2007: ASSESSMENT AND EVALUATION OF ENGINEERING SENIOR DESIGN AT COLORADO SCHOOL OF MINES

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Assessment and Evaluation of Engineering Senior Design at Colorado School of Mines

Abstract

The Multidisciplinary Senior Design Program in the Engineering Division at the Colorado School of Mines encompasses a two-semester course sequence, with an average enrollment of 225 students/year working on 45-50 externally-sponsored projects/year, has a faculty team of 8 members, and has five stated program objectives. These objectives are:

- To practice opened-ended problem solving skills through a hands-on, technical project
- To improve oral and written communications skills
- To participate in a multidisciplinary team
- To interface with the "real world", and
- To develop a professional work ethic.

The major goal of the first semester is the preparation of a formal design proposal. There are weekly lectures in the first semester that provide systematic design tools and aid in the process of engineering design, project management, workplace issues, and communications. During the second semester, students implement the proposed project that was designed during the first semester. On-going assessment of the students, teams, instruction and class structure has taken place for over twenty years. Students are assessed through individual assignment grades, self-evaluations, peer evaluations, and individual interviews with a team faculty advisor. Team performance is evaluated through team assignment grades, external client feedback, trade fair judging and faculty advisor ranking. The class grade from each semester is based on both team and individual measurements. Instructional assessments include a school-wide faculty evaluation "bubble form", as well as student comments on a course survey. Finally course evaluations come from a variety of sources: students, clients, alumni, Trade Fair Judges, Corporate Advisory Board, and design faculty. These data have helped in continual improvement of the Senior Design Program. Examples of changes made as a result of this assessment and evaluation are included. These data have provided a solid portfolio for ABET evaluation of both the program and the department. More importantly, analysis of these data has helped in making positive changes to the program.

Course Description

The Colorado School of Mines Senior Design Program is a multi-disciplinary design experience from combined efforts in civil, electrical, environmental, and mechanical specialties in engineering. Within the engineering community, it is widely believed that many of the challenges which are facing practicing engineers in the 21st century can best be met by exploiting multi-disciplinary approaches[1]. This course has been designed to comply with the 2005 ABET criteria[2] for accrediting engineering programs that require graduates to demonstrate:

- The ability to design a system, component, or process to meet desired results
- The ability to function on multi-disciplinary teams
- An understanding of professional and ethical responsibility

- An ability to communicate effectively
- The broad education necessary to understand the impact of engineering solutions in a global and societal context
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

With the ABET criteria as a guide, our course objectives are:

- Practice open-ended problem solving skills through a hands-on, technical project.
- Improve oral and written communication skills
- Work in interdisciplinary teams
- Interface with people in the "real world"
- Develop a professional work ethic.

The course structure varies from the first to the second semester of this academic year-long program. During the first semester, students are scheduled for four hours of structured class time with the expectation that four to twelve hours will be spent outside of the scheduled class to work on a project. The first one and one-half hours of the four hours is reserved for a lecture or special workshop that provides systematic design tools, and aids in the process of engineering design, project management, workplace issues, and communications. The emphasis is on the engineering process, not the project. The remainder of the four hours is spent in team meetings with a team faculty advisor and in teamwork applying the engineering process to their particular project. Specific team assignments include a project-choice application, a letter of commitment to a client, a Quality Function Deployment analysis[3], a safety/liability analysis through a Failure Modes and Effects Analysis[4], a Work Breakdown Structure, a project schedule through use of MSProject, and a project budget with economic justification. Students, individually, are required to keep a project notebook, complete an ethics assignment, and attend weekly meetings. Periodic oral presentations and written monthly progress reports are also required. The final product for the first semester is both an oral and written presentation to the client of a formal design proposal to solve the project problem that was assigned at the beginning of the semester.

The second semester is much less structured. Student teams are expected to meet weekly with a faculty advisor, but they work independently in managing their projects. At the middle of the semester, students meet with the project client and faculty advisor for a 50% project review. An oral presentation on the greater societal impact of the project is also scheduled. At the end of the semester, teams participate in a Trade Fair and must have both oral and written presentations of their final project report to their clients.

The average annual enrollment in the senior design program is 225 students with 45-50 externally-sponsored projects per year. The open-ended design project problems are supplied by industry, government agencies, professional organizations, or individuals. There are eight faculty representing each of the engineering specialties. Our goal in the selection of faculty is to assemble a mix of people with real world experience in industry coupled with current faculty that have teaching and research experience.

This program is intended to be a transitional course for students between their academic training and their upcoming "real world" work experience. Each team is administered in much the same fashion as a consulting engineering team working for a "real world" client. The design problems

are purposely open-ended, meaning that they have multiple ways of being solved. It is the challenge for each team to develop the best solution.

Assessment Process

On-going assessment of the students, teams, instruction and class structure has taken place for over twenty years. For the students, a variety of both formative and summative evaluation tools are used. Both formative and summative evaluations of teams also occur. The instructors are evaluated through a campus-wide survey, as well as through feedback from students on course evaluation forms. Finally, the course itself is evaluated through information gained from students, faculty, alumni, clients, and industry representatives. Details of each of these assessment processes are presented below. Using the Principles of Continuous Improvement[5], changes have been made to the course as a result of the assessment process.

Assessment of students to provide grades comes from a variety of traditional[6,7], as well as non-traditional[8] methods. Traditional assessment tools include oral presentations, final written reports, intermediated written reports, and peer/self assessments. Less traditional methods include an external review committee, in our case, Trade Fair Judges. Formative evaluation occurs through weekly meetings and monthly written progress reports. In addition, students complete a written ethics assignment. At the end of each semester, summative evaluation occurs through interviews and extensive end-of-course surveys. Each student completes a Self Evaluation where he/she is afforded the opportunity to outline his/her team contributions. The students are asked: "List your four or five most important individual contributions to your team's work. Tell us how your expertise enabled you to help your team succeed on your project." Students also complete a Peer Evaluation. On this form each member of a project team rates him/herself, as well as their teammates in six general categories: reliability, attitude, technical ability, leadership, cooperation and inventiveness. A one-on-one interview is held with each student with their team faculty advisor for a duration of about 15 minutes. The students are asked about their key technical contribution and key project management contribution to the team. As well, the student and professor discuss the student's grade in order to compare the student's perception of where they stand with the team faculty advisor's actual grade assessment. Suggestions for project and course improvements are also solicited from each student, as well as any problem areas of team dynamics. In addition to individual evaluations, team evaluations contribute to each student's final grade. The team assignments during the first semester include: a Client Letter clarifying the project scope of work, a Quality Function Deployment document, a safety document (Failure Modes and Affects Document), a Work Breakdown Structure, a project schedule, a mid-semester 50% design review (oral), a project budget and economic justification , and a formal project proposal (both oral and written).

After assessing both the student and team assignments, a letter grade is assigned at the end of each semester. The letter grades have the following meanings:

A: exceeded expectations, work above what is required, superior
B: met all expectations as specified for the class in a professional manner
C: met minimum class requirements
D: did not meet minimum requirements but shows evidence of being able to complete project with the team during semester 2

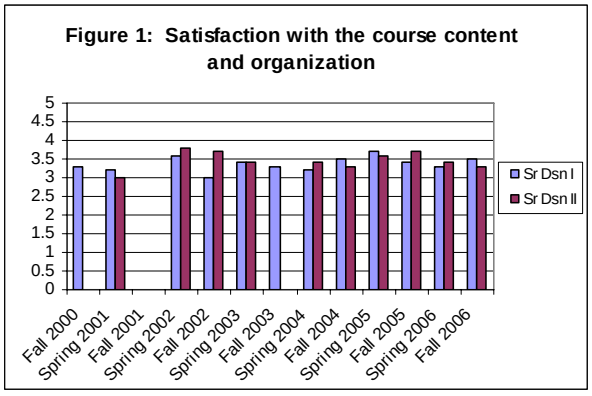
F: did not meet minimum requirements and must repeat the first semester (EGGN-491) with a new team at a later semester.

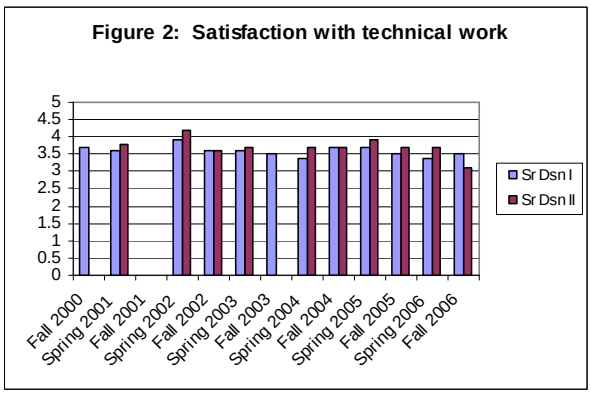
The weighted value for each component is as follows:
25% - Individual Assignments (Each team member earns an individual letter grade)
25% - Team Assignments (All team members earn the same letter grade)
25% - Peer/Instructor Review (Each team member earns an individual letter grade)
25% - Final Proposal and Presentation (All team members earn the same letter grade)
The combination of individually earned grades and team-earned grades results in individual final grades for each team member. In other words, it is possible that team members receive different final grades based upon their individual contributions.

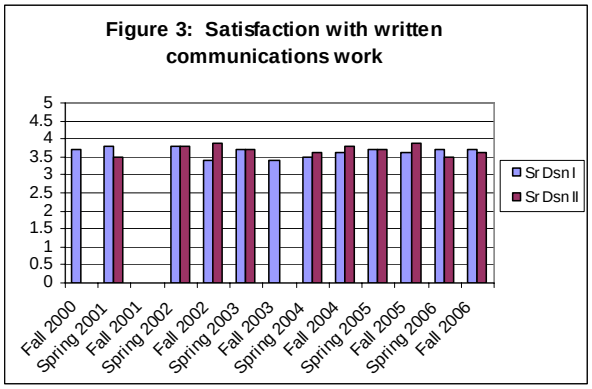
Course evaluations come from a variety of sources: students, clients, alumni, Trade Fair Judges, Corporate Advisory Board, and design faculty. These data have helped in continual improvement of the Senior Design Program. At the end of each semester, students are required to submit an anonymous course survey. The survey uses a Likert Scale (1 – 5) to assess the following topics:

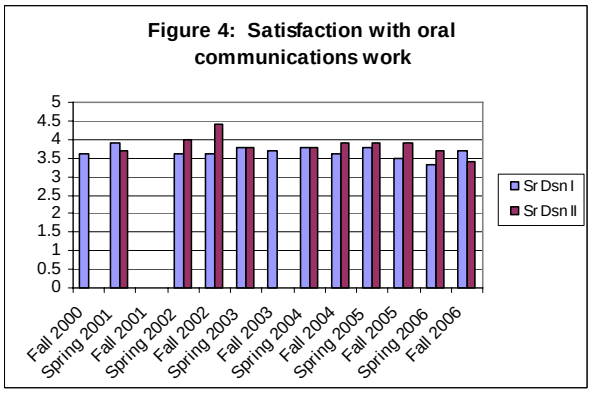
- Satisfaction with course content and organization
- Satisfaction with technical work
- Satisfaction with written communication work
- Satisfaction with oral communication work
- Satisfaction with client relations

Figures 1-5 illustrate the results for the two semesters of senior design (Senior Design I and Senior Design II). In general, ranking of the questions was between average and good with all of the components surveyed. Students were given the opportunity to make written comments, as well. The most common dislike was the requirement to attend lectures. The students were much more positive in their comments about actual project work and client interaction. Because of the transitional nature of this program, we find that some students make the adaptation to the format very well, while others struggle with dealing with the normal ambiguity of "real world" life. This often gets reflected in their overall satisfaction ratings.









Additional feedback was received from many constituents. The students during one-on-one interviews felt positive that the course met it stated goals. Students also expressed their preference for project work as opposed to lecture. However, after graduation, reflection from alumni has shown that the information gained in lectures is important. One alumnus stated: "I would like to thank you for the experience in Senior Design. They (his employer) were very interested and impressed with the knowledge of the design process I gained from the courses. I am convinced that experience was integral in landing the position." Another student thanked us for putting him through the Failure Modes and Effects Analysis process, as it turned out to be his first assignment while working on a new aircraft oxygen system for his company. The Corporate Advisory Board reviews the department and its curriculum. In 2006, one reviewer stated: "The ability of seeing the big picture and having multi-disciplinary technical understanding are key strengths for a young engineer. I strongly endorse your format."

Changes as a Result of the Assessment Process

Based upon the evaluations from students, faculty, clients, and Corporate Advisory Board, many changes have been made in order to maintain a quality Senior Design Program. In following the practices of continuous improvement, this is an on-going process. Several example problems and changes are presented.

Problem: Clients indicated that they wanted to know more about the progress in the first semester by the design team.
Improvement: The mid-semester oral presentation was changed to be a mid-term 50% design review. The purpose was for each team to give a status report to their clients and to see if they

were on the right track. This also helped to keep their work progress steady throughout each semester. The added benefit was an opportunity to host some clients and give them a tour of our senior design facilities.
Result: This change has been very well received by clients and has resulted in numerous mid-course corrections leading to better project outcomes.

Problem: Three faculty were assigned to senior design so that each faculty member was advising up to a total of 14 – 17 individual project teams. This was too many teams for each faculty member to do a quality job of coordinating.
Improvement: Five more senior design faculty members were added.
Result: This helped to reduce the number of teams that each member was advising by more than half. This single item made more impact in providing positive feedback on the course than any other change and sanity has returned to the faculty team!

Problem: One topic of Senior Design has been the Failure Modes and Effects Analysis (FMEA), but there was not an understanding as to why we were doing this process.
Improvement: We added a discussion of project Safety and Liability to go along with the FMEA lecture. One faculty member, who is a specialist in accident investigation, developed a lecture regarding the use of codes and standards in order to address safety and liability issues.
Results: Student feedback has been that the FMEA process is only applicable to projects that produce a prototype, and the writing of specifications has been difficult for students to understand. We have now implemented examples of the FMEA process to other types of projects, and we received feedback from one alumnus thanking us for introducing him to FMEA, as it was his first job assignment.

Problem: On "paper design projects", students were completing drawings, but clients wanted appropriate specifications to go along with the drawings in order to put the job out to bid for construction.
Improvement: We also introduced the concept of writing formal specifications to go along with drawing work on projects that were "paper design projects" versus prototype building. Students now use the AIA MASTERSPEC library to develop project specific specifications.
Results: Clients are pleased with the formal specifications that the students prepare.

Problem: Trade Fair Judges commented that students did not express an understanding of the impact of their project engineering solutions in a global and societal context.
Improvement: An oral presentation was added during the middle of the second semester with the topic of "Societal Impacts of the Project".
Problem 2: Despite our students having to produce a "Societal Impacts" oral presentation, we continued to see low ratings by the Trade Fair judges in the category on their rating forms.
Improvement 2: We made a significant 2nd semester syllabus schedule change and moved the "Societal Impacts" presentation to the week before the Trade Fair. The intent was to keep the information fresh in the students' minds.
Results: This change has resulted in improvement in the overall judges' ratings on this item at the Trade Fair.

Conclusions

These data have provided a solid portfolio for ABET evaluation of both the program and the department. More importantly, analysis of these data has helped in making positive changes to the program.

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