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Assembling a Successful Industry-Sponsored Senior Capstone Program – Lessons Learned From a Startup Effort at a Liberal Arts University

Abstract

A medium-sized (around 4000 students) liberal arts university recently began a general engineering program. The program's first graduating class was in May 2016, and the program obtained initial ABET accreditation in August 2017. Entering the 2015-2016 academic year, program faculty envisioned a capstone design experience that would engage student teams in a year-long, professional level design project sponsored by an industry client. The first two years of the capstone design program have been inarguably successful, and in this paper we identify and reflect on the keys to our success. The intention for writing this paper is to ensure the success of the program is repeatable, and to assist other programs, especially those residing in small liberal arts universities, in starting or revising their own senior design experience.

Our key factors in assembling a successful industry-sponsored capstone design program have been: (1) faculty buy-in and involvement, (2) engaged industry partners, (3) our teaming and project assignment strategy, (4) flexibility to address curricular concerns in program, and (5) building a corporate-like environment within the classroom. Early indicators of success include formal feedback from industry partners, feedback from our program's industrial advisory board, and job placement of our program graduates.

Background

The institution that is the focus of this paper is a faith-based liberal arts institution with approximately 4000 residential undergraduate students. The first cohort of students pursuing a degree in general engineering began classes in Fall 2012; students from that cohort entered the program's first capstone course in Fall 2015. Changes in program leadership as well as timing for new faculty hires resulted in the bulk of strategic planning for the year-long capstone experience taking place in Spring 2015. Preparations began in earnest with the on-boarding of two new faculty hires in August 2015.

Early defining decisions for the capstone experience included:

- Projects are, whenever possible, industry sponsored
- Program director responsible for sourcing capstone projects
- Two engineering faculty members co-direct the capstone program
- Each project required to have a dedicated industry liaison willing and able to have weekly interaction with student project team

The first engineering capstone cohort consisted of 16 students; 4 of these students were physics majors fulfilling degree requirements by completing the engineering capstone course. The physics students were integrated into project teams with engineering students, not unlike what many will encounter in industry jobs and/or research opportunities. The students were assigned to four different projects, with team sizes varying from 3 to 5 students depending on the content and complexity of the project. The second senior capstone cohort (academic year 2016-2017)

consisted of 17 engineering students; this cohort completed 5 projects using teams of 3-4 students in size.

Of the 9 projects completed during the first two years of the capstone design program, 8 have been externally sponsored by 6 distinct companies/organizations. (We count it as a meaningful success that two sponsors from our first year chose to continue in their relationship with us and sponsor a second project team the next year.) The external sponsors have included:

- A local civil and environmental engineering firm
- Two major defense contractors from the nearest large metropolitan area (approximately 150 miles away)
- The United States Air Force
- An entrepreneur seeking help to develop and implement new technology to assist with smoking meat
- A local manufacturer of industrial machines

Financial support for these projects has varied from project to project; the total amount of external funding through the first two years of the capstone program exceeded $40,000.

Indicators of Success
In addition to the ability of the capstone design program to generate significant external funding in both of its first two years and the continuing relationship of two of the four initial external partners, there are several additional indicators that the program has been successful.

First, client feedback has been overwhelmingly positive. For example, feedback on satisfaction with project outcomes ranges from "satisfied" to "10/10." Industry liaisons rated the teams' professionalism as ranging from "9/10" to "very satisfied." Satisfaction with project team in general also ranges from "9/10" to "very satisfied." Liaisons commented that project outcomes "exceeded expectations" and that they were "very pleased with the outcome and generally enjoyed working with" the students. (Data is difficult to aggregate due to a format change in our feedback instrument.)

Second, our program's industrial advisory board made note of improvements observed from presentations in the inaugural capstone year (2015-2016) to those made in the second year (2016-2017). In the board's summary report from the Spring 2017 meeting:

The board attended presentations of engineering major senior clinic projects…The board noted significant improvement in senior project presentation from improvement points recommended from the inaugural 2016 presentations. While the 2016 presentations (4 total) were successful and had recognized elements on the high side, the board noted that there was not uniform minimum quality across all presentations and presenters sufficient to meet industry professional standards. To this end, the 2017 senior clinics (5 total) did show an improved professional quality across all projects and presenters. As noted by board member Gibbs, "prototypes looked professional, the entire team was present, and each team members knew details of the entire project." The board was pleased to see the improvement, and

recommends continued focus on the professionalism of the event, particularly as engineering fairs can serve as evaluation by companies for future hires.

Finally and perhaps most importantly, our students are in demand. Two companies who hired graduates from our first graduating class in Spring 2016 have expressed explicit interest in hiring additional students from our program. One company has since hired an additional graduate (they now employ two graduates from our first engineering capstone cohort.) Three projects have led directly to the hiring of one of the student team members after graduation. As of the writing of this paper, our published employment rate for 2016-2017 graduates is 93%, and anecdotally (due to recent hires) is higher. With only two cohorts of graduated students, our program is already producing the highest-earning graduates from our university. We have had students hired by Lockheed Martin, Raytheon Space and Airborne Systems, Rockwell-Collins, Page Southerland Page, and Varian Medical Systems. The ability of our students to land such competitive positions is especially remarkable given that at the time of their interviewing and hiring, our program was not yet formally accredited. (Note that our recent accreditation now retroactively applies to their degrees.)

Factors for Success
While there are a wealth of best practices to consider for engineering capstone, there is not one right approach. Starting a capstone design course from scratch in a new engineering program was like a working a jigsaw puzzle; all the pieces are important, but it is impossible to assemble the puzzle by focusing on all the pieces at the same time. Furthermore, it isn't clear what all the pieces are or even how many there are. In the "puzzle" of starting our senior capstone course, we focused on a set of pieces to form the basic structure and culture of our senior design program.

Our key pieces to the puzzle so far:

1. Faculty buy-in and involvement – everyone in the department (department of engineering and physics) was invited to be part of the visioning process for engineering capstone, and every faculty member in the engineering program had a role in capstone during the first two years. Two faculty members were charged with co-directing the capstone program, one engineering faculty member served as program director (and therefore was responsible for sourcing capstone projects), and all remaining engineering faculty members served as team "coaches" (i.e. technical and professional mentors) for student project teams. While this was a lot of "cooks in the kitchen," it also kept capstone at the forefront of the attention of faculty and administrators.

2. Involved industry partners – our partners have committed to, and followed through on, engaging with their respective teams on a weekly basis, hosting them for site visits, and participating in person in a critical design review and final demonstration and presentation. The consistent interaction has resulted in richer professional development opportunities for the students. For example, students become accustomed to receiving professional critical feedback as well as praise. They develop in their ability to communicate via teleconferences, emails, in-person meetings, and in formal reviews. They become acclimated to the professional expectations of their sponsoring organization

(with respect to culture, documentation, presentation practices, etc.) Additionally, project outcomes benefit due to weekly client interaction - students have to pay attention to project all the time, not in fits and starts leading up to a major deliverable.

3. Teaming and project assignments – capstone design co-directors desire student input regarding project preferences, but retain the right to assign student resources to projects. This approach is a reasonable reflection of what students should expect in the real world, and (more importantly to the program) ensures that projects can be staffed to reasonably ensure success. Project abstracts are published to the students on the first day of class, and students are required to apply to a minimum number of projects. (The required number depends on the year and number of projects the capstone course can support; it has varied between 2 and 3.) The abstracts contain general information about the project, but do not include any information that would directly identify the sponsoring company. The students "apply" to a project by submitting a cover letter and a resume specific to each "job opening;" we also solicit preference rankings from the students for the jobs to which they have chosen to apply. Following the receipt of all applications, capstone co-directors make staffing decisions based on student input, demonstrated student skills from previous coursework, and input from colleagues. (Our program is small enough that staffing decision can be made on a case-by-case basis "by hand;" we recognize this is a luxury that is impractical for larger programs.) Once teams are formed, students engage in a team-building activity of their choice (with funding for the activity provided by the capstone program), develop a team contract, and nominate a team leader.

4. Flexibility to address curricular concerns in program – it really helps if capstone design isn't the first time students are engaged in a significant engineering design project since their first-year introductory experience. Yet, such was the case for students in our first engineering capstone cohort. Program leadership and colleagues were very responsive to this early identified problem, and worked to offer a correction. Students in their junior year in Spring 2016 (note that this was only the second semester of the inaugural capstone course) were offered a course titled "Junior Clinic" – a course designed explicitly to prepare students for senior capstone. Capstone co-directors worked closely with the instructor for this course to identify weaknesses observed in five areas, and Junior Clinic strengthened these skills using design projects as a vehicle for discovery and mastery. The Junior Clinic course was an elective for juniors in Spring 2016 and Spring 2017, and starting with the cohort of third-year students 2017-2018 academic year it is a requirement of their degree plan. Despite it being elective and not mandatory, it is already making a big difference in observed preparedness of students. Our second capstone cohort had five "graduates" of junior clinic. We were able to disperse them across three different project teams, and all three of these teams were led by students who had experience leading teams in junior clinic.

5. Bring the corporate environment to the classroom (within reason) – this element of our capstone course culture is primarily due to two factors. First, one of the capstone co-

directors has decades of industrial experience leading engineering groups, and naturally brings that experience and expectation into the classroom. For one example, students are expected to produce professional-level engineering drawings, which is quite a jump in expectation from their standard "Intro to CAD" class. Second, capstone design co-directors attended the 2016 Capstone Design Conference held in Columbus, OH, where one prominently discussed best practice (most notably by Susannah Howe of Smith College) is to strive to make the capstone course mimic a corporate environment. To this end, we have a student ("employee") manual, standard operating instructions, forms, and work instructions. Our students undergo performance evaluations. Recently, we adopted the practice of students addressing us by our first names in the context of capstone projects. Our intention with these practices is to help bridge the transition from student to employee; a transition that can be very steep for our students. Anecdotal feedback from recent graduates now employed in industry supports that these practices were indeed helpful in their transition.

The five key elements identified above are a starting point. As our program matures we are working to figure out the next "pieces of the puzzle." Challenges we are currently working through include: (1) Team roles – what are the right team roles to define? How often (if at all) should students rotate through these roles? (2) Standardization of documentation – for example time sheets, meeting minutes, liaison feedback instruments, etc. (3) Assessment, and (4) Standardizing the financial commitment and contract required from sponsoring organizations.