AC 2008-2729: ENHANCEMENT OF CAPSTONE INDUSTRY SPONSORED SENIOR PROJECTS THROUGH TEAM-BASED, PRODUCT REALIZATION ACTIVITIES

James Widmann, California Polytechnic State University
Jim Widmann is an Associate Professor of Mechanical Engineering at California Polytechnic State University, San Luis Obispo. He received his Ph.D. in 1994 from Stanford University. Currently he teaches mechanics and design courses. He conducts research in the areas of design optimization, machine design, fluid power control and engineering education.
Enhancement of Capstone Industry Sponsored Senior Projects
Through Team-Based, Product Realization Activities

Abstract

Senior capstone design courses are critical components of undergraduate education and satisfy many requirements set forth by the Accreditation Board for Engineering and Technology (ABET). In 2005, the faculty in the Mechanical Engineering Department at California Polytechnic State University, San Luis Obispo, enhanced their capstone senior design and senior project experiences of their mechanical engineering students by developing a new industry-sponsored, Project-Based Learning course. Previously, students undertook individual senior projects of their own choosing as well as a one quarter industry sponsored course that resulted in a paper design. In this new two quarter senior project experience, small groups of students work together in teams on real-world, externally sponsored projects that result in testable hardware. During the first quarter, students working in teams design a new product, process, or system. During the second quarter, the students build and test their design. The students go from design to product and in the process complete their capstone experience. This new approach allows for the complete engineering process to be pursued.

This new hardware intensive capstone experience must support approximately 190 undergraduates each year. Hardware construction is supported by an extensive Mechanical Engineering Student Projects Center and a newly built, college-wide Bonderson Engineering Projects Center. Both facilities are dedicated to Project Based Learning. The new facility will serve as design and fabrication space to encourage multidisciplinary industry sponsored projects. The intent of the curriculum change is give graduating engineers a better understanding of engineering practice. This capstone model is currently being adopted by the entire college to support Multidisciplinary Project-Based Learning. This paper provides a description of the curriculum change, the necessary logistical support and the methodology of assessing student outcomes.

Background

California Polytechnic State University – San Luis Obispo (Cal Poly) was founded in 1903 and is one of 23 campuses of the California State University (CSU) System. Cal Poly is primarily an undergraduate institution with approximately 19,500 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 190 undergraduate degrees each year.

University-Wide Senior Project
All students at Cal Poly are required to complete a Senior Project\(^1\). 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 under the direct supervision of a faculty member. Later, 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. In 2004, it was decided that these two experiences should be combined into a new Senior Design Project course described here.

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, 20 week 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 90-100 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 work on their project and meet with their advisor weekly.

The first quarter of Senior Design project is dedicated to design activities, including problem definition, conceptualization, decision making, detail design and analysis. The second quarter focuses on construction and testing of the design. Topics covered in lecture or labs are listed in Table 1. For a survey of typical capstone content see Eggert. More detailed information on this course structure and organization is provided by Widmann and Mello.

Table 1. Lecture and Laboratory Content

<table>
<thead>
<tr>
<th>Lecture</th>
<th>Laboratory</th>
<th>Deliverables</th>
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<tbody>
<tr>
<td>Design Process and Methodology</td>
<td>Requirements/Specifications</td>
<td>Design Logbooks</td>
</tr>
<tr>
<td>Project Management</td>
<td>QFD – House of Quality</td>
<td>Requirements Document</td>
</tr>
<tr>
<td>Teaming: Theory, Skills, and Practice</td>
<td>Teaming Exercises</td>
<td>Interim Report</td>
</tr>
<tr>
<td>Creativity and Idea Generation</td>
<td>Concurrent Engineering</td>
<td>Design Report</td>
</tr>
<tr>
<td>Idea Selection/Decision Schemes</td>
<td>Drawings/Layouts/Analysis/Economics</td>
<td>Critical Design Review</td>
</tr>
<tr>
<td>Design for Sustainability</td>
<td>Design Verification/Test Plans</td>
<td>Manufacturing and Test Review</td>
</tr>
<tr>
<td>Design for Safety</td>
<td>Technical Reports</td>
<td>Senior Design Expo</td>
</tr>
<tr>
<td>Design for Manufacturability</td>
<td>Presentation Skills</td>
<td>Final Project Report</td>
</tr>
<tr>
<td>TQM</td>
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Continuous Improvement

The new capstone model created at Cal Poly is considered a working template that is subject to continuous improvement efforts. The flexible model allows for changes based on the entire program learning outcomes (see section on Assessment). Since the successful implementation of the new Senior Design Project, improvements have been implemented. Each spring, faculty members who participate in the Capstone experience meet and plan for enhancements. Information from the previous year assessment is used to guide these changes. So far significant improvements include better teaming instruction, the addition of a sustainability component, multidisciplinary project teams, an increase in service-learning projects, stricter requirements for design verification, and the addition of a global partner.
One common difficulty with Capstone Design courses is finding a comprehensive textbook specific to the implementation. A common guide is highly beneficial when trying to maintain commonality for all students with teams of faculty teaching the class. In order to provide sufficient background information and a list of resources, four faculty members have generated an 80 page Reference and Survival Guide. The guide contains background reading on content presented in the course, a complete description of the required deliverables, a description of various resources and how to use them as well as advice for interacting with faculty, sponsors and each other.

Teaming
After the first year it was apparent that the students needed more team-work skills. An entire lecture and lab period dedicated to basic team skills along with team check up surveys have been added to the class. The challenge to keep students on a functioning team for twenty weeks cannot be understated. Formal teaming knowledge, skills and attitudes are stressed and the students are taught Tuckman’s ideas of team development based on “Forming, Storming, Norming and Performing.” There is also training on communication and conflict resolution. The students take the CATME online survey several times during the project and receive peer feedback on their teaming performance. Finally the students are made aware of Social Styles (see Knight et al) and practice identifying how Social Styles impact their team performance.

Multidisciplinary Project Teams
Partnerships with other disciplines within the college of engineering have led to a “trading” of students between various departments capstone course. Although complete articulation agreements between departments do not formally exist, many students have “switched” capstone courses with great success. Participating departments include Computer Engineering, Materials Engineering, Electrical Engineering and Aerospace Engineering. In the fall of 2008, a new college-wide, industrially sponsored, multidisciplinary capstone course will be available to students on a limited basis. The course will be taught by a team of capstone instructors from across the college of engineering. Project sponsorship will be obtained through the College of Engineering’s new Project Based Learning Institute (PBLI).

Service-Learning
The University administration has called upon programs to make service-based learning experiences available to their students. Service-based design projects are an excellent way for engineering students to practice their discipline while serving the community. Students report a high level of satisfaction with this type of work. The number of service-based projects has been increased to 1/3 of the projects supported by the class (see Table 2). Service-based projects are funded by leveraging other project sponsorship fees.

Global Design Teams
A partnership with the Munich University of Applied Sciences (FHM) was forged in 2005. After running parallel teams during the 2006/2007 school year, two international project teams were formed for the current academic year. These teams are working to design, build and test
solutions to externally supplied problems. Each team consists of two Cal Poly and three FHM students. Plans to add an Asian University are included as an enhancement for the fall of 2008.

**Extension to a Full Year**

Based on broad agreement that the capstone course is one of the most important as an integrating element in the mechanical engineering curriculum, the faculty has agreed to extend the experience to a full year. This will allow additional topics such as engineering ethics, leadership and career development to be added to the content portion of the course. It will also allow students greater time for both the design and the construction process. Both elements are currently compressed in the 20 week schedule. It is anticipated that at 10 weeks the students will have a preliminary design review with the critical design review occurring mid-way through the second quarter.

**Logistics**

**Faculty Organization**

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. There are typically five lab sections offered representing each containing six design project teams, eighteen students and led by a faculty advisor. Figure 1 shows how information flows in a typical quarter. The organizing faculty member has the responsibility to make sure all logistical support necessary to complete the design, construction and testing of 30+ projects is in place.

![Figure 1: Course Information Flow](image)

**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 design experience is the presence of an external “customer.” With 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. During the first three years, the Capstone students have undertaken 194 different projects. Table 2 contains the breakdown of the various sources of the projects.

Table 2: Projects and Sources by Year

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<tbody>
<tr>
<td>Industrially Sponsored</td>
<td>30</td>
<td>41</td>
<td>26</td>
<td>97</td>
</tr>
<tr>
<td>On-Campus Research Support</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>Student Club Support</td>
<td>14</td>
<td>6</td>
<td>11</td>
<td>31</td>
</tr>
<tr>
<td>Service Related</td>
<td>2</td>
<td>6</td>
<td>19</td>
<td>27</td>
</tr>
<tr>
<td>Individual Student Proposed</td>
<td>17</td>
<td>1</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>72</strong></td>
<td><strong>61</strong></td>
<td><strong>61</strong></td>
<td><strong>194</strong></td>
</tr>
</tbody>
</table>

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.

**Student Projects Laboratory**

In order to effectively maintain the capstone experience, significant facilities must be provided for design, fabrication, assembly, and testing. As mentioned earlier, it is the course organizers responsibility to see that the resources are available for the students to complete their project. In order to support student projects, the Mechanical Engineering department has a 7000 ft² 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 a converted aircraft hanger and managed 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 2 and 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 ft² Bonderson Student Projects Center (see Figures 4 and 5). This building is maintained by the PBLI and 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 to be organized and maintained by the Mechanical Engineering Department.

Figure 2: Overview of the Student Projects Laboratory

Figure 3: Woodshop in SPL

Figure 4: New Bonderson Projects Center

Figure 5: Winter 2007 – Senior Design Expo in Bonderson Projects Center

**ABET Outcomes and Assessment**

Content and experiences in the capstone design course are required to ensure students demonstrate certain capabilities as outlined in criterion 3 and 4 for ABET accreditation. Many
requirements of criterion 4 are also addressed by the capstone course. Specifically, Cal Poly’s 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. 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 and 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 and work closely with qualified technicians.

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. Their feedback is then reviewed by the course instructors during their spring continuous improvement meeting and changes are made accordingly.

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.

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 completely new to them. 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.
Senior Exit Exam and Senior Survey
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 department’s ABET coordinator and seeks to assess student outcomes related to 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. Results from the exam are reviewed by the faculty. During the first year, deficiencies in the ability of the students to construct free body diagrams and to generate appropriate safety factors in structural design were identified and corrective action taken within the curriculum. 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.

Conclusions and Recommendations

The capstone design course remains a critical element of the mechanical engineering curriculum as evidenced by its importance to assessment of desired ABET outcomes. Cal Poly’s Senior Design Project capstone course is an excellent example of experiential design learning and an appropriate platform to assess outcomes for the entire curriculum which is being done through a Senior Exit Exam and Survey. The success of the program in its first three years lies heavily on its format and the dedicated faculty that work together as a team. The department possesses the necessary infrastructure to support building and testing of hardware in this “hands-on” program. Additional resources provided by the College of Engineering’s new PBLI and Bonderson Projects Center will enhance and support the course as well as a multidisciplinary integration of other departments. The lengthening of the course to a full year will allow the integration of more design activities to enhance the education of future mechanical engineers. 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.

References

