

Capstone experiences that build discipline identity

Jennifer R Amos

Department of Bioengineering, University of Illinois at Urbana-Champaign

How do we provide capstone experiences that build an identity for our graduates in a still-forming discipline where industry is still nascent? This need is consistent with our desire to develop skill-building hands-on labs that provide unique skills to students that other disciplines cannot provide but that this new industry needs. We are a new department with our first graduates entering the job market in 2007. Our design course has undergone much iteration to address the changing market place and industrial preferences in undergraduates entering the workforce. This article addresses the importance of undergraduate training in design concepts to help graduates remain adaptive in the changing marketplace of bioengineering.

Corresponding Author: Jennifer Amos, jamos@illinois.edu

Introduction

Capstone projects help students put their education into practice by giving them an opportunity to work as a team with clients to solve real-world problems of interest to a rapidly developing industry. We have asked dozens of corporate recruiters over the past 4 years why they might hire a bioengineering graduate over other types of engineering graduates for jobs in the biotech sector. They respond by emphasizing the need for professionals who are well grounded in fundamentals, and with a unique skill set honed through team project experiences related to clinical projects. They are especially interested in experiences developed through a rigorous sequence of educational laboratories that culminate in a successful capstone design project.

To address the aforementioned needs of adapting to a changing marketplace, we have to challenge our students, create memorable experiences, and let them have more control over the experience. The perfect stage for this is in project driven capstone courses. As educators, we often are teaching technical skills that will no longer be relevant when students reach the workplace, so we focus on traditional engineering concepts that transcend time and field of study. We must constantly teach our students not to just learn what we teach them, but to learn how to transform what we teach them into the next great thing. To best make a lasting impression, we must let the students explore their field of study through inquiry and innovation¹. Students must undergo an emotional cultural change in their work environment and be pushed outside of a lecture style classroom. In our curriculum, that challenge lied in the capstone design courses. We had a curriculum designed with a yearlong design project to immerse students in the “real world” for as long as possible.

The first challenge we faced was, as a new Bioengineering department with fewer than 100 alumni, we are lacking industry involvement in the capstone design project market. Early design projects were research-related side projects and did not stress the importance of team work, the design process, and innovativeness in the field of bioengineering. The instructor made great strides in reaching out to the community and integrated the medical field into the design course with successful results.

During the iterations, over the last 3 years, team effectiveness has increased, design projects are becoming more relevant and innovative and, as a result, student motivation has greatly increased. The department is also raising the profile of the college through key partnerships with colleges of medicine and local and regional hospitals. We have undergone many iterations to get where we are today and wish to share best practices in Bioengineering Design from the University of Illinois at Urbana-Champaign.

What is a design project?

Design teams for the department are typically made up of 3-4 students. The most important factor for success was to improve the quality of projects. Project solicitations were sent out in the form of a letter from the instructor in May of the academic year of classes. The letter was sent to all core and affiliate faculty and a few outside contacts at local hospitals. Students are also emailed and urged to share with their summer employer at their research institution or industry job. Students are also encouraged to come up with their own ideas and the instructor will help guide them to a faculty sponsor, or in some cases, the instructor will act as a sponsor providing guidance to the students. The letter defines the sponsoring experience as

“interaction with highly qualified and motivated students who can bring creativity and out-of-the box thinking to current challenges facing your organization, “back burner” ideas that need brainstorming, or a fresh look at a current technology of significant interest to your group.”

The instructor then pre-screened each of the project ideas by sitting down with the potential sponsors to define objectives, scope, estimated cost, and any other needed resources. By pre-screening and doing some investigation into the projects well before classes start, the instructor was able to improve the quality of the projects and provide better facilitation to the teams.

What is needed in the course curriculum?

During the iterations of academic year 2009-2010, a large portion of the curriculum was changed to include an improved timeline and new emphasis on parametric or systems design, Six Sigma Design, team management and client needs. Students view design as a creative inventing process but don’t often relate the design back to coursework or to a constructive design process once they actually start working on the project². In the new course layout, outlined in Table 1, students are given the project earlier and deliverables are related directly to the project versus made-up assignments as exercises used in previous offerings. This allows students to learn the design process in the context of their projects. Students have expressed a preference for this mode due to lack of, what they feel is, wasted time and increased retention of skills. This also allowed them to create the Design History Files earlier than previous offerings. The Design History File is required for all medical devices for FDA approval. Every document must be dated and signed by the team. By integrating parametric design into the lectures and pushing up the delivery of reliant on peer review as an important element of team work. I have implemented the CATME tool for peer

projects, students are able to gain a greater glimpse into industrial design where modeling is an important part of the design process. We are often forced to cut the timeline in the academic setting to allow students time to work on the project, however, this is not a realistic view of the process and does not incorporate enough of the course concepts that they have learned³. Through parametric design, students are able to identify key variables, defined parameters (either by environmental or client needs) and boundary constraints to the system⁴. This exercise proved to be more helpful than simply a brainstorming exercise, for some projects, this was paramount to an upcoming decision which would define the product. Students were also able to see the equations from previous mechanics, circuits, instrumentation in their designs or even material properties and how they would affect the design. The Six Sigma element came in the form of a two week intensive training. Student received three lectures in key concepts including LEAN processing, design of experiment, DMAIC, brainstorming tools (Fishbone, Thought Map), and Factorial Design. Students were then led through a series of simulations and mini-projects to cement the ideas⁵. Simple paper airplane competitions and production of happy or sad faces from construction paper led them through advanced ideas of design and forced them to identify concepts of Push and Pull and how to evaluate success of models created in DOE⁵. Lectures in team management and client relationship are often not the most popular in Phase I but students appreciate them the first time that they meet with a client who is not impressed with team efforts. Many clients are not clear with expectations or do not know enough about design to set reachable goals. Allowing students to interact with their clients on their own is the best way to learn how to interact and thrive in an industry environment. Part of the class is also review and students are always surprised at how insightful the peer review process is for their feelings

Fall Semester: Phases I and II	Spring Semester: Phase III
Phase I: Design Concepts – Lectures and Activities <ul style="list-style-type: none"> • What is design? (Design is not research, inventing, etc.) • Client Needs and constraints • Inputs and outputs of design • Configuration design • Parametric design • Evaluation in the design process • Team Management • Design of Experiment – Six Sigma Training • Regulatory Concerns (FDA, Patents, IRBs, etc.) 	Phase III: Product Development <ul style="list-style-type: none"> • Continue Phase II Deliverables • Prototype Development • Patent applications • Working Prototype • <u>Design History File</u> • <u>Presentation and Vendor Fair</u>
Phase II: Design Process – Team Deliverables <ul style="list-style-type: none"> • MOU with Client • FMEA • QFD • Thought Maps • Gantt Charts • IRB Proposal for Testing (if needed for project) • <u>Version 1.0 (Written report and presentation)</u> 	

Table 1: Outline of Objectives for BIOE 435 Senior Design I and BIOE 436 Senior Design II

about team members and their own performance on the team⁶.

During Phase II, the teams continue to attend class but lectures change into guest speakers on topics of interest such as a US Patent Officer, a director from our Office of Technology Management to discuss IP rules on campus, etc. The design team and instructor also meet every two weeks to monitor progress. Before the meetings, teams are instructed to send a progress update to both instructor and client denoting what was accomplished in the last two weeks and what will be done in the next two weeks.

At meetings, we often discuss resources, vendor selection, troubleshoot problems with design, and discuss timeline. Early in Phase II, each team is also tasked with negotiating what Version 1.0 will be. For some teams, this is a working prototype, for others, it's a model of the system or key component. A report and presentation on Version 1.0 are due upon the completion of the Fall Semester.

Phase III fills the entire spring semester and consists of the continuation of progress reports and meetings every two weeks and ends with delivery of the Design History File and working prototype to the client and a presentation and vendor fair open to the public.

Clinical partnerships

Partnerships with the College of Medicine at the University of Illinois at Urbana-Champaign as well as College of Medicine at the University of Illinois at Peoria and nearby OSF Saint Francis Medical Center have proven to real world experience to our capstone course. I have been approached by physicians in practice and medical faculty to help address issues seen in practice or in the teaching classroom, such as the upcoming Jumptrading Simulation and Education Center simulation center. Students feel an immediate connection to the projects because they see the patient body in need of a solution. I have found that physicians have many of the "if only 'this' existed" moments throughout their daily tasks and simply bringing those up in conversation with me, no matter how insignificant it seemed to them, was a fast track to innovate design projects. We have had 6 clinical sponsored teams in the past 2 years since we added this group to the mailing list.

Faculty Sponsors

Academic sponsorship of projects has long been the norm until ABET accreditation made the push for more industry involvement in the design process and advisory boards for undergraduate education. Many faculty

members see design as "free research" and jump at the opportunity to fund a project, though, most unsuccessfully. Faculty projects typically cost more than student or physician led projects due to equipment involved in the analysis required for publication or grant review. Projects adapted from grants are also very narrow in scope, the faculty members often already have the plans for the design or very little creative space for the students to explore. Further, faculty interaction with the students is always a bit different than outside sponsors. Students and faculty have pre-defined roles in the university system that design does not easily comply with; it requires back and forth conversations about ideas, a level playing field between design team and sponsor, and allowing failure during the design process. If the student team has had the faculty member throughout the undergraduate education, then the relationship is often complicated due to past history of interaction. I often ask that the faculty have the main point of contact as a postdoctoral assistant or graduate student so that the interaction is more comfortable and more frequent than the faculty-team interaction. We have had # faculty sponsored teams over 4 years.

Discussion

What is the "real world" in Bioengineering? It can take on so many roles, such as hands-on work with equipment through design or repair, cell culture, computer programming, and the newest aspect, consulting for hospitals and device design companies. How can a design experience encompass all of those needs? The best that we can do is to emphasize working effectively on a team and make the project offerings as broad as possible to encompass the majority of career interests. The experiences that I've chosen to highlight are the design process (b, c, e, k), client relationship (d, g, c), effective teams (d, g), presentation and report/lab notebook writing skills (g), and legal/ethical issues (c, f, h, j)⁷. The other ABET criterion are covered through the curriculum and capstone course, but the cited objectives are emphasized. One way that the students are made to respect the emphasis on team work and client relationship is through the grade distribution. Where previously, the peer and client evaluations made up 10% of participation points, the reviews together make up 20% of the semester grade. Reviews are kept confidential, but the instructor will talk to groups who show signs of team problems reflected in comments or ratings, or client disapproval. Through the changes made to the course, students and sponsors have benefitted. Student have benefitted from the decrease in non-project related coursework and increase of emphasis on soft skills. Design sponsors have

benefitted from better project definition upfront, more frequent updates from the team, and overall better experience. The instructor has also benefitted from less paperwork in hand to grade and more positive student evaluation at end of term. We hope that these successes lead to further projects in both the clinical and industrial realm as the department and our resources grow.

References

1. Bransford, J. (2007) Preparing People for Rapidly Changing Environments. *Journal of Engineering Education*, 96(1), 1-3.
2. Regan, T. M., Dally, J. W., Cunniff, P. F, *et al.*(2001), Curriculum-Integrated Engineering Design and Product Realization. *International Journal of Engineering Education*, 17(4), 386-390.
3. Dunsmore,K., Turns,J. & Yellina, J. M. (2011). Looking Toward the Real World: Student Conceptions of Engineering. *Journal of Engineering Education*, 100(2), 329–348.
4. Farr, J., Lee, M., Metro, M., &Sutton, J. (2001). Using a Systematic Engineering Design Process to Conduct Undergraduate Engineering Management Capstone Projects, *Journal of Engineering Education*, 90(2), pp. 193-197.
5. Wulf, W.M., Fisher, G. M. C. (2002). A Makeover for Engineering Education. *Issues in Science & Technology* 18(3), 35-39.
6. Loughry, M. L., Ohland, M. W., & Moore, D. D. (2007). Development of a theory-based Assessment of team member effectiveness. *Educational and Psychological Measurement*, 67, 505–524.
7. Hazelwood, V, Valdevit, A, & Ritter, A. (2010). A Model for a Biomedical Engineering Senior Design Capstone Course, with Assessment Tools to Satisfy ABET “Soft Skills”, *Capstone Design Conference, Boulder, CO*.