Project-Based Learning: Teaching Engineering Design Not Tinkering

Dr. Scott F. Kiefer, York College of Pennsylvania

Scott Kiefer has spent the past eleven years teaching mechanical engineering at four different institutions. As an exemplary teaching specialist in mechanical engineering at Michigan State University, Scott received the Withrow Award for Teaching Excellence, given to one faculty member in the College in Engineering for outstanding instructional performance. Scott specializes in machine design, vibrations and controls, and mechatronics. He started his career at the University of Puerto Rico at Mayaguez in the traditional role of teaching and administering a modest research program. At Trine University, a small private school in Angola, Indiana, Scott taught ten different courses from introductory freshman courses to senior design, while serving as adviser to many undergraduate research projects. He recently moved to York College of Pennsylvania where he has been able to concentrate on undergraduate education in mechanical engineering.

Dr. Stephen N Kuchnicki, York College of Pennsylvania

Dr. Stephen Kuchnicki has been an Assistant Professor of Mechanical Engineering at York College of Pennsylvania since January 2008. Previously, he was a postdoctoral research associate at Rutgers University, specializing in computational modeling of dynamic deformations in solids. His areas of technical expertise include solid mechanics, crystal plasticity, vibration, and fluid-structure interaction. He received his Ph.D. from Rutgers University in 2001.

Project-Based Learning: Teaching Engineering Design Not Tinkering

Abstract

Engineering educators are continually faced with the challenge of supplying employers with young engineers who possess the skills necessary to analyze and solve real industrial problems. Industry has specified, and ABET reinforced, that mechanical engineering graduates need to be able to accurately apply design analysis and mechanical design principles within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. In addition, students need to function on multidisciplinary teams, have good communication skills, and use modern engineering tools to solve problems. These requirements suggest that engineering courses should be using real life project-based learning throughout the curriculum. Research has also indicated that a good percentage of the high quality students who are dropping out of engineering are doing so because they have either lost interest or actually come to dislike studying it. This point provides another argument for including project-based learning in engineering courses, and also provides an argument for having our students experience the complete design, build, and test stages of a design project. However, there can be a danger in including all aspects of design development in project-based learning assignments. Students tend to concentrate more on the build and test issues and ignore some of the critical aspects of the design work. This can lead to our students becoming backyard inventors and tinkerers rather than mechanical engineers.

This paper describes an effort to address two issues using project-based learning in mechanical design courses. First, it makes an argument for and describes the details of using project-based learning. It explains through examples how project-based learning can be an effective way to better connect good students to mechanical engineering and produce high quality mechanical engineers ready to solve mechanical design problems. Second, it discusses the issue of insuring that the project-based learning projects are achieving the desired outcome—good design engineers not tinkerers. Assessment is provided in the form of student feedback and individual student project evaluation as judged by faculty and industry representatives. A historical perspective of using project-based learning in two different mechanical design courses is used to provide evidence as to some of the pitfalls that can arise.

1. Introduction

This paper provides a description of project-based learning done in two different mechanical engineering design courses at two different types of universities over about a four-year period. The main focus is to simply provide a description of how the projects were carried out and what types of improvements were made as the courses evolved. The intent is simply to provide some insight into some of the positive things that can be done with project-based learning and how they can best be accomplished. One of the most common problems with using project-based learning in mechanical engineering courses is that many students prefer to either use the "trial and error method" when constructing prototypes, or they just assume that "bigger is better" when they get to the shop and begin construction. They abandon the solid engineering principles and design optimization tools that they are taught in the classroom, and become tinkerers instead of engineers. Because this can be a major problem, and because it is very detrimental to students' engineering education, ways to avoid student tinkering are specifically addressed.

The two courses that are discussed in this paper are a junior-level machine design course and a senior capstone design course. The machine design course is the typical follow up to introductory solid mechanics and dynamics courses. Using a standard homework and exam format, the course covers failure theories, deflection analysis, energy methods, fatigue analysis, gear and shaft design, fastener design, finite element analysis, and system integration. In addition, a small scale design project is assigned to students in groups of three to address good design practices including using formal design methodology to evaluate design solutions, proper design documentation, and teamwork and communication skills. The capstone course is a two-semester sequence that includes the design and construction of a large scale design project with a class of about twenty students working together. Students are divided into subgroups that work on individual aspects of the complete design. They must work together to keep the design on schedule and under budget constraints. They also must communicate their design intent as the design progresses and come together with the other subgroups to complete the fabrication phase. In both courses students must complete the product development sequence of designing, building, and testing their projects.

The courses that are described in this paper were taught at two very different universities. The first was a large state university with a substantial research program and class sizes of sixty to eighty students. The other was a small, private, undergraduate institution with class sizes closer to twenty students. While there were some adaptations that were made for the two different venues, the basic principles of project-based learning worked equally well in either environment.

2. Description of Project-based Learning Projects

The projects used in the two courses were very different in scope, but they both included the use of good design practices and all required a final product build to be evaluated at the end of the course.

2.1 Machine Design Project

The project used in the machine design course was given as a semester long project, but it was simple enough in nature that it could be completed in parallel with weekly homework assignments and exams. The project always involved a mechanical design that used topics that were covered in class. The course was arranged so that a topic would be covered and an individual homework assignment given before the students would need that concept for their design project. Students could then apply the concepts in the context of their "real life" designs. Individual exams were also given to evaluate how well each student was able to apply the concepts.

The projects were done in groups of three students with any left-over students making a group of two. The projects always involved some type of competition to determine which group had constructed the best device at the end of the semester. For example, one semester project asked the students to design a tabletop device to extract juice from apples. The projects were judged on amount of juice produced, smallest size and weight, and overall design impression. A peer evaluation was used at the end of the semester to adjust grades according to the dedication to the project and performance of each individual on the design teams.

Since communication skills are always important in the design process, the students were assessed using three different types of communication. First, the students were asked to prepare for a design review at the midpoint of the semester. At this time, their mechanical analysis was to be complete and they were asked to prepare for a ten minute meeting with their "project supervisor" (professor or teaching assistant) to defend their design decisions and present a plan for fabrication. One class period was canceled for these meetings, although some were actually scheduled at a time other than the usual class time. At the large research school, a teaching assistant was used to help evaluate some of the design teams after sitting in with the instructor for the first few meetings. The students were also asked to complete a final written design report and give a ten minute oral presentation including all stages of product development at the end of the semester. The oral design presentations were given during the time that was normally set aside for a final exam. The final written reports were also due at that same time. Because of the number of students involved, an additional room and faculty member was needed at the large research school to evaluate all of the oral presentations.

2.2 Senior Capstone Design Project

The two-semester capstone projects were on a much grander scale and were designed to give students a different design development experience. Most of the design work was completed in the first semester of the course, while the fabrication and testing was completed in the second semester. Because of the scope of the project and number of students involved, the students were typically broken into teams of four to six students. Each team included a team leader. The team leaders were responsible for maintaining communication between the groups and insuring the complete design, fabrication, and testing of one final product. The total number of students involved in the project was typically a little over twenty, and the course was team taught by two faculty members. An example project for the capstone course was the design and construction of a formula style car for the student design competition sponsored by the Society of Automotive Engineers.[1]

During the capstone course, students were assessed both individually and as a group through formal oral presentations, poster presentations, written technical reports, and through weekly review of design notebooks. To provide continuous assessment and guidance, design notebooks were collected from each individual student once a week and feedback was provided as to progress and quality of work complete. About two weeks into the first semester, each individual student was also required to give a research review in the form of an oral presentation to the entire class. At the midpoint of the semester, each student was again required to give an oral presentation this time demonstrating the progress of their individual design work. Approximately two weeks from the end of the first semester, as part of their design team, students were required to create a poster and present it to local industry representatives who evaluated both their team and the project as a whole. At the conclusion of the semester, each student was required to prepare a technical report documenting their individual design work. The entire class was also required to prepare a design presentation to be given to local industry representatives and engineering faculty not directly involved with the project.

The second semester of capstone focused more on the fabrication of the final product. Design notebooks were still evaluated each week, but with the expectation that progress was being made toward the construction of the project. That is, documentation of fabrication work was acceptable and encouraged for this term. Each team was also given milestones complete with dates that depended on what part of the project they were responsible for and how their work fit into the final product. The instructors evaluated the completion of the each milestone and the quality of the work. At the end of the semester, each team was required to prepare a final poster documenting the design and fabrication of the project and present it to local industry representatives and/or competition judges. Each individual student was also required to prepare a written technical report documenting the final design and any relevant fabrication issues.

Grades for each semester were calculated using weekly notebook averages, the formal presentation and report grades, and a professionalism grade which was influenced by peer evaluations. The peer evaluations were used to measure dedication to the project and the individual performance of each student. Each student in the course rated everyone they felt that they had been able to work with or observe. The responses of the other students within a student's own subgroup were weighted more heavily when calculating the professionalism grade.

3. Course Necessities for Helping Achieve a Positive Outcome

Throughout the roughly four years that project-based learning has been used in these two courses, improvements have been made on a continuing basis. Some of the most significant advances are mentioned in this section.

3.1 Instructor Dictated Milestones

In the first versions of both of these project-based courses, the students were given the task of implementing their own project management strategies to keep the projects on schedule. They were required construct Gantt charts, but were given very few constraints from the instructors and no deadlines other than the final completion date of the project. The philosophy was that the students should have the freedom to schedule their own time, and should be able to direct their own progress toward design completion. In addition, this philosophy required students to include the higher-level (big picture) deadlines as a part of the course experience. However, this proved to be an unrealistic expectation from engineers at this level.

While the students did create Gantt charts and gave the outward appearance of trying to follow them, the truth is that they did not have enough experience in the design area they were working for the charts to be accurate and useful. Students did not have enough experience to anticipate many of the problems that they would encounter, so there were many missing tasks and the timing of activities was grossly inaccurate. In addition, several of the projects changed directions completely in ways that the students had not anticipated or included on their charts. Adding to the inaccuracy of the Gantt charts was the fact that there were no consequences if deadlines were not met. Therefore, it was easy for the students to ignore the dates entirely when assignments or exams were due for other classes. In truth, most students completed the projects with the feeling that Gantt charts were not valuable for project management and that they were "just another piece of busy work the instructor assigned". The design projects themselves were often moved to the back burner, and students were usually struggling at the end of the semester with not having enough time to complete their projects. This lack of time usually led to incomplete analysis, sloppy fabrication, and lots of tinkering to make certain that something was deliverable on the project completion date. In general, many of the good engineering principles that the projects were intended to reinforce were abandoned.

After witnessing the initial failure of letting the students entirely manage their own project schedules, the instructors decided to step in with more guidance. In retrospect, it was a little unrealistic to expect students to have enough background to do their own project management. After all, we would not expect an entry level engineer to be able to accurately create project schedules for the development of a new product. Therefore, milestones including specific deliverables and dates were created by the course instructors. For the machine design course, there were three simple deliverables the students needed to meet: the completion of the design and analysis phases, initial fabrication to a point where the device showed some preliminary functionality, and completion of the final prototype. For the capstone course, the milestones were different for each subgroup and they needed to take into account the dependence of the groups on each other's progress. This was all the more reason that the instructors were the correct people to create the milestones. For both courses, the students were graded as to the completion and quality of their assigned milestone, and the grades were weighted similarly to what an exam would be weighted in a completely lecture based course. In this model, the instructors took on the role of engineering managers who were responsible for the overall view of the project. This was a task that was much better suited for the course instructors. An example of the milestones set for both the machine design course and the capstone course can be seen in Figures 1 and 2 below. The milestones are followed by an example of one of the rubrics that was used to assess the milestones (Figure 3).

Milestone	Date
Completion of Design and Analysis Phases	Midpoint of semester
Physical Proof of Preliminary Functionality	¾ point of semester
Completion of Prototype	Day of competition (last class day of semester)

Figure 1: Milestone Dates for Mechanical Design

Milestone	**Date**
ECU Connected and Engine Sparking	January 30
Frame Fabrication Complete	February 6
Suspension Components Fabricated	February 6
Engine Mounts Installed	February 13
Intake Fabricated	February 13
Exhaust Fabricated	February 13
Suspension Components Installed and Functional	February 13
Body Design Complete	February 13
Brake Pedal Installed and Functional	February 20
Seat and Headrest Installed and Functional	February 20
Shocks, Springs, etc. Mounting Brackets Fabricated	February 20
Intake Installed and Functional	February 20
Exhaust Installed and Functional	February 20
Fuel Tank Fabricated	February 27
Seatbelt Harness Installed and Functional	March 13
Electrical Enclosure Fabricated and Mounted	March 13
Shocks, Springs, etc. Installed and Functional	March 13
Brake System Installed and Functional	March 13
Steering Installed and Functional	March 13
All Engine Sensors Calibrated and Functional	March 13
Fuel System Installed and Functional	March 13
Cooling System Installed and Functional	March 13
Shifter Installed and Functional	March 13
Differential Installed and Functional	March 20
Drivable Vehicle **All Subgroups are Evaluated**	March 22
Body Fabrication Complete	April 3
Torsional Rigidity Test Completed	April 3
Competition Ready Vehicle **All Subgroups are Evaluated**	May 3

Figure 2: Milestone Dates for Capstone (Formula SAE project)

Topic (Weight)	Unacceptable (0)	Marginal (7)	Exceptional (10)	Points	Weighted Points
Analysis **Weight: 10%**	None completed	Not completed, but correct and useful **or** Complete with minor errors	Everything completed and correct		
Future Plan **Weight: 20%**	None Provided	Not thorough **and/or** Not reasonable **and/or** Unclear deadlines	Thorough and reasonable including deadlines for all necessary tasks		
Degree of Completion **Weight: 50%**	Project may be started, but no part carried to completion	Very minor finishing work needed	Complete		
Confidence **Weight: 20%**	No confidence in analysis, quality of manufacture, and possibility of meeting future plan	Questionable analysis **and/or** Questionable quality of manufacture **and/or** Unrealistic possibility of meeting plan	Nothing questionable in analysis, high quality craftsmanship, and clear ability to meet future plan deadlines		
TOTAL					

Figure 3: Milestone Assessment Rubric

The addition of the milestone evaluations not only helped the students stay on task, but they also helped avoid tinkering. Before the milestones were implemented, students would often put off fabrication and then panic as the project due date approached. Good design practices were often ignored in favor of getting something finished. The addition of the milestones helped alleviate this last minute tinkering.

3.2 Graded Feedback on Design Work

Another observation that the instructors had when the students were attempting to do their own project management was that too many of the groups would not perform a good analysis of their designs before beginning manufacture. Many students wanted to rely on their intuition, or apply trial and error methods in the shop rather than doing a correct analysis before beginning construction. They instinctively leaned toward tinkering. Most of the students who tried these methods learned that they could save themselves time and money, and come up with a better prototype, by doing good design work first. However, there were a lot of bad practices being implemented. In addition, some students would come up with a functional design after several build iterations leaving them with the idea that this was an acceptable way to develop a product even though they had wasted a large amount of time tinkering. Because the focus of both of these courses is good design work and efficiency in prototype development, it was clear that design analysis must be included in the given milestones so that it could be graded before prototype fabrication was started. Because of their lack of experience and their natural tendency toward tinkering, it was clear that students must be given graded feedback on their design work before they begin the construction of their prototypes.

Another benefit to having initial design work graded was that it provided an opportunity to give feedback on manufacturing methods the students were considering. Often manufacturing problems and student frustration could be avoided with this feedback.

3.3 Written Design Reports

Along with providing feedback on design work as it progressed, it was also of vital importance that students were required to produce written documentation at the completion of the project. Making it clear to students as the design work progressed that all design decisions must be backed up by analysis, and provided in written form, was another method that was used to avoid tinkering. While there were still some changes made in the shop at the last minute, they were minimized by the fact that the students understood they needed to provide justification for their final decisions. At the very minimum, the written report insured that the students had considered the long term reliability of the design.

3.4 Communication Issues

Communication issues are to be expected with any course that uses a project-based learning experience, and these courses were no exception. The mechanical design course had many student groups without any major problems, but there were always one or two groups that required intervention by the instructor at some point. Because the groups were so dependent on one another, the capstone course always had several major breakdowns in communication throughout both the design and fabrication phases of the project. In both classes, the course instructors were required to step in and act as engineering project managers to resolve communication problems.

Students had many different types of problems with each other, and there was no magic formula for working them out. However, it was important that the course instructor was alert for problems and tried to catch them as early as possible. Waiting for the students to come to the instructor with a problem that needed intervention would have been too late. In the capstone course, the design notebooks were the easiest place to catch problems early. In the machine design course, peer evaluations were used part way through the project specifically to look for early communication problems. These peer evaluations were not used as part of the course grade, but they did point out problems that might not otherwise have been noticed until the end of the semester.

Most often, communication problems involved the fact that expectations of what each student would be responsible for were not clear to everyone in the group. In many cases, a five minute meeting with the course instructor to clarify responsibilities was very helpful.

3.5 Peer Evaluations

Peer evaluations were a necessity because these classes incorporated project-based learning with students working in groups. By nature, group project work provided a place for underperforming students to hide and rely on the effort of more motivated students. By clearly stating (and often reminding) that peer evaluations would be used to adjust the grades for all project work done by the student's team, the instructors were able to suppress this behavior. Simple peer evaluation forms were used where the students rated themselves and the other students they had worked with. The average scores of each student were compared to the average score of the group, and the grades were adjusted accordingly. This style of peer evaluation was adapted from one presented at a workshop given by the National Effective Teaching Institute.[2] As previously mentioned, peer evaluations were also used in the machine design course as the semester progressed to look for communication problems students were having within their design groups. These midterm peer evaluations had no effect on final grades.

The peer evaluations used for the two courses were very simple in nature, but proved to be very effective and accurately matched the observations of the course instructors. However, there are many more comprehensive ways of doing peer evaluations. A good example is a piece of free software called CATME that was developed through an NSF grant[3].

4. Assessment of Project-based Learning

Three types of assessment were done to evaluate the project-based learning done in these courses. First, standard university student evaluations were used. Second, industry representatives were asked to assess student design work and formal presentations. Finally, instructor observations were used. Rather than include all course evaluation data from the past four years, a summary of the evaluations is provided here, and the raw data from the most current sections of each class are provided in the appendix. Obviously, the evaluations have improved throughout the years because the courses have been modified to include the attributes that are mentioned in the previous sections. Many of the components mentioned were developed because of past feedback from student and industry evaluators.

4.1 Student Course Evaluations

Standard online university course evaluations were available only for the machine design course. The results collected from the most current version of the machine design course (18 responses from a class of 24 students) were very positive. Well over half the students rated both the course and the instructor "above average" or "excellent". Also, almost all of the students indicated that they had learned a great deal in the course.

There were two open ended questions on the course evaluation. The first asked which aspects of this course were most valuable. Of the 16 students who responded to this question, every one mentioned some aspect of the project. The second open ended question asked which aspects of the course were least valuable. None of the student responses to this question mentioned any part of the project.

4.2 Industry Project Evaluations

Near the completion of the semester, the students in the capstone course were asked to display their work in a poster session. After completing evaluations of each student group's design work in the poster session, industry evaluators were asked three survey questions about the work of the class as a whole. The responses of eleven different industry evaluators were also very positive. All industry evaluators agreed that the students communicated at an appropriate level for an entry-level engineer, and all but one of the evaluators agreed that the quality of the work presented was equivalent to that of an entry-level engineer.

After hearing the formal oral presentation for the final design for the capstone course, evaluations were collected from both industry representatives and other engineering faculty (11 total responses). The responses to the oral presentation also stated that the students were doing quality work. There was only one marginal response to the assessment of technical content with the other responses being competent or exceptional. All responses were competent or exceptional with respect to questions about design quality, analysis quality, and organization and scope of the project. The industry and faculty representatives were also very satisfied with the communication skills and presentation quality of the students.

4.3 Instructor Observations

In addition to the formal evaluations, the instructors of these courses had the opportunity to make many personal observations about the effects of project-based learning. Perhaps the most satisfying observation was the growth that took place in the students as their projects progressed. Watching students mature from being very insecure and needing constant verification of their analysis to being confident designers who could correctly apply mechanical design principles without much intervention was a very satisfying experience. The growth and maturity as an engineer which occurred in many students in these project-based learning experiences is unmatched in a typical lecture only course.

There were also many subtle lessons that students needed to experience to truly internalize. For example, the instructors told the students that it was important to consider manufacturing and machining methods in their initial designs. However, it was not until they got to the shop and tried to turn their CAD model into a working machine that they truly appreciated how important it really was. Another important lesson students learned was the fact that things rarely go exactly as planned and fabrication can take much more time than anticipated. Along these same lines, many students experienced how vitally important it was that there was a back-up plan in place to overcome unanticipated problems. While most students say that they understand these issues, experiencing some of them first hand was very beneficial to their development as engineers. The effects of poor communication also became apparent in nearly every project, especially in the capstone course. There were many problems that arose during the project build that could have been avoided if the subgroups had communicated better with each other.

The competition element that was used in both of these project-based learning courses was a bit of a double-edged sword. There were many inherent benefits to having either a competition among design groups within a course (the machine design course), or having the entire course participate in a national competition (the capstone course). The most apparent was the automatic inclusion of a firm completion date for the project – there was no opportunity for late projects. Another benefit was the motivation to do well by creating a quality device that came with the competition element. This motivation was extremely valuable in helping the students be able to design and build a successful prototype. The bad part of the competition element was that it sometimes consumed the students. They became obsessed with doing well in the competition to the point where they did not appreciate the value in what they are learning.

Some students came to equate the success of their design in the competition with their own success in achieving course outcomes. It was important that the instructors continuously reminded the students about the positive things that they were accomplishing even if there were some disappointments with their prototypes.

5. Future Modifications

To continue the ongoing improvement process, planning is currently in process for the next time these design courses will be offered. There are three main areas that the instructors have chosen to target for improvement. First, while the milestones have been successful, the way they are evaluated needs to be altered. In the past, if a student or group did not have their milestone complete, they would receive a penalty in their grade. However, since the grade was already given, there was little motivation for the students to finish all the work for that milestone. Their next milestone may be several weeks away, and they were fatigued from trying to complete the first milestone on time. This caused many delays because other teams were waiting for the completion of their work. To remedy this situation, future milestones will not be graded until the work is complete with a penalty for each day it is overdue.

The second area targeted for improvement is the research aspect of the design projects. Students often shy away from reading journal articles because they complain about it taking too much time and because the articles are written over their heads. The next time the capstone sequence begins, the instructors will take a class period to read through some journal articles with the class. They will provide examples of how to quickly decide if an article is of importance to their project, and what parts of the article require in depth understanding and what parts can be skimmed.

The final target area for improvement lies in the milestones themselves. They will always need to be evaluated and improved each time the course is taught. Especially as new projects are chosen, timing may not work out as expected. The instructors of these two courses will continue to complete an evaluation of the milestones as a part of the standard ABET assessment cycle, and the metrics will be continuously refined.

6. Summary and Conclusions

It can be clearly seen from the students' course evaluations, and from personal observations of the instructors, that project-based learning is an extremely valuable tool in teaching mechanical design. The instructors have witnessed firsthand the growth and learning that students experience during courses with project-based learning. The students have verified the positive impact the projects have in their course evaluations, and industry representatives have verified the quality of the work and the professional conduct exhibited by the students.

There are several components that the instructors of these courses feel are a necessity in any project-based learning course. First, projects should have milestones with dates set by the instructor. Second, students must get graded feedback during the design process, not just a final grade at the conclusion. Third, there should be a written final design report required as part of the project grade. Fourth, communication problems will often occur and instructors must do all they can to monitor project groups and intercede when necessary. Lastly, peer evaluations should be used to determine the dedication and quality of work put forth by all students.

Finally, it is especially important that project-based learning courses are continuously evaluated and improved. Each new class or project brings a new set of issues and possible changes in the project-based component of the course.

7. Bibliography

1. “Formula SAE”, Society of Automotive Engineers, <http://students.sae.org/competitions/formulaseries>.
2. R. Felder, R. Brent, J. Stice, *National Effective Teaching Institute Workshop*, given at 2004 ASEE Annual Conference, handout page E-16, < http://www4.ncsu.edu/unity/lockers/users/f/felder/public/CL_forms.doc>.
3. M. Ohland, L. Bullard, R. Felder, C. Finelli, R. Layton, M. Loughry, D. Schmucker, “Comprehensive Assessment of Team Member Effectiveness”, software created as part of NSF DUE-ASA Award #0243254, <http://www.catme.org>.

Appendix

A.1 Student Course Evaluations

Standard online university course evaluations were not used for the capstone course. However, they are available for the machine design course. The results collected from the most current version of the machine design course (18 responses from a class of 24 students) are as follows:

1) Overall, I rate this course as:
    a. Excellent 6
    b. Above Average 7
    c. Fair 5
    d. Below Average 0
    e. Poor 0
2) Overall rating of instructor:
    a. Excellent 6
    b. Above Average 6
    c. Fair 4
    d. Below Average 2
    e. Poor 0
3) I learned a great deal in this course.
    a. Strongly Agree 6
    b. Agree 9
    c. Neutral 1
    d. Disagree 2
    e. Strongly Disagree 0
4) Which aspects of this course were most valuable (open responses – all students who responded are included)?
    a. Design and machining experience
    b. Gaining more shop experience
    c. Working on an actual project and applying all the theory that was taught in class
    d. Designing and building a project throughout the semester
    e. Shop time during class to complete project
    f. Everything was valuable to engineering and different analysis that we performed throughout out our engineering career.
    g. Applying classwork to analyze the project
    h. Extra shop time for working on the project was great. Finding principal stresses without using Mohr's circle was easier to understand. I am now more able to visualize and solve combined loading problems.
    i. Learning new aspects to account for when designing something
    j. Finally got a good sense of how combined loads work and how to use the equations properly. Gave a good understanding of how and under what circumstances an object might fail.
    k. Some real world analysis. Did work with us for giving project work time.
    l. Projects

m. Refreshment for old topics learned in previous years, and a lot of new information. Ability to apply what was learned in class to a real-life application (end of the year project).
n. how much a team mate can really ruin an entire project for you
o. Stress analysis, deflections bla bla bla. Best of all I learned to weld and gained valuable machining experience. That is something a lot of engineering students are missing. We have the equipment, and we should use it more. More actual machine shop TRAINING prior to machine design would be helpful.
p. Building the project

5) Which aspects of this course were least valuable (open responses)?
   Nothing was stated in the responses to this question that mentioned the project.

A.2 Industry Project Evaluations

After completing evaluation of each student group's capstone design work in a poster session near the end of the semester, the industry evaluators were asked three survey questions about the work of the class as a whole. The questions and responses collected from the summer of 2012 (11 total responses) are as follows:

1) The students I spoke to about the Capstone Design posters communicated at an appropriate level for an entry-level engineer.
   a. Strongly Agree 3
   b. Agree 8
   c. Disagree 0
   d. Strongly Disagree 0
2) The Capstone Design posters included work equal to that of an entry-level engineer.
   a. Strongly Agree 4
   b. Agree 6
   c. Disagree 1
   d. Strongly Disagree 0
3) The quality of design work reflected by the Capstone Design posters was equivalent to that of an entry-level engineer.
   a. Strongly Agree 3
   b. Agree 7
   c. Disagree 1
   d. Strongly Disagree 0

After hearing the formal oral presentation for the final team design for the capstone course, evaluations were collected from both industry representatives and other engineering faculty. The questions and responses collected from the summer of 2012 (11 total responses) are as follows:

1) Effectiveness of Communication – Appropriate speech rate, volume, clarity, use of gestures/movement, use of language
   a. Exceptional 1
   b. Competent 8
   c. Marginal 2
   d. Unsatisfactory 0

2) Organization and scope - Presentation well-organized and easy to follow; transitions between topics clearly signaled; scope and depth of the presentation congruent with the expertise and expectations of the audience and allotted time
    a. Exceptional 2
    b. Competent 9
    c. Marginal 0
    d. Unsatisfactory 0
3) Technical Content - Presenters clearly explained their arguments and provided sufficient evidence for their claims; presentation significantly increased audience's knowledge of topic; presenters clearly defined terms/acronyms when needed
    a. Exceptional 2
    b. Competent 8
    c. Marginal 1
    d. Unsatisfactory 0
4) Design and Analysis Quality - Design problem well-understood by presenters; designers considered sufficient variety of solutions; depth of analysis satisfactory; reached well-supported conclusion
    a. Exceptional 1
    b. Competent 10
    c. Marginal 0
    d. Unsatisfactory 0
5) Quality of Visual Aids - Well-written; engaging; emphasized points without distracting focus from technical content
    a. Exceptional 6
    b. Competent 5
    c. Marginal 0
    d. Unsatisfactory 0
6) Overall Presentation Quality - Audience learned something new; presenters enthusiastic about their work; captured audience's attention/curiosity; raised thought-provoking questions and insights
    a. Exceptional 2
    b. Competent 8
    c. Marginal 1
    d. Unsatisfactory 0
7) Ability to Answer Questions Effectively - Answered questions with appropriate detail and knowledge; not confrontational with questioners; showed interest and respect for questions
    a. Exceptional 5
    b. Competent 6
    c. Marginal 0
    d. Unsatisfactory 0