Turning Bioengineering Seniors into Successful Engineers through Senior Project
At the University of the Pacific, Stockton, California
Deborah Munro, D.Eng., 2007

Because of new ABET criteria, in response to the demands of industry, Senior Project has become the most important in a bioengineering student's undergraduate curriculum. Seniors come into this course with a strong background in engineering and biology, and yet most have few if any skills to succeed as bioengineers in industry, as they have never applied their education and training to the development of a marketable product. The University of the Pacific has thus integrated a multi-faceted approach to bioengineering senior design, involving industry-sponsored projects, interdisciplinary teams, project management, and marketing. The goal is to provide every graduating bioengineer with a team-based product development experience they can use as a foundation for how products are designed, developed, and marketed to meet a customer's needs. It is the authors' hope that these completed projects will either be continued into production by the industry sponsor or further developed independently by the students.

Goals of Senior Project

At Pacific, the bioengineering Senior Project faculty require that all projects be funded and have an advisor that is independent of the course faculty who is an expert in the field of the project. In the past three years, projects have come from the Long School of Pharmacy, cooperative education employers, local businesses, Industry Advisory Board members, and other engineering faculty. The sponsor of each project writes up a description of the problem to be solved with a description of resources available and "deliverable" expectations. The students then review all the projects and meet with sponsors who are offering projects of interest. Ideally, each team will have two or three students, one or two research advisors, a suitable lab space, and a budget of $800 or more for prototyping, testing, and manufacturing of the finished product.

Other universities have adopted similar strategies to provide projects that involve innovation, entrepreneurship, and clinical and/or industry involvement. At the Florida International University, they formed a "Biomedical Engineering Partnership Program" within its Biomedical Engineering Institute, designed to be an "engine of biomedical innovation and a driver of regional technology". Like Pacific, they are focusing on three equally significant components of commercialization success: academia, industry, and clinical medicine. Academia is their source of innovation and intellectual property, while industry provides product development "know-how", and clinical medicine provides a format for testing and feedback [1]. Another idea, used by the University of Tennessee, Knoxville, is to involve NASA as the source of their projects. In 2002, NASA sponsored two new projects, "Microgravity" and "Lunar Rover Vechicle", both of which allowed students to improve their analytical and design skills while solving real engineering and scientific problems [2]. Pacific's bioengineering program is fortunate to have such a broad cross-section of potential project advisors, ranging from pharmacists to electrical engineers to mechanical engineers, which allows students of diverse educational backgrounds to work together of challenging, multidisciplinary projects. This is also being attempted in the biomedical engineering program at the University of Tennessee,

Knoxville, by involving clinical doctors with senior projects. So far, they have had an orthopedic surgeon, neurosurgeon, and veterinary orthopedic surgeon actively involved in projects such as total knee replacements, cranioplasty implants, and video systems to measure canine stride length [2]. The University of the Pacific has had similar success, with projects such as microfluidic pharmaceutical drug analyzers, bio-chip electrical cell impedance analyzers, water algae quality test equipment, and rear-wheeled walkers for handicapped patients.

Like other schools, Pacific has also formed collaborations with industry and other departments on campus to provide guest lecturers for its Senior Project course. Pacific has focused on core skills, such as database searching, career planning, intellectual property, and entrepreneurship, but has also included guest lectures from various industries, including some of the research project sponsors. This has added great depth to the course, giving students a larger set of "tools" they can then apply directly to their projects, and later in their careers. An affiliation of universities called VanNTH for Vanderbilt University, Northwestern University, University of Texas at Austin, and Harvard/MIT also have a collaboration with Datex-Ohmeda to enhance their biomedical engineering program. Like Pacific, they include Datex-Ohmeda in their senior design curriculum and invent the company to present guest lectures and provide projects for their seniors. Datex-Ohmeda benefits from this exchange by providing input into research projects to improve their quality and by the opportunity to evaluate potential future employees [3].

Team Formation

Forming teams with an essential skill mix while still providing students with the freedom to choose their own teams and projects. The project sponsors also have to choose between multiple teams as well, selecting the one they feel best qualified to complete the work. This is very realistic for the students, as it models entrepreneurship and contract work in industry. Because of the competition, the students try to recruit diversity into their teams, either by selecting members from different career paths offered at Pacific (Bioelectrical, Biomechanical, Biomedical, and Bioinformatics) or by recruiting a student from another major, such as Mechanical or Electrical Engineering. This cross-disciplinary interaction is highly encouraged, and the faculty emphasize that Senior Project is not a course where the students learn new technical skills, but rather where they learn to put into action skills they already have. As Pacific's bioengineering Senior Project is only one semester, the students do not have time to learn new engineering skills, and really need to recruit the skills they do not have in order to be successful. As the other engineering degrees offered at Pacific have their own methods for teaching Senior Project and also have different semesters for participation in Pacific's mandatory cooperative education program, the bioengineering Senior Project course is flexible in terms of recruiting from other majors. The course offers students from other majors undergraduate research units, and they are only required to attend on presentation days.

Early lectures are devoted to team dynamics, choosing a good team, and conflict management, but even so, students always learn things about their teammates that they did not anticipate. Although the faculty will intervene when a student is not contributing

their fair share, they rely on each teams' elected manager to resolve other issues. Never again will the students have the opportunity to choose their teammates, so Senior Project is an excellent opportunity to acquire these skills in a low-risk environment. Le Tourneau University in Canada has also worked at creating interdisciplinary design teams. From their years of attempting this approach, they have learned it is key to provide 1) multiple and varied projects for teams to select among, 2) early involvement of all teams members on the projects, 3) specific training for teamwork, 4) coursework in project management, and 5) various mechanisms to determine the contribution of each team member [4]. Pacific's approach is to attempt to incorporate the teamwork and project management within the course itself, thus Senior Project meets four hours per week.

Teaching Soft Skills

In addition to teamwork and project management, students need an opportunity to practice their soft skills. Some, like project presentation, are easier to implement by requiring all students to participate in the numerous presentations of their project throughout the semester. All presentations must be on Microsoft PowerPoint, and not only is the quality of their research and progress evaluated, but the quality of their presentation as well. Among other project management skills, all teams must maintain a Gantt chart, a budget, and a list of design requirements and design constraints. The current status is included in every presentation. The faculty provide feedback on everything from how the students are dressed (business attire is required) to the visual impact of their graphics. At the end of the course, the students are judged by the Bioengineering Industry Advisory Board for the highly coveted, "Best Bioengineering Senior Project" Award. They also must participate in Senior Project Day and demonstrate their finished project while speaking to a mixed audience from their poster.

But other soft skills, such as ethics and safety, are much more difficult to teach. It is well-studied that students do not learn these skills from a lecture-style "inoculation" approach [5, 6]. To overcome this, Pacific has implemented a discussion-based curriculum that involves the students in decision making. For safety, the faculty begin by talking about medical device failure, drawing from multiple texts, such as "Set Phasers on Stun" and the FDA. This leads to an open discussion of what is important to consider and why. A follow-on lecture then discusses tools available to evaluate safety, both computer-based and fault-tree analysis based. The students receive an assignment to complete at home [7].

Ethics, which can be very dry and is also subject to personal bias, Pacific teaches twice. First, the students all take Ethics in a lower-division separate course. During Senior Project, the students play a game based on Lockheed Martin's board game, "The Ethics Principle". This game plays like "Clue", but the characters travel from business office to business office. In each room, there is a token that the teams need to collect. Pacific's bioengineering Senior Project substitutes the clues provided with the game with ones more relevant to bioengineering, such as animal testing, biohazardous waste, and statistical methods in clinical test design and/or reporting. This game opens up a lively discussion, and the students benefit from hearing what their fellow students believe is ethical.

As engineers, all of these future employees will need to be able to communicate in writing, so the faculty offer ample opportunities to write. Each student must prepare a biweekly status report memo for "management" (the course faculty), which must include what the student was personally responsible for completing, what they actually accomplished, their goals for the next two weeks, and their adherence to the Gantt chart. In addition, the teams prepare a preliminary report and final report. These must include a complete literature review and all works cited in proper format. Usually, the preliminary reports do not follow the guidelines established by the faculty for the mandatory table of contents, introduction, literature review, methods, results, discussion, conclusions, and works cited, but this early grade provides them enough feedback to create excellent final reports.

Finally, working with a customer is an all-important skill. The students meet regularly with their research advisors and project sponsors to make sure they are meeting their project requirements. The research advisor or project sponsor is required to perform the "beta testing" based on a user manual created by the students and provide them feedback on problems, suggestions for improvement, and what features they particularly liked. Whenever a technical issue arises, the faculty direct the students to work directly with their sponsor, but the faculty often help arrange and attend these meetings to make sure the students correctly interpret what they are hearing. Afterwards, the students write up a meeting summary and include it in their notebooks.

Teaching the Basics of Product Development

In order to know if a product is worth commercializing, the students need to fully understand what is already on the market, what is patented, and what "void" their product will fill. Thus, all the teams must submit a literature review and patent search on their project. This is an acquired skill, so at first, the literature and patent reviews are superficial and inaccurate. After instruction by the head librarian, an immensely popular guest lecturer/inventor on patenting, and feedback on their preliminary report, the teams make a second attempt and are often astounded at what is already available for what they thought was an entirely original idea. Many times, the students must then work with their project sponsor to modify their project to provide some novel advantage or enhancement to avoid intellectual property issues in the future [8].

Equally important is market research. Who is going to buy this great new product and why? Often, the students want to base their opinion strictly on what their project sponsors and research advisors tell them, but the faculty for Senior Project require the students to do an internet search for existing solutions to the identified problem as well as why their solution would be better. Brainstorming sessions are included in this process to help the students realize that their *first* solution is not usually the *best* solution.

Prototyping and testing is done early at Pacific, as this is the fastest way to learn which ideas work or are feasible and which are not. Using the philosophy of Ideo, an innovation and product development firm, the students are encouraged to make rapid, inexpensive

prototypes out of found objects and materials, such as paper, wood, wire, Legos, and anything else they can find. Following two lectures on prototyping, the students bring their early prototypes to class for a brief presentation on what they learned. Once the students realize how beneficial prototyping can be and how much data they can collect from the crudest of prototypes, they become proponents of the method and do lots of prototyping and testing. The faculty teach the concepts of "alpha" and "beta" prototypes and what that means, and bring in examples of their own functional prototypes. Pacific has a student machine shop where they can build their own prototypes or enlist the help of the machine shop technician if they do not already have the skills required to use the shop tools. Often, these prototypes are quite good, and become the finished, working projects for the end of the course. Once the prototype is working, usually a month before the end of the course, the students begin to collect their final data for analysis.

Pacific's bioengineering Senior Project course requires all student teams to obtain official customer feedback and sign-off. The project is not considered complete until the project sponsor has accepted it as done. Although stressful, the students learn that some deadlines are non-negotiable, and that they will have to do everything necessary to complete the project by the final day and get the required sign-off, as Pacific does not allow a grade of "incomplete" for Senior Project. If the team has fallen too far behind at any point in the semester, they must present a revised project proposal to their sponsor and get the sponsor's permission to change the deliverable to something more feasible. The sponsors are always willing to do this, but it is yet another learning opportunity for the students.

In order to have a truly successful finished product for the customer, it should be patentable. To ensure that this can be pursued by the customer (or the students if it is a faculty-sponsored project), each student must maintain a correctly formatted project notebook. These notebooks must be bound with numbered pages and are graded biweekly for adherence to legal guidelines, such as all pages being signed and dated in ink, a table of contents, completeness of content showing due diligence towards a solution, and all data. These notebooks are a required part of any new product development in industry and can be used during patent disputes to show date of idea conception. Most engineers are notoriously bad about maintaining their design notebooks and design technical files, so the faculty felt it is an important skill to begin practicing early.

Encouraging Project Continuation

It is the goal of Pacific's bioengineering Senior Project course to have all projects continued after graduation in some fashion. Whether this be publication of results in a technical journal or product development to the next level with the project sponsor, the faculty want the students to become involved with entrepreneurship and lifelong learning. Engineers that read technical literature and benefit from the knowledge gained are more likely to contribute that body of knowledge themselves from their own research. As of yet, publishing is not required for Senior Project, but the faculty are considering making this a part of the course. Even if it is ultimately not published, going through the process of trying is worthwhile.

Ultimately, the success of the University of the Pacific's Bioengineering Senior Project is tied to the success of its graduates. So far, graduates of the program have provided positive feedback on their experience and what they learned from the process. Graduates have gone onto graduate school at top-tier research universities, obtained employment in research labs, and are working throughout the United States as successfully employed bioengineers.

1. Amit, O., Richard Schoephoerster, Alan Carsrud, Vish Prasad *The Biomedical Engineering Partnership Program: An Integrated Educational Approach to Biomedical Innovation and Entrepreneurship,* in *2004 ASEE Annual Conference & Exposition: Engineering Education Reaches New Heights*. 2004, ASEE: Salt Lake City, UT.
2. Parang, M., Viatcheslav Naoumov, Lawrence Taylor, *Challenging Projects in Aerospace and Mechanical Engineering Senior Capstone Design Experience,* in *45th AIAA Aerospace Sciences Meeting and Exhibit*. 2007, AIAA: Reno, NV.
3. Fries, R.C., *An industry perspective on senior biomedical engineering design courses.* IEEE Engineering in Medicine and Biology Magazine, 2003. **22**(4): p. 111-113.
4. Leiffer, P., Roger Gonzalez, Thomas Helhnuth *Interdisciplinary Teams: Lessons Learned From Experience*, in *2006 ASEE Annual Conference & Exposition: Excellence in Education*. 2006, ASEE: Chicago, IL.
5. Benkeser, P., Wendy Newstetter, *Integrating soft skills in a BME curriculum,* in *ASEE 2004 Annual Conference and Exposition, "Engineering Researchs' New Heights"*. 2004, ASEE: Salt Lake City, UT.
6. Goldberg, J.R., *Changing student attitudes, perceptions, and awareness.* IEEE Engineering in Medicine and Biology Magazine, 2005. **24**(4): p. 15-17.
7. King, P.H., Wayne C Christensen, *Teaching Safety Through Design In Biomedical Engineering Design*, in *2002 ASEE Annual Conference & Exposition: Vive L'ingenieur!* 2002, ASEE: Montreal Canada.
8. Goldberg, J., *Intellectual property and confidentiality issues in senior design courses.* IEEE Engineering in Medicine and Biology Magazine, 2004. **23**(6): p. 16-18.