AC 2008-1987: A BLANK SLATE: CREATING A NEW SENIOR ENGINEERING CAPSTONE EXPERIENCE

Mark Chang, Franklin W. Olin College of Engineering

Mark L. Chang is an Assistant Professor of Electrical and Computer Engineering at the Franklin W. Olin College of Engineering.

Jessica Townsend, Franklin W. Olin College of Engineering

Jessica Townsend is an Assistant Professor of Mechanical Engineering at the Franklin W. Olin College of Engineering.

A Blank Slate: Creating a New Senior Engineering Capstone Experience

Abstract

This paper presents some of the challenges, successes, and experiences in designing a new senior engineering capstone program at the Franklin W. Olin College of Engineering. Senior capstone design programs in engineering colleges have evolved over many years and are often modified and reinvented to keep up with the needs of both students and external constituencies. Harvey Mudd College's Clinic program is one of the largest and longest-running capstone programs in the country that relies heavily on industry sponsors to provide real world problems and funding to execute the projects. For many reasons, and in no small way because of its track record of success, our own capstone course offering is modeled closely upon the Harvey Mudd Clinic program.

However, completely importing a well-established program into a different context would be haphazard at best, and would ignore a unique opportunity to retool the program to meet the specific needs of a different college. This paper presents our experience in developing SCOPE, the Senior Consulting Program for Engineering at Olin College, and applying lessons learned from the Clinic Program and other successful capstone programs. We discuss the difficulties such as recruiting industry sponsors for a new and unproven program, developing assessment methodologies, and developing the policies and procedures needed to keep the program running smoothly and in a sustainable fashion. Through this narrative, the authors endeavor to inform other programs that are in need of modification, and educators who find themselves with the opportunity to start a capstone program from the ground up.

Olin College Background

Franklin W. Olin College of Engineering is a new, four-year engineering school in Needham, Massachusetts. The college was started and funded by the New York-based Olin Foundation, which has awarded grants totaling more than $300 million to construct and fully equip 72 buildings on 57 independent college campuses. Starting in the late 1980's, the National Science Foundation and engineering community at large started calling for reform in engineering education. In order to serve the needs of the growing global economy, it was clear that engineers needed to have business and entrepreneurship skills, creativity and an understanding of the social, political and economic contexts of engineering. The F.W. Olin Foundation decided the best way to maximize its impact was to help create a college to address these emerging needs. The Foundation's commitment in excess of $400 million to Olin College remains one of the largest such commitments in the history of American higher education.

The college officially opened in Fall 2002 to its inaugural freshman class. During the prior year, thirty student "partners" worked with Olin's faculty to create and test an innovative curriculum that infused a rigorous engineering education with business and entrepreneurship as well as the arts, humanities and social sciences. They developed a hands-on, interdisciplinary approach that better reflects actual engineering practice. From the beginning, it was clear that a two-semester,

senior-year, engineering capstone project course would be part of the curriculum for all Olin students. Just prior to the first year of instruction at Olin, the Curricular Decision Making Board put together plans for the senior year, and noted that "by the time students are seniors, they'll be doing the real engineering on their own, in a year-long capstone project that will look very much like professional practice." Development work on this program, eventually named SCOPE, the Senior Consulting Program for Engineering, began in earnest in the fall of 2004, when the first SCOPE Director was hired, Dr. David Barrett.

The unique challenge, and, perhaps, the greatest advantage, in developing the SCOPE program was the absence of a pre-existing capstone program. The intent was to launch the SCOPE program during the first senior year offered at Olin College. Although an overall vision for the senior year had been developed, faculty and administration needed to create and implement a fully-functioning capstone program so that the very first Olin College class would receive as close to the same capstone experience as those students that followed. Olin College is certainly not the first institution to develop a new engineering capstone program, therefore the most logical course of action was to look at how other schools have run their capstone programs.

Due in part to its similar mission, scale, and approach to undergraduate engineering education, an obvious model for Olin's capstone program is the Harvey Mudd Clinic Program. The Clinic Program is the longest running sponsored capstone program for undergraduates. For reasons detailed in later section, the Clinic Program became the blueprint from which the SCOPE program was designed.

Goals of this paper

In writing this paper, the authors intend to describe through a narrative, the history and evolution of the program over its first three years. The intention is to put the reader into the context of developing a capstone course from the ground up such that our experiences may inform the efforts of other faculty and administrators seeking to build, expand, or enhance their own capstone programs.

It is important for the reader to keep in mind that while this paper was written in consultation with faculty and administrators involved in all aspects of the capstone program, it represents the interpretation of the challenges, successes, and experiences of many people by the two primary authors. We have made an effort to synthesize our observations with those of our colleagues, and would like to acknowledge the hard work of all those involved in the design and execution of the program.

The Harvey Mudd Clinic Program – A Major and Direct Influence

Harvey Mudd College was founded in the mid-1950s. The original curriculum was strong in engineering science analysis, but engineering practice and professional training was lacking. Specifically, students were not getting experience in solving open-ended problems, or with project and team skills.[1] The Harvey Mudd Engineering Clinic Program was started by professors Jack Alford and Mack Gilkeson in 1963 as a way to address these issues by bringing

real-world engineering problems to the campus in a close approximation to professional engineering practice.[2]

The Clinic Program has been in operation for more than 40 years and has proven to be sustainable, both financially and logistically. Funding for Clinic comes directly from the sponsoring companies. Students work in four- or five-member teams, along with a faculty advisor and a liaison from the sponsoring company on a project that is meaningful and useful to the sponsor. The students are responsible for developing the project statement, goals, and outcomes in concert with the sponsor liaison, and then are fully responsible for carrying out the project. The faculty advisor is a mentor, coach, and assessor. The student teams give a number of design presentations to the Harvey Mudd College audience, the sponsor, and to the general public as part of the end-of-year Projects Day.[3]

The Evolution of SCOPE

Year Zero: The First Steps in Developing the Olin College SCOPE Program

In creating a new engineering college, the founding faculty and administrators were presented with the unique challenge of wholesale *invention* of a four-year engineering curriculum. From the outset, every version of the Olin curriculum, "retained a two-semester senior capstone project course."[4] At the conclusion of Olin College's first sophomore year, it was clear that the succesful execution of a year-long, authentic, project-based experience would require significant planning effort. While there exist many models of capstone experiences, our then Dean of Faculty, Dr. Michael Moody, advocated the adoption of the Harvey Mudd Clinic Program as our model in his June 2004 memorandum on the upcoming senior capstone course. His experiences as Chair of the Mathematics department at Harvey Mudd, participating in the Math Clinic Program, and having signficant exposure to the Engineering Clinic Program, greatly influenced this decision. As a limitation of his experiences, and because of the anecdotal successes of the Clinic Program, this was the only model considered. By leveraging his direct experiences and intimate knowledge of a successful program, much of the work of "creating" the program was lessened. Dr. Moody remains a key leader in the continued evolution of our program, and his experiences were and continue to be invaluable to our efforts.

In creating a sponsored program, two key decisions needed to be made which strongly influenced the rest of the program: the grant vehicle for sponsors to make monetary contributions to the program, and the dollar amount to charge for participation in the program. The fee for the program was set at $50,000, compared to approximately $41,000 for the Clinic Program in 2006/2007. The justification and rationale for this price tag was that given the nature of our institution, we should be able to support a program of comparable complexity and cost to the Clinic Program. Specifically, given the high caliber of our students, the residential nature of our college, proximity to high-tech companies in the greater Boston area, our qualified faculty and administration, and the two-semester capstone engagement structure, we believed to be in a position to offer an experience similar in scale to the Clinic Program. Our costs being higher than the Clinic Program come primarily from taking into account program startup costs.

With respect to the sponsorship vehicle, the program opted for a fairly complex contractural agreement between the College (signed by students and faculty advisers) and the corporate sponsor. This agreement addressed issues such as confidentiality, intellectual property rights, idemnification, and set baseline expectations for deliverables. It was felt that in the startup phase of the program, protecting the students and the College through a legally binding document would be preferred by both parties. This approach received considerable thought and revision in later years.

By April 2005, the program had been named SCOPE, and key personnel that would ultimately be responsible for the day-to-day execution of the capstone were chosen. This included the SCOPE faculty, the student representatives, an external advisory committee, and the program director. Initial sponsor solicitation began, and two signed contracts were in place with 30 potential candidates being actively courted. It was at this point that the faculty who were to participate in SCOPE starting in September of 2005 were notified. They were asked to target companies they would like to work with, help prioritize the current list of candidate sponsors, and help respond to new contacts and projects.

One unique aspect of the SCOPE program is the support of the Franklin W. Olin SCOPE Project. As Olin College itself is the result of a philanthropic organization, and each of our students the recipient of philanthropy, it was important to provide an outlet for student philanthropy through engineering experiences. The Franklin W. Olin SCOPE Project was conceived of as a student-generated, Olin-funded SCOPE project of the same scale and level of technical challenge as a paying sponsor project. The vision was to have students craft detailed project proposals, of which one or two per year (depending on budget flexibility) would be selected and funded by the College.

Reflections on Year Zero

Development of Pedagogy: During the development year prior to the launch of SCOPE, a great deal of administrative energy was spent on soliciting potential sponsors. This focus, however, left many pedagogical issues untouched until the summer preceding the launch of the program when many of the faculty responsible for advising teams and running the program finally joined the development effort. Important issues such as how to best utilize the class time within the weekly schedule, program-wide curricular milestones and objectives, common deliverables, grading and assessment rubrics and techniques, and team advising methods and techniques, for example, were only briefly discussed in meetings and drafted into the handbook before launch. After the program got underway, many of the details were either finalized just in time to be implemented, or the faculty members were left to decide their own course of action.

In retrospect, there was not enough development time for faculty before launch to permit a thorough investigation into what portions of the teaching tasks should be common between faculty, and which portions were best left up to individuals to decide. A common struggle was, and continues to be, finding the balance between treating SCOPE as teaching multiple sections of the same course and therefore requiring common practices; versus acknowledging that each project is unique and therefore requires specific decisions regarding policies such as advising/mentorship and grading. Providing more time for faculty development of the

pedagogical tools would significantly ease the anxiety of all parties, and would perhaps ensure a more even level of performance between teams.

An important lesson learned was that although the adoption of the Clinic Program gave our program a strong and successful framework to build upon, it does not adequately inform the day-to-day operations and procedures that one must have to actually carry out the program. More preparation time and faculty thought would have made the first year a much less anxiety-filled for all parties. This preparation would improve the chance for success in any program.

Capstone Advising Committee: While the program had as a model the Clinic Program, one thing that we did not import from Harvey Mudd was an advisory committee. Harvey Mudd has an approximately 20-person advisory committee that includes members of the Board of Trustees and members from industry. Their purpose is to help sustain and improve the Clinic Program by providing feedback to faculty, staff, and students, and through conducting a satisfaction survey of the industry partners. While the SCOPE program has a very small handful of external advisors, they serve more in a technical advisory role for individual projects rather than aiding the program as a whole. While recruiting an advisory committee can be challenging, their presence could provide some useful and directed industry and academic feedback to improve our program. Without them, we run the risk of being short-sighted and limited in our contextual understanding of the corporate partner experience. We will soon be starting development efforts to create such an advisory committee for SCOPE.

Contracts: The contractual agreement also received some criticism as the first summer of sponsor solicitations came to a close. While it was thought that a more industry-flavored contract would make it easier for sponsors to agree to fund a project, in many instances, it was a bottleneck in negotiations. If we had used a less formal agreement mechanism—a letter of understanding, for example—the legal teams for the sponsors may have been less inclined to get involved. With the complex legal document we drafted, however, as it was clearly a contract, it required the attention of the legal departments within potential corporate partners, slowing (and sometimes halting) negotiations.

The agreement as a contract also changes the psychology and expectations of the program as whole. With a firm legal document in place, sponsors might have felt the relationship more as a subcontractor rather than primarily an educational partnership. This significantly alters the expectations of the sponsor and might put inappropriate pressures on the student teams.

Successful Launch: In the positive, going into launch, the program was very successful in soliciting 13 paying external sponsors for a completely new and unproven program at an almost equally new and unproven institution. Much of the credit for this success is given to the tireless effort of Dr. David Barrett, the SCOPE program director. Coming directly from 25 years in research and industry, Dr. Barrett brought with him siginificant relationships with individuals and corporations in a position to sponsor a project. With a concrete capstone framework, Dr. Barrett could promote a well-structured and proven program that met corporate needs. Additionally, the college had received a large amount of media coverage during its startup years, and had already established itself as an engineering education innovator and a business-friendly

atmosphere. The general excitement surrounding Olin piqued interest among corporations looking for new ways to engage academia.

Year One: Off and Running

The launch of the SCOPE program in the first week of September 2005 coincided with the last of the 13 contracts being signed. In the summer months leading up to the launch, many of the mechanisms needed to successfully execute a project were put into place but never tested. The return of the students and the beginning of the SCOPE program would put not only our planning to the test, but also our ability, as a program, to be agile and adapt to the needs of the program. In this section we will reflect on the year's experiences in three sections: curriculum and student experience, facilities, and program & infrastructure. We will discuss some of the challenges and lessons learned in each of these areas.

Curriculum and Student Experience

As previously mentioned, the amount of pedagogical preparation that was done prior to starting the program was not as much as any faculty would have preferred. The negative impact of this is perhaps minimized at our institution due to the fact that significant portions of the curriculum already involved large-scale projects and student-directed learning. The students had experience working with the unknown, and faculty had experience leading and advising these efforts. However, it was still not decided when to treat the capstone as a single course taught by many faculty, and when to treat it as a collection of completely separate and autonomous projects.

While there is no correct answer, the vagueness was felt not only by the faculty, but also experienced by the students, as individual faculty led their teams in their own unique ways. In hindsight, it would have been useful to devote more time to discussing how the program could most effectively support these unique project experiences by enforcing uniformity in places, and encouraging autonomy in others.

These decisions directly influence much of the student experience. Program activities such as design reviews, assessment and grading, and faculty-student interactions are all areas that draw from either programmatic direction or from individul faculty preferences. Without significant preparation, these many activities become more ad-hoc in nature, and students' motivation can suffer from the lack of coherency.

It became more clear as the year progressed that maintaining student motivation was a key component to success. An area that could see improvement is in the scheduling of activities, especially those toward the end of the second semester. As seniors start finalizing their post-graduation plans, having accepted job offers or gained admission in graduate school, motivation can be problematic. One lesson learned in our inaugural year was the importance of scheduling end-of-year events. In particular, the culminating final presentations to sponsor personnel was scheduled after finals. Many students found themselves "burned out" from their capstone experience, the crunch of finals for their other classes, the stress of graduation and impending major life changes, and simply the wear of four years of college. Positioning such a high-stakes and high-visibility event such as final presentations at a time when many students feel they should be celebrating can spell disaster.

Finally, in contrast to the Clinic Program, our students have no direct training in project management. The program offered several hours of instruction and guidance, but only to the student project coordinators. By introducing a required course in project management earlier in the curriculum, or by introducing formal instruction in various required project courses leading up to the capstone, our students might find managing their peers and interfacing with liaisons easier.

Facilities

After just a few weeks, it became clear that the capstone program's impact was not isolated to the faculty and staff directly associated with the program. As projects moved forward, puchases, services, and space became more necessary. While the mechanisms for purchasing were already in place for the College as a whole, the disparate and frequent needs of the projects put a significant strain on purchasing personnel. Beyond purchasing, project needs found the students wanting physical space, computing resources, and IT resources that were not adequately planned for.

All teams were assigned their own team room, a small office outfitted with tables and chairs, a whiteboard and a lockable file cabinet, but many projects required additional physical space to store, fabricate, and test devices. Some needs were modest and could be accommodated in the team rooms or existing laboratories. However, the handbook had no guidelines for requesting rooms or other types of spaces, nor did the program have any significant predefined space allocated in advance. As is with most other colleges, excess space is rarely available. The process was therefore ad-hoc and required the involvement of many college administrators to help "find" space. This lack of immediate space influenced the student team's ability to develop an appropriate statement of work in partnership with the sponsor liaison as they could not make an assumptions about having dedicated facilities.

A lesson learned here is that if at all possible, the program and college should find dedicated work spaces for some fraction of the student teams with the assumption that some projects will have significant space requirements. Fortunately, the needs of the projects and the resources of the college came into alignment and physical space was temporarily granted when necessary.

While physical space only affected a few teams, computing resources were a problem for a wider selection of teams. The nature of team-based engineering often requires sharing files between students, sharing files off campus, and purchasing high-performance workstations. In the first year, we did not adequately prepare our IT department for the flood of requests from student teams for support and equipment. Complex issues such as maintaining confidentiality of digital information on a network, issues of trademark and liability when making information publicly available on web sites, and advanced development that required different access rules than typically allowed by the college network and computing infrastructure were not adequately addressed or anticipated. While we resolved the majority of these issues, it was a heavy additional burden on a separate department that could have been lessened with some planning.

Program & Infrastructure

As it was our first attempt at executing a set of large-scale engineering projects for corporate sponsors, no amount of planning could have prevented some of the challenges detailed in this section. However, a lesson learned was that perhaps solving some of these issues beforehand might make the road to a new capstone program a bit smoother.

Project confidentiality: In the first year of the program, we were not in a position to turn down many projects. Therefore, we found ourselves with several projects that had very restrictive confidentiality requirements. While the projects may have been successful and interesting, their closed nature prevented students from presenting much information regarding their work at design reviews. In addition to being logistically problematic, the students missed opportunities to get valuable feedback on their work from anyone that had not signed the non-disclosure agreement.

Cross-registered students: Olin College has a very close relationship with Babson College and Wellesley College, allowing Babson and Wellesley students to freely cross-register in nearly any Olin course, including the capstone. From our experiences this first year, it became clear that given the high-stakes nature of working on sponsored projects, having a system to screen for appropriate students was necessary. Having an adequate match between potential students in both interest and skill set would give the project a better chance of success.

Human subjects policies and review: Due to the heavy design component of many of the projects, soliciting feedback from volunteers at various stages of product development would be a common practice. Protecting these users from harm is an ethical requirement and responsibility of any college. We did not have the sufficient infrastructure in place to perform human subjects review of the work related to the capstone. In many cases, it was suggested that students follow the human subjects practices and requirements of their sponsoring company. However, sometimes the internal corporate review committees did not move at the pace necessary to be useful for a student team with a short time budget, and sometimes corporations had no internal review boards to leverage. Having a more program-wide solution to this need would be both educational and practical.

Reflections on Year One

As the faculty looked back over the first year of SCOPE, it became clear that Olin students were utilizing the design skills learned earlier in the curriculum in their SCOPE projects. In many ways, design is at the center of the engineering curriculum at Olin. All Olin students take Design Nature during their first year where they receive instruction in design processes and methodologies. During their second year they take a class called *User Oriented Collaborative Design*, which focuses on including the user in the design process. Many teams found that these design processes and the collaborative approach were useful tools for their projects. Both faculty advisers and program sponsors noted the teams' strengths in this area.

A second area of strength noted was the communication skills of the students, particularly when interfacing with the sponsor companies and during design reviews and presentations. This was likely due to the emphasis on oral communication and presentations throughout the entire Olin curriculum and to the strong oral communication skills many students enter Olin with.

Finally, the students seemed able to handle many team dynamics issues on their own. The first senior class at Olin College had only 66 students, and most students were very aware of each other's work and communication styles going into the SCOPE program. This did not mean that team dynamics issues were non-existent, just that the teams had some skills to work through these kinds of issues already.

An area of weakness noted by many faculty advisers was the students' willingness to take on hard analytical problems. There was a sense that students were capable of this level of work, but had difficulty in setting up the problem, making assumptions and working out a first order model. This was attributed not to a lack of open-ended problems in the curriculum, but to a lack of open-ended problems that required engineering science analysis.

Although these issues that surfaced during the first year of SCOPE were regarded as important to address, it would be premature to make major changes to the program or to the Olin curriculum without more steady state data. The feedback regarding analysis was given to faculty responsible for teaching the engineering science classes, and some small changes were made programmatically. Most of the feedback we received from Year One was incorporated through faculty advising of teams. Faculty now had a year behind them and were able to bring those lessons learned, both on a team scale and a program-wide scale, to their advising. Having weekly SCOPE faculty meetings provided the best opportunity to compare notes and share experiences. This is something that Harvey Mudd faculty have noted as well, that learning to advise a Clinic Project is experiential learning for the themselves. The most valuable resource a new Clinic faculty member can have is a solid group of experienced Clinic faculty members to talk to. A cohort of dedicated faculty members is what will keep a successful capstone program running and sustainable.[3]

Years Two and Three: Small Changes, Gaining Experience

Much of the programmatic structure that was put into place during Year One was kept in subsequent years. One change made in Year Three was renaming the main student leadership position from "Project Coordinator" to "Project Manager." The original intent was that the Project Coordinator would handle many of the administrative and sponsor communication duties, but would not necessarily be "managing" the other team members. It was expected that students would take responsibility for keeping up with their work and all team members would ensure that work was distributed fairly. During the first two years it became evident that students would not have a problem with one student managing the project and the work, and some students preferred this altogether. In the end, the position was renamed, but more emphasis was put on letting students rotate through this position during the one-year project. After one semester, this leadership scheme seems to be working well for the teams.

There are several other major issues that the SCOPE Program has looked at and revamped over the first two and half years of the program. These are highlighted in the sections below.

Projects and Sponsors

During Year Zero, the SCOPE Director spent many months on the road recruiting sponsors for the first year of SCOPE. The pitch to sponsors included a description of the types of projects that would have the biggest return on investment for the sponsors, and would also provide the most meaningful learning experience for the students. As the SCOPE Director explains, "All companies have three classes of problems. Class 1: are the mission critical problems that your best people must focus on for survival. Class 2: are the strategic problems that have been sitting on your back burner for years, for lack of time and skilled labor to address them. Addressing these problems could significantly and positively affect your bottom line, provide a foundation for explosive growth or enable successful entry into a profitable new business area. Class 3: are low-level problems that have no significant impact on your corporation's operations." When talking to potential sponsors, we emphasize that Class 2 problems are ideal for SCOPE projects.

However, in the first few years of SCOPE, we did take on several projects that were not exactly Class 2 problems. One project was done for a small start-up and involved development of a technology that was on a mission critical path for the company. In this case the faculty adviser spent a lot of time managing the sponsor's expectations of the outcome. Another project involved a technical analysis that was beyond the scope of the students' abilities. The team spent the first semester attempting the problem and eventually went back to the sponsor with evidence that the project was better suited for a PhD dissertation, and asked the company if they had another project they could tackle. In this case, the company responded well, brought another project to the table, and in the end was pleased with the students' efforts.

One way to help appropriately set sponsor expectations is in how the program is pitched. In our original efforts to recruit sponsors, we indicated that sponsoring a SCOPE team was very much akin to hiring five talented entry-level engineers who could make traction on a problem that that company did not have the resources to solve. After the first year, we adjusted our pitch to maintain more of a balance between a learning experience for the students and a benefit for the company. We also found that it became easier to help guide a sponsor towards an appropriately scoped project for our students.

Finally, we learned that projects that are highly successful have an involved and accessible sponsor liaison (the company representative that interfaces directly with the team).

Design reviews

All SCOPE teams are required to give regular design reviews to the Olin community throughout the year. The purpose and intent of the design reviews has changed over the three years of the program, with different faculty advisers setting different expectations for their teams. In general, the purpose is to present technical issues and challenges, show progress, describe and justify design decisions and receive feedback from the audience. The design reviews during Year One were not as interactive as we would have liked, and in Year Two we told students that they were expected to contribute whether they were on the presenting team or not. However, during the first two years of the program, teams were expected to give design reviews every two weeks. This was taking time away from the technical work that needed to get done, and in Year Three, teams have been presenting twice a semester instead.

Grading and Assessment

Prior to launching the program the SCOPE faculty did not explicitly discussed grading and assessment. While course outcomes, grading criteria and deliverables were described in the SCOPE Handbook, no common method for assessment was presented. Faculty were encouraged to provide students with a mid-semester grade, but by the end of the semester it was clear that the methods of assessment for the SCOPE projects varied quite widely.

The first major discussion of grading and assessment came at the end of the first semester of SCOPE where there was general agreement of what level of achievement each letter grade indicated. In subsequent semesters, faculty made progress in agreeing on a common set of deliverables and a common set of competencies and outcomes for SCOPE students. By the second year of SCOPE a set of peer assessment forms had been developed that were in use among most teams, and faculty advisers were more clearly communicating their grading policies to their teams. However, it is fair to say that assessment does still differ among faculty advisers, although more of an effort is made to streamline the assessment process, and faculty are communicating with each other more to maintain a similar set of expectations for their teams.

Finding the Balance

The creation of a capstone experience for our students was, and continues to be, a challenging effort that requires significant resources. In preparing this document, our goal was to discuss lessons learned along the way such that other programs seeking to incorporate new, or revamp existing, capstone programs would benefit from our experiences. One consistent theme in the struggle to make our program successful was finding the right balance between the investment of our sponsors and the expectations of our students. There are many factors that contribute to this "balance".

Overall curriculum

Matching the goals of the capstone experience to the content and trajectory of the entire curriculum ensures a better chance of success for our students. Set the bar too low, and the experience is not authentic. Set the bar too high, and the students struggle to succeed. Recruit projects with the wrong balance of technical challenges, design, and humanities, and our students will struggle. Match the project to the curricular goals of the college, and the students will flourish.

Time in the academic schedule

Originally conceived, the program was 16 credit hours, essentially half the academic workload for a year. This was scaled back to 8 credit hours before launch. Balancing the time the students put into the project versus the expectations of the corporate partner is critical to success.

Team resources

Giving the students an appropriate budget and physical space to complete hard engineering work is critical to the students achieving success. While how much money and space a particular project needs varies significantly, ensuring that the program generates appropriate value for the sponsor is critical to sponsor happiness and sustainability of the program. It is important to recognize, however, that if simply measured against "consultant" efficiency, student teams will

not compare favorably. Providing value goes beyond the deliverables generated by the students to encompass philanthropy, recruiting opportunities, and investment in an academic mission.

Faculty advising
Faculty must be engaged in the process and the outcome of the program, and given schedule space to dedicate time to the capstone as any other course. Without a dedicated and passionate adviser, the experience is not as rewarding for the students, and the work suffers as a result. Involved faculty can also play a large role in sustainability—with successful projects, sponsors may be more willing to partner with individual faculty long-term, easing the burden of finding sponsors.

The sum of these factors serves as a coarse indicator of how one might set the fee for corporate participation in the program. The more the college dedicates to the endeavor, the higher the valuation becomes. While it is not a simple task to balance this system, keeping it in balance can ensure a higher chance of sponsor satisfaction and program sustainability.

Future directions

In developing the SCOPE Program, the intent was to create an industry-sponsored capstone design program that would provide meaningful educational and professional experiences for our students, while providing enough value to the industry sponsors so that the program would be sustainable. In each of the first three years, we have brought in enough funded projects for all the fourth-year students, and our program can be considered a resounding success if observed day-to-day. Much of this success is due to the tireless dedication of the current capstone director.

Implementing a capstone course can give students a truly unique experience that can solidify their engineering education and propel them into the next stage of their careers. The costs to the college are as high as the rewards. Sustainability of the program is probably the biggest challenge we face going forward. We have started to recognize that while a dedicated individual can be primarily responsible for the success in recruiting sponsors, more needs to be done to set a positive track record that will help us continue to recruit sponsors in the future. We remain cautiously optimistic that the continued short-term successes of the program will make sponsor recruiting easier and more sustainable.

Bibliography

1. J. R. Phillips and M. M. Gilkeson, "Reflections on a Clinical Approach to Engineering Design," *Proceedings of The International ASME Conference on Design Theory and Methodology*, Miami, FL, September 1991.
2. A. Bright and J. R. Phillips, "The Harvey Mudd Engineering Clinic: Past, Present, and Future," *Journal of Engineering Education*, *88* (2), 189–194, April 1999
3. A. Bright, "Student, Faculty and Liaison Roles in the Engineering Clinic Program at Harvey Mudd College," *Proceedings of the 26th Fundamentals in Education Conference*, Salt Lake City, UT, November 1996.
4. M. Moody, "Capstone Project Issues", *internal memorandum*, June 6, 2004, revised June 15, 2004.