undergraduate courses ask students to measure, record, and interpret data, and to draw final conclusions about the data based on engineering principles or theories. A capstone design project with real industrial sponsorship and interaction is a very forceful mechanism for reinforcing with students the connection between what they have studied and how this knowledge is actually applied in the real world in making engineering decisions to efficiently provide a product or service.

Benefits to Industry for Their Involvement with Capstone Design Courses

The industrial partners who agree to participate in the capstone design course do so for several reasons. These include raising the awareness of their company name, products, and career opportunities on a particular college campus, being able to evaluate potential future employees without a large financial commitment, and the desire to be more active in their community by interacting with people outside their usual workday contacts with vendors or corporate customers. In the case of Western Michigan University, the corporate sponsor for the current student design project also sees an opportunity to interact with faculty members in a relatively new baccalaureate chemical engineering degree program to allow faculty greater access to current engineering practices which could be incorporated in the undergraduate curricula. Sponsoring a capstone design problem allows the company the benefit of moving forward on a design project that may not necessarily be a high enough priority for them to assign their own full-time employees to work on extensively, but is a project that the company wants to address if engineering manpower is available. By providing knowledgeable practicing engineers to act as mentors or "managers" to the student design groups, the company is able to receive and use the results from the students' work, and have a structured mechanism for company input and guidance as the design project proceeds.

Findings from Current Student Design Project

Students working on the industry-sponsored capstone design problem were asked to identify "skills or topics outside of science or engineering theory" that were important to successfully completing the solvent recovery scoping study. The four categories below represent the areas addressed by every student polled. The ABET Criterion 3 that fit with each of the four identified topic areas are also given.

Problem Solving (ABET Criterion 3a, b, c, e, k)

- Application of classroom-learned science, engineering knowledge, and software tools.
- Overcoming "road blocks," such as finding other methods to obtain needed data.
- The classic "open-ended problem," realizing that what they are working on could have multiple correct solutions, and they must use their knowledge to recommend one final choice, or a hierarchy of acceptable choices. Students commented that this capstone design project was the best opportunity they had had as undergraduate students to use their own creativity in arriving at an acceptable engineering design.

Communication (ABET Criterion 3g)

- Communicating with fellow workers in a clear, concise, and professional manner.
- The importance of writing skills, especially appropriately structuring contacts by e-mail to receive needed data for their project.
- Recognizing an individual's personal communication style and adapting their requests to take advantage of it.
- The use of good grammar and spelling.

Working Relationships and Teamwork (ABET Criterion 3d, f)

- The realization that teamwork is an integral part of everyday engineering activities in industry.
- Learning patience and using a professional demeanor in dealing with fellow workers, as students' own individual highest priority item or task does not necessarily deserve an immediate response from someone else.
- Documenting conversations and group activities, for later review and clarification.
- Negotiating and compromising with other team members to identify and achieve common goals, as well as an acceptable level of quality for the final product of the team effort.

Scheduling, Timelines, Planning, and Goals (ABET Criterion 3d, e)

- Developing intermediate goals and milestones as the project progresses, rather than being explicitly reassured by a faculty member their answer is correct (as when submitting homework solutions).
- Producing significant results by given deadlines, or risk delaying other project work areas.
- Looking to the future and planning additional information requests needed, in light of students' requests not being of highest priority to someone else.
- The flexibility needed to schedule blocks of time to complete project work, both as an individual and within a team.

As can be seen from the list above, a number of the ABET Criterion 3 areas are addressed. Teamwork activities are much more complex as students must address more layers than in classroom assignments, such as scheduling, prioritization of tasks, and acknowledging others' learning styles and contributions.

The actual application and practice of science and engineering knowledge learned in lecture or laboratory courses continues to be a major area that capstone design activities serve to reinforce, and allows students to become more confident in their abilities. Although other undergraduate courses use open-ended engineering problems, the capstone experience continues to provide a much greater opportunity for student creativity due to the broader nature of the design projects.

Students also gain a greater appreciation for the role of communication skills in the everyday work activities of practicing engineers. Although attempts to integrate communication activities into the undergraduate engineering curricula are ongoing and valuable to the student, the capstone design project is an excellent opportunity to reinforce with students the integrated nature of communication and daily engineering work tasks. As mentioned by one student, "I have gained a new appreciation for the teamwork and communication skills that are pounded into our heads throughout college. I now see how important these skills are in order to work with teammates and fellow employees to accomplish my agenda."[11]

Due to the short-term nature of the design project (one academic semester), students were not exposed to some of the other big picture ABET criteria, such as ethical responsibility, life-long learning, contemporary issues, and global and societal contexts of their work. The students do gain a sense of some of the ethical and societal impacts of their work, through the consideration of the design aspects of process safety, the environmental impact of products or chemicals that would be produced should their project be implemented by the industrial sponsor, and the mitigation or treatment of resulting waste streams. These big picture ABET criteria remain perhaps the most difficult challenge for incorporation in undergraduate engineering courses, and continue to present opportunities for curriculum development and pedagogical change.

Differentiating Capstone Design from Student Co-op Experiences

While an increasing number of students typically participate in co-op or summer intern experiences, students acknowledge distinct differences between the requirements and skills used on their co-op or summer intern assignments and the structure of the capstone design experience reviewed for this paper. The capstone design experience is more data or design oriented, and forces the individual student to rely more on other people for information. Partly due to this greater reliance on others, a stronger emphasis and appreciation for appropriate communication and teamwork skills was needed for the capstone design project than what the students had previously experienced as co-ops or interns. The time scale and deadlines to be met are tighter than what was needed or accepted for co-op or intern projects. In some cases, the co-op experience did not result in a tangible outcome (written report or recommendations), which would not be an option in the current structure of the capstone design project. The capstone design project was broader and more open-ended. It required a greater effort by the students to determine a method of solution, and forced students to see the larger goals of the overall project. Co-op or intern experiences were tailored for the students to work on specific tasks, and just how their tasks fit in with other engineering work at their co-op employer was not always clear or well understood by a co-op student.

Conclusions

The current study supports the value of industrial involvement in capstone senior design courses. Faculty, corporate sponsors, and—most importantly—the students themselves found it to be a valuable, motivating, and interesting experience. Students reported benefits clearly beyond what they would have received in a purely classroom situation. The greater complexity and multiple layers of communication and teamwork activities provided students a more genuine knowledge of industry practice. Throughout the project, valuable ABET criteria were integrated in a natural, rather than tangential, manner, to the extent that students self-reported their heightened awareness of these issues without specific prompting. The next stage in this ongoing process is to expand corporate sponsorship opportunities, to introduce multi-disciplinary teams where possible, and to explore ways to more effectively address the larger global and societal issues associated with engineering practice.

Bibliography

1. Lave, Jean and Etienne Wenger. *Situated Learning: Legitimate Peripheral Participation* Cambridge: Cambridge UP, 1991.

2. Dias, Patrick, Aviva Freedman, Peter Medway, and Anthony Pare. *Worlds Apart: Acting and Writing in Academic and Workplace Contexts.* Mahwah, NJ: Lawrence Erlbaum, 1999.

3. Dannels, Deanna. "Learning to Be Professional." *Journal of Business and Technical Communication* (Jan. 2000), 5-37.

4. Herrington, Anne. "Writing in Academic Settings: A Study of the Contexts for Writing in Two College Chemical Engineering Courses." *Research in the Teaching of English 19:*4 (1985), 331-359.

5. Geisler, Cheryl. "The Relationship Between Language and Design in Mechanical Engineering: Some Preliminary Observations." *Technical Communication 40:*1 (1993), 173-176.

6. Barabas, Christine. *Technical Writing in a Corporate Culture: A Study in the Nature of Information.* Norwood, NJ: Ablex, 1990.

7. Harrison, Teresa. "Frameworks for the Study of Writing in Organizational Contexts." *Written Communication 4:*1 (1987), 3-23.

8. Paradis, James, David Dobrin, and Richard Miller. "Writing at Exxon ITD: Notes on the Writing Environment of an R & D Organization." In *Writing in Non-academic Settings.* Lee Odell and Dixie Goswami, eds. New York: Guilford Press, 1985, 281-307.

9. Aller, Betsy M. *Writing Practices in the Engineering Workplace: Findings and Implications for Teachers of Engineering Communication.* Department of Humanities, Michigan Technological University, Houghton, MI. 2001.

10. Aller, Betsy M. "'Just Like They Do in Industry': Concerns about Teamwork Practices in Engineering Design Classes." In *Proceedings of Frontiers in Engineering (ASEE/IEEE) Conference,* 1993.

11. Hooper, Gretchen L. *Personal communication with paper authors*, March 2002.

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