2007: Redesign of a Senior Capstone Design Experience: A Flexible Model for Continuous Improvement

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Abstract

In the 2005-2006 academic year, the Mechanical Engineering Department at California Polytechnic State University, San Luis Obispo initiated a redesigned capstone experience to serve an average of 180+ graduates each year who solve 70+ different "externally" supplied problems with functioning hardware. Prior to that time, the department required two separate senior design experiences. The first was an industry sponsored design class that lasted one quarter and resulted in a "paper" design solution to the given problem. The second experience involved an individual student initiated project that required a design, build and test regimen that nominally lasted two quarters. In an effort to improve graduation rates and student learning, to address ABET review concerns and to reduce faculty workload, these experiences were combined into a single project-based, team learning experience. Results from the first year indicate an approximate doubling of project completion rates and a significant decrease in faculty workload with no sacrifice of student learning or project quality. A major requirement of the course redesign was to incorporate sufficient flexibility for modification and continuous improvement. This paper describes the course structure, the student learning objectives, the attainment and organization of the externally sponsored projects, the organization of the involved instructors and the assessment of student learning and performance. Also described is how the flexible course structure allows the incorporation of multidisciplinary, service, sustainable, entrepreneurial, global and undergraduate research based design projects. Recommendations and requirements for implementing this type of program as well as plans for future improvement and expansion to include the entire college of engineering are given.

Background

California Polytechnic State University – San Luis Obispo (Cal Poly) founded in 1903 is one of 23 campuses of the California State University (CSU) System. Cal Poly is primarily an undergraduate institution with approximately 18,500 enrolled undergraduates and 1180 faculty. 5000 students are enrolled in the College of Engineering which is comprised of nine departments. The largest department, Mechanical Engineering, has approximately 1000 undergraduates, 40 Masters students and 23 full time tenure and tenure track faculty. The department awards about 180 undergraduate degrees each year.

University-Wide Senior Project

All students at Cal Poly are required to complete a Senior Project. This requirement was born out of Cal Poly's roots over 100 years ago as a Vocational High School.[1] The educational philosophy has not strayed from the fundamental value of "hands-on," kinesthetic learning and Cal Poly's motto of "Learn by Doing". Cal Poly's university-wide requirements for Senior Project stipulate that it be "a capstone experience that integrates theory and application from across the undergraduate educational experiences."[2] The experience must fall in one or more of the following categories:

- a design or construction experience,
- an experiment,
- a self-guided study or research project,
- a presentation,
- a report based on internship, co-op, or service learning experience, and/or
- a public portfolio display or performance.

Further requirements allow for group projects; however, "…the number of students participating in a group senior project should not be so large as to unduly limit individual experience or responsibility and initiative." Final requirements for all senior projects include a written report that is archived in the University's library. Each department must design their students Senior Project experience within this framework.

For over 40 years and up until the spring of 2005, the Mechanical Engineering department's requirements for Senior Project included a five-unit experience over two quarters involving the design, build and test of hardware to solve a need of the students choosing. The students worked under the direct supervision of a faculty member. Students were expected to find an advisor among the faculty during the last year of school to complete the project. There was no classroom/laboratory structure and the vast majority of projects were individual effort. During the first quarter the student derived functional requirements and designed a solution to their problem which included engineering drawings. During the second quarter the student built and tested their design and wrote a detailed Senior Project Report. Students followed strict guidelines concerning reporting and all wrote a Senior Project Report. Projects varied widely in scope and quality depending on the level of student and faculty skill and motivation.

Mechanical Engineering Senior Design

In the 1980's, the Mechanical Engineering department recognized that fundamental ideas concerning design process, new design methods, current industrial practice and teaming were not being adequately addressed in the curriculum. To rectify the missing experiences, a new course was added titled "Senior Design." This class involved teams of students designing a solution to an industry supplied problem. This four unit course was taken during the student's last year. The course length was one quarter and students met with the instructor four times each week; twice for 50-minute lectures (36 students each) and twice for 3-hr lab sessions (18 students each). Lecture topics included problem definition, QFD, design process, project management, idea generation and creativity, idea selection, economic decision making, advanced analysis and other design related subjects. During the laboratory sessions, the students applied the various techniques to their industrial sponsored projects. Teams of three students tackled each project. Various reporting was required and a final design report was prepared for the sponsor. Finally, a formal design presentation and review was given at the sponsor's site. Although little hardware was constructed due to the time constraints, the students were encouraged to build models or prototypes to prove some aspect of their design.

Broader Mechanical Engineering Design Curriculum

The Mechanical Engineering curriculum at Cal Poly is laboratory intensive with design experiences in every year. Incoming freshmen take an exploratory course consisting of a weekly laboratory that introduces them to Mechanical Engineering. During the course the students explore their creativity by designing and building a solution to an open-ended design project. Freshmen also take three courses in graphic communication including hand drawing, CAD drawing and solid modeling. During the sophomore year, students take a three unit course focusing on need finding and the creative process. During the third year, students take two courses in mechanical design. The first focuses on designing for strength and stiffness and the second on the design and selection of machine components to build mechanical systems. Each of these courses have a weekly three hour laboratory meeting where students work on open-ended design projects, many involving the construction of hardware. Outside of the formal curriculum, the mechanical engineering department supports a plethora of clubs engaged in the design and construction activities. These include SAE formula, SAE Baja, ASME Human Powered Vehicle, a Supermileage vehicle, a Robotics Club and a Hybrid Vehicle Club that is building a hydraulic hybrid SUV.

Build it Culture

Cal Poly's Mechanical Engineering Department advocates an experiential, "hands-on" approach to engineering education. Incoming students during their freshman laboratory are introduced to the importance of building and testing what they design. This design and build culture at Cal Poly is also supported by early laboratory experiences involving basic fabrication processes (welding, machining, casting, etc.). In order to support student projects, the Mechanical Engineering department has a 7000 ft^2 student shop including assembly and storage space. No classes are run in the facility; its sole purpose is to support student projects. This Student Projects Laboratory (SPL) is housed in an old aircraft hangar and is run by a department employed technician. Student assistants are hired to run the shop and promote safety. All machines are exclusively for student work and the facility is available to anyone on campus. Figures 1-3 show the shop populated by students working on projects. The shop contains cutting and welding equipment, woodworking equipment, and metal machining equipment. Currently the shop area can support sixty students while outside the shop another 40 can be working on assembly and testing activities. In the fall of 2006, a new resource was added for student project work. The Cal Poly College of Engineering dedicated the new 19,000 ft^2 Bonderson Student Projects Center (see Figure 4). This building is available for use by students working on senior projects, especially those that are multidisciplinary in nature. The building will contain approximately 3000 ft^2 of space for fabrication and machining.

Figure 1: Overview of the Student Projects Laboratory

Figure 2: View of the Student Projects Laboratory Assembly Area

Figure 3: Woodshop and Student Assistant Offices

Figure 4: New Bonderson Student Projects Center

Motivations for Changing the Capstone Experience

During an Accreditation Board for Engineering and Technology (ABET) review in 2002, auditors noted a lack of consistency in the quality and scope of Senior Project outcomes for Mechanical Engineering students. They also noted the redundancy in requiring both the Senior Project and the Senior Design experiences. Internally, the faculty noted that less than one third of senior projects were completed in two quarters and was the main cause of graduation delays. In many cases students never completed their degrees only due to the lack of a completed Senior Project (similar to the “all but dissertation” problem with graduate students). Another department issue was the lack of advisors for the growing student population. In 1996, the Mechanical Engineering Department had approximately 800 undergraduates and 23 full time tenure and tenure track faculty. This amounted to approximately six senior projects per faculty member per year. In 2004, the undergraduate population had grown to 1100 undergraduates which amounted to nine senior projects per faculty. Furthermore, the Senior Project workload was not distributed evenly among faculty. Younger faculty and design faculty were advising a disproportionate number of senior projects. Finally the overall program’s teaching demands did not allow for any work credit given to faculty for the supervision of senior projects. Faculty were expected to take on more and more senior projects without any release from other job functions. A more general requirement for curricular change was necessary to better meet ABET criteria for the 2008 review and to meet new University-wide learning objectives with regards to sustainability and global awareness. A final push to change the curriculum came from a College-wide mandate to reduce times to graduation through a unit reduction.

Designing a New Senior Project

Starting in the 2003 academic year, the faculty began the process of designing a new senior capstone project experience that remained true to the University's traditions and would better prepare students for their future careers. A committee of faculty who teach design courses met over the next year and half and developed a plan for the new experience. Data gathering included reading relevant literature and the exploration of capstone design programs at other institutions (notable influence came from programs at Harvey Mudd, Michigan Technological University, Penn State University and Stanford's Masters level Design class). Several surveys of typical topics covered in capstone design courses are good reference as well[4,5]. Constraints were placed on the unit count equaling the old Senior Project count of five units to meet the new College unit requirements. This experience would replace the Senior Project and Senior Design courses thereby lowering the unit count to graduation. It became clear early on that changes throughout the Mechanical Engineering curriculum would be necessary to improve student outcomes. These included course structural changes and content to make an integrated design experience for undergraduates. The changes have resulted in the pre-senior curriculum as outlined earlier under the heading: *Broader Mechanical Engineering Design Curriculum.*

For the new capstone course, the faculty adamantly wanted to maintain the design, build and test components of the traditional Senior Project and promote Cal Poly's "Learn by Doing" motto. Since the new course would be considered the student's Senior Project, institutional requirements would need to be met as well. These constraints would require an open-ended design project that integrated student learning from across the entire undergraduate experience. Also, the new course would have to contain some topics included in the Senior Design class while other topics would need to be moved elsewhere in the curriculum as noted above. Less certain was the faculty in how to proceed with the type and duration of the project and whether the experience should be individual or team-based. This second being a polarizing issue for both students and faculty. In the end, ABET requirements concerning teamwork outcomes as well as faculty workload concerns tilted the scale towards team based. University requirements would require these teams to be "small" in size. Other goals included giving students academic credit for club activities, improving student retention, improving time to graduation and better meeting ABET a-k objectives. The committee also needed a course structure that could support change and continuous improvement.

Course Structure

The new Cal Poly Mechanical Engineering Capstone design experience, Senior Design Project, was launched in the fall of 2005. Students are required to commit to a two quarter sequence. The course is offered in the fall/winter and again in the winter/spring. During the first quarter, students meet for one lecture on Monday for each week of the 10 week quarter. This is a large lecture setting with approximately 90 students. Students then meet for two, three hour lab sections each week. These lab sections contain approximately 18 students each and are overseen by a faculty advisor. Students are organized so that all design team members are in the same lab section with the same advisor for the two quarters. During the second quarter, there is no lecture component and student teams continue of their project and meet with their advisor weekly by arrangement.

Faculty Workload

At Cal Poly, a full time teaching load consists of 12 teaching units each quarter. For each offering of Senior Design Project, one faculty member is assigned the course organization task. They are responsible for finding the projects, organizing the students into teams, giving the weekly lecture and organizing the participating faculty members who are advisors/lab instructors (perhaps the most difficult task!). There are typically five lab sections offered. The course coordination task gives the faculty member four teaching units. A lab section advisor is given four teaching units per laboratory section. It is possible to divide or team-teach laboratory sections which give faculty a scaled amount of teaching units depending on the number of students and projects advised. A full teaching load of Senior Design Project for the course organizer would consist of the lecture and advising two lab sections (approximately 12 projects). During the second quarter, faculty members are given four teaching unit credits for each lab section. There have been between 4 and 5 instructors participating in the experience for each running of the class.

Lecture and Laboratory Content

The first quarter of Senior Design project is dedicated to design activities, including problem definition, conceptualization, making decisions, detail design and analysis. The second quarter focuses on construction and testing of the design. Of the ten weekly lectures for the first quarter, the first and the last do not cover any specific design content and are used for organizational purposes. The other eight lectures are devoted to design process and specific design methodologies at the discretion of the course organizers. Further content is delivered to and practiced by the students during the first laboratory meeting each week of the first quarter. These experiences typically involve a short presentation of material and then an exercise directly applied to the project. As and example, the students are expected to develop a QFD house of quality for their project while determining a detailed design specification. This laboratory period starts with a 45 minute lecture on QFD along with a handout describing the process. Then for the remaining two hours the students develop a House of Quality with their teammates. The faculty advisor is available to answer questions and assist with the process. A finalized version is expected as part of the student's Project Proposal. The second weekly laboratory meeting is dedicated to individual team and advisor meetings run with agendas and minutes by the students. A typical schedule for lecture and laboratory content is given in Table 1.

Table 1. Typical Lecture and Laboratory Content and Deliverables for the First quarter of Senior Design Project

WEEK	DATE	LECTURE TOPIC	Deliverables
1	Lecture Tues. Lab Thurs. Lab	**Course Introduction** Project Presentations by Sponsors Project Presentations by Sponsors	 HW#1 Project Preference Form 5:00pm
2	Lecture Tues. Lab Thurs. Lab	**Design Process and Methodology** Requirements and Specifications Team Meeting with Advisor	 **Introduction Letter to Sponsor** **Agenda/Minutes**
3	Lecture Tues. Lab Thurs. Lab	**Project Management** QFD – House of Quality Team Meeting with Advisor	 **Agenda/Minutes**
4	Lecture Tues. Lab Thurs. Lab	**Creativity and Idea Generation** Teaming Team Meeting with Advisor	HW#2 Project Schedule Due **Project Proposal Due** **Agenda/Minutes**
5	Lecture Tues. Lab Thurs. Lab	**Idea Selection/Decision Schemes** Concurrent Engineering Team Meeting with Advisor	 **Design Logbook Review** **Agenda/Minutes**
6	Lecture Tues. Lab Thurs. Lab	**Design for Sustainability** Detailed Design/Layouts/BOM Analysis Team Meeting with Advisor	HW#3 Decision Matrix Due **Interim Design Report to Sponsor** **Agenda/Minutes**
7	Lecture Tues. Lab Thurs. Lab	**Failure Modes and Effects Analysis** Design Verification/Test Plans Team Meeting with Advisor	 **Agenda/Minutes**
8	Lecture Tues. Lab Thurs. Lab	**Design for Manufacturability** Technical Reports and Presentations Team Meeting with Advisor	 **Agenda/Minutes**
9	Lecture Tues. Lab Thurs. Lab	**Taguchi Methods/Design of Experiments** Design Presentations Design Presentations	 **Agenda/Minutes**
10	Lecture Tues. Lab Thurs. Lab	**Discussion Review, Next Quarter Planning** Presentations at Sponsor's Site Presentations at Sponsor's Site	 **Design Report Due** **Design Logbook Review**
11		**No Final Exam**	

Course Deliverables

A common set of deliverables are required for all students and teams in the class. In the first quarter these include a few homework assignments to reinforce lecture material as an individual exercise. Each student is also required to document their individual process and work with a design logbook. This is reviewed by faculty advisors twice during the quarter at a minimum. Students are also evaluated on their individual participation in laboratory and lecture. Team deliverables include a formal Project Proposal, an Interim Design Report and a Final Design Report, all reviewed by the advisor and the external sponsor. The first quarter ends with a design presentation in the form of a critical design review at the project sponsor's site. Student grades are based on 25% individual and 75% team activities. The second quarter begins with the students making any necessary design changes to address sponsor concerns and moves quickly to building and testing the hardware. A final hardware presentation is made at the "Senior Design Expo" poster session (See Figures 5-7). During this second quarter student teams meet with their advisor weekly and other times by arrangement. There are no formal class or laboratory meetings for this quarter.


Figure 5: Winter 2007 – Senior Design Expo


Figure 6: Winter 2007 – Senior Design Expo in Bonderson Projects Center

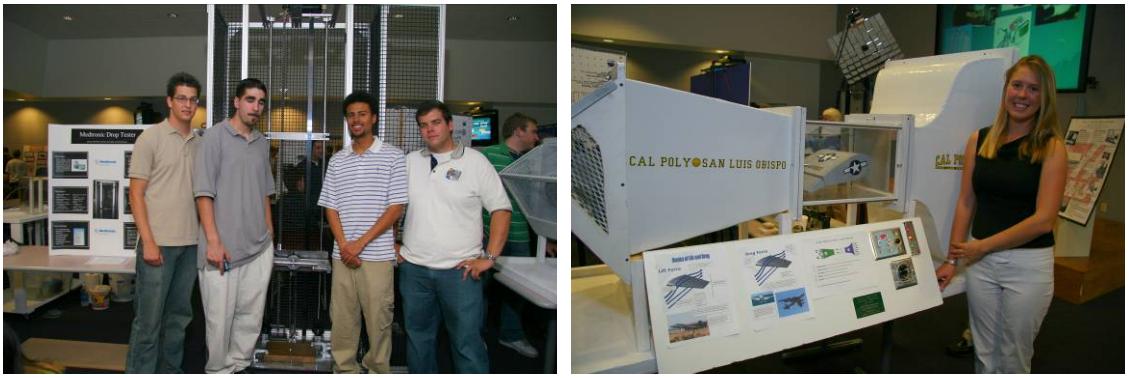

Figure 7: Spring 2006 – Senior Design Expo – Typical Hardware Build out

Obtaining the Projects

One of the unique challenges of running a small group capstone design course is obtaining an adequate number of properly scoped design projects. Critical to the capstone experience is the presence of an external "customer." Self-sponsored projects are also not allowed. By this, students learn how to communicate, generate functional requirements and follow through on stated deliverables to a client. Also having an external customer validates the project as "real" in the minds of the students, not merely an academic exercise. Note also that basic research projects often do not allow for adequate exploration of the design process and generally do not make good Senior Design Projects. Design projects that center on necessary hardware to perform research (such as test equipment) are entirely appropriate. To allow those undergraduates and faculty who also like to pursue more academic or applied research, the department has changed its curriculum to allow an independent study course to substitute for a technical elective credit. All undergraduates must take the capstone course.

Each time Senior Design Project is offered at Cal Poly, there are approximately 90 students. In order to satisfy the University learning objectives of small senior project group sizes, the faculty of the Mechanical Engineering department tries to maintain project team size of 3 students, thus the class requires approximately 30 projects. Some adjustments are necessary depending on the scope of projects and teams from 2-5 students are considered. An exception was made during the first year of the course offering for students who proposed an individual project of their own choosing. These students had been planning for their projects throughout their academic career and were allowed an exception.   During the first two years, the Capstone students have undertaken 133 different projects. Table 2 contains the breakdown of the various sources of the projects.

Table 2: Projects and types per year

	2005/2006	2006/2007	Totals
Industrially Sponsored	30	41	71
On-Campus Research Support	9	7	16
Student Club Support	14	6	20
Service Related	2	6	8
Individual Student Proposed	17	1	18
Totals	**72**	**61**	**133**

Obtaining the projects is the responsibility of the course organizer. This task must be completed prior to the beginning of the quarter. The time and effort required obtaining and organizing the projects and sponsors should not be underestimated. Cal Poly was fortunate to already have an industrial sponsored project course in place prior to inauguration of the new Capstone experience. Some existing sponsors were able to continue sponsoring projects under the new system while others could not. Tracking of the time required to obtain the projects for the most recent Capstone offering indicated a requirement of approximately 160 hours of faculty time. This included contacting sponsors, travel and editing project proposals. Individuals should expect the project identification time to be far greater when starting a new program. The usual sources include recent alumni employed in industry, faculty requiring hardware to support research, service related projects, entrepreneurs, student clubs and competitions and student identified projects with an external customer. Those students proposing their own product design projects, must do market surveys and find potential business or venture capital partners prior to project acceptance.

Another obligation of the course organizer is the appropriate scoping of projects. Two ideas must be made clear to sponsors. First, the scope must be appropriate for undergraduates to complete in the two quarters. Second, the sponsor cannot expect delivery industrial quality hardware. The program has been a huge success so far in providing many working prototypes, some of which are used in production environments, testing laboratories, museums, by student clubs, to support research and help disabled individuals. This success is due to the aforementioned “build it” culture prevalent in the department. Cal Poly students are highly motivated to produce working hardware that satisfies the design requirements. Despite excellent intentions, the class makes no guarantees of success. The experience is intended as a learning experience first. Regardless of hardware outcomes, sponsors do receive a complete set of documentation which is an invaluable starting point for further product/hardware development.

Sponsor Obligations

Sponsors wishing to have students work on their problems are obliged to pay a nominal fee ($1000) per project. This fee is routinely waived for clubs, on-campus sponsors, service-related projects and for those sponsors who are unable or unwilling to pay. Fees collected pay for student travel, the Senior Design Expo and are leveraged to fund the construction of many of the service-related projects. Sponsors must travel to campus during the first week of classes to give a short presentation concerning their problems. From short written descriptions and these presentations, students submit a project preference form indicating which projects they would like to work on. Sponsors are obligated to pay for all materials related to the building and testing of the hardware intended to solve their problem. Sponsors are advised by the course organizer of the estimated materials cost prior to the start of the project. Sponsors also are obligated to respond to student questions and written reports in a timely manner and host the students for a formal design review at the end of the first quarter. Sponsors are viewed as partners in the educational process as well as partners in the success of the project.

Intellectual Property and Non-Disclosure Agreements

Sponsors wishing to protect any Intellectual Property (IP) that might be generated from the projects must state so at the beginning of the class. Since any work products are a result of an undergraduate course, Cal Poly makes no claim to IP. Students and faculty are informed during the project presentations that certain projects will require them to sign IP and Non-Disclosure Agreements (NDAs). If the student does not want to sign, then they are placed on a different project. The course has developed its own standard IP agreement or the industry sponsors may provide their own for the students to sign.

ABET Outcomes and Assessment

Some content and experiences in the Capstone Design Course are required to ensure students demonstrate certain abilities as outlined in the Criterion 3 of the ABET a-k outcomes. Many requirements of Criterion 4 are also addressed by the Capstone Course. Specifically, the Mechanical Engineering program relies in some part on the capstone design course to provide students with instruction, application, and feedback with respect to criteria a-d, g, i and k[5]. For other outcomes, students may receive experience depending on the nature of their project. The following briefly outlines how these outcomes are practiced and sometimes assessed. In order to satisfy the accreditation requirements, the Mechanical Engineering graduates must have:

a) an ability to apply knowledge of mathematics, science and engineering

Students are required to appropriately analyze their designs both at a conceptual and detail level to adequately predict that their designs will meet the required specifications prior to construction. The student's application of basic engineering is evaluated by faculty advisors and more importantly by sponsors, many of whom have teams of engineers who evaluate their designs at a critical design review at the end of the first quarter. Assessment is done through surveys of sponsors. Students self assess their work when they build their hardware and experimentally verify (when possible) their analysis.

b) an ability to design and conduct experiments, as well as to analyze and interpret data.

All students in this hardware oriented program must build and test their designs. A formal design verification plan must be formulated and approved by the faculty advisor to test physical hardware against the design specifications. Students are responsible for conducting their own testing (whenever possible) or write detailed test plans if others do the physical work. No formal assessment of the Senior Design Project generating this outcome is currently in place.

c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

The capstone experience clearly gives the students instruction and practice in order to attain this outcome. In many ways the students are asked to self-assess their ability through the construction and testing of hardware. Ultimate acceptance is in the hands of the external sponsor. Assessment of student's ability to design is done through the critical design review process by both faculty and the external sponsor. Further external assessment is accomplished by giving copies of final reports to the Mechanical Engineering Departments Industrial Advisory Board (IAB). The IAB members grade the reports on a rubric. The board meets each fall and spring and completes the assessment as an on going effort.

d) an ability to function on multi-disciplinary teams.

The capstone course requires the students to work for 20-weeks on a team of students. Teaming skills are presented and emphasized to the students along with teaming activities. See the section on on-going improvements for a discussion of multi-disciplinary options. No formal measure for the course is in place at this time.

g) the ability to communicate effectively.

Students are required to practice both written and oral communication skills throughout the course with feedback from both the faculty and the external sponsors. Assessment of oral communication skills for ABET is done through a formal rubric from the sponsors during the critical design review.

i) a recognition of the need for, and an ability to engage in life-long learning

The students universally face the difficulty of engineering a solution to a problem for which they don't know enough about. Consequently the students experience the need to do thorough research and learn about new concepts and techniques. Although the students are forced to learn as they go, there is currently no formal assessment of these skills taken in the course.

Whole Program Assessment

Due to its integrative nature and its offering during the students last year of study, Senior Design Project was selected by the department to use as a platform for assessment of many ABET outcomes. Two instruments are used. The first is a "Senior Exit Assessment." This is essentially an exam which is given during the second quarter of the class. The exam is assembled and administered by the departments ABET coordinator and seeks to assess student outcomes of a variety of ABET criteria. All students must take the assessment in order to graduate. To give the student incentive and to take the assessment seriously, the score on the exam counts 15% of the students mark for the quarter. The second measure is the Senior Exit Survey given to students near the end of the class. Results of these will be presented during the Mechanical Engineering Department's next ABET review.

Continuous Improvement

Since the successful implementation of the new Senior Design Project, improvements have been made. During each spring quarter, faculty members who participate in the Capstone experience meet and plan for enhancements. For the first year, these included better teaming instruction, the addition of a sustainability component, multidisciplinary project teams, more service-learning projects, stricter requirements for design verification and the addition of a global partner.

Teaming

After the first year it became apparent that the students need more team-work skills. A lab period dedicated to basic team skills along with team check up surveys has been added to the class on an experimental basis and will be adopted for all sections in the upcoming year. The challenge to keep students on a functioning team for twenty weeks cannot be understated. Formal team training and team self-assessment techniques will be published in a new laboratory manual for the class.

Multidisciplinary Project Teams

The new Senior Project model initiated by the Mechanical Engineering department has gained attention across the College of Engineering. Other departments are having similar problems with the older individual senior project model. Departments that treat their senior project as a Capstone Design experience have expressed interest in joining the Mechanical Engineering Department's program. On a trial basis during this past year, students from Electrical Engineering and Computer Engineering were allowed to substitute the Mechanical Engineering Capstone class for their department's senior project. Multidisciplinary projects were not difficult to obtain and six projects had multidisciplinary teams during the 2006/2007 academic year. Expansion of the program will continue depending on curricular changes in the other departments. Students outside the college are being sought for various projects for the fall of 2007. Students who participate on the teams must attend the class, are mutually accountable for deliverables and included in the grading. No predefined role on the team is enforced for students in other disciplines.

Service-Learning

Service based design projects have been very successful and students report a high level of satisfaction with their work. Opportunities exist for the fall in having one lab-section entirely devoted to service-learning projects. The requirements would not differ from other sections. One key to their success is having the ability to leverage funds from the project sponsorship fee. Note that service learning projects must be centered on problems requiring hardware solutions. Need-finding is not included in the course due to time constraints. This task is the responsibility of the project sponsor.

Global Design Teams

A partnership with the Munich University of Applied Sciences (FHM) was forged in 2005. During the 2006/2007 academic year, student project teams from Cal Poly and FHM worked in parallel on a design project in order to assess the feasibility of incorporating students from both universities in the design class. Funding for the study was provided by the Bavarian California Technical Exchange (BACATEC). Results of this study have led to the inclusion of globally-based design team projects for the fall of 2007. For these projects, teams will be comprised of two students from each school, mutually accountable for the project results. Project sponsors will be from Germany and the U.S. and five projects (20 students) are planned for the fall of 2007.

Future Plans

It is anticipated that the interest across the College will continue to grow in the Mechanical Engineering's Senior Design Project. To accommodate more students will require more faculty support from participating departments. These departments would provide projects and faculty based on number of students involved. For example, if 18 electrical engineering students enroll in the class, the Electrical Engineering department must provide for one faculty member teaching a lab section and six projects. The students would then be mixed into projects based on their preferences as any other student in the class. Full scale implementation will depend on the speed with which other departments can implement curricular changes to allow students to make the substitution. The international component is expected to grow and partner universities in both Asia and South America are being sought for the 2008/2009 academic year. Other improvements will be the inclusion of a course reader (to be compiled in the summer of 2007) and the establishment of standardized grading rubrics for reports and presentations. Formalized assessment procedures for all desired outcomes expected of the course are currently under development and will be in place in the fall of 2007.

Conclusions and Recommendations

The new Senior Design Project capstone course in Mechanical Engineering at Cal Poly has been extremely successful during its first two years of operation. The course integrates experiences across the student's undergraduate education and gives them practice in solving real-world problems. Cal Poly's motto of "Learn by Doing" is emphasized in the hardware oriented approach to design by including building and testing. On-time completion rates from the first year were greater than 90% compared to lower than 33% for the old Senior Project. For most faculty members in Mechanical Engineering, workload has decreased since they do not need to support individual Senior Projects. This frees many faculty to devote more time to advising undergraduate and graduate research projects. Teaching credit is now given to those participating in the class. Workload for those who teach the class is considered high at this point and is currently under review. The course structure allows for more focus on team discipline skills and the lab format allows for better experiential learning of design techniques by having supervised implementation. A continuous improvement environment is established among the faculty and has been successful for implementing changes. All students have the same required deliverables, yet there is plenty of opportunity during the lab portion for individual faculty to convey material in their own format and style. Overall this change took the efforts of a half-dozen dedicated faculty whose fundamental educational philosophy is that students learn best in experiential, active-learning environments.

True to the Cal Poly philosophy of "Learn by Doing", those who would start a truly experiential capstone design course must have student shop facilities for product realization along with the expectation that students actively participate in the manufacturing process. For Cal Poly, the existence of a vibrant, "just build-it" environment created by the existing Student Project Laboratory was essential. Unfortunately the formalization of project construction has at times overwhelmed even our large student shop. The new Bonderson Projects laboratory will alleviate this overcrowding. The time commitment required to create and organize (especially the faculty) the course can not be overestimated. In addition to time, those seeking to start a program should also have available funding to travel and observe benchmark institutions. A strong program will require the involvement of many faculty members who are unified in their expectations and diverse in their approach. To accomplish this, faculty members must be willing to work together in a consensus building environment to generate a course structure and common set of deliverables. All participants must understand that a capstone design project has significant differences from an undergraduate research project.

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