2007: IMPROVING THE RESULTS OF A CAPSTONE DESIGN PROGRAM – A CONTINUOUS PROCESS

Jack Zable, University of Colorado – Boulder

Dr Zable was recently named The Industry Professor of Mechanical Engineering Design, a new chaired professorship position. He created and has directed the new capstone design program in the mechanical engineering department for the past seven years. Prior to joining the mechanical engineering faculty, he held various management and high level technical positions at IBM. He was a member of IBM's prestigious Academy of Technology. He is an ASME Fellow.

Improving the Results of a Capstone Design Program – A Continuous Process

Jack Zable

Introduction:

In the Fall of 2000, the Department of Mechanical Engineering at the University of Colorado (CU) initiated a change to their capstone design program whereby the great majority of the projects would be sponsored by industry and government labs. A center was formed, called the Industry/University Cooperative Projects Center (I/UCPC), to obtain, oversee, and administer these projects. As mentioned in a sister paper entitled 'The Move to Industry Sponsored Capstone Design Projects – Why and How', a fair amount of success was obtained after the first year, Fall 2000- Spring 2001, of the program. However, there were areas of deficiency that needed to be improved upon. These problems occurred as a direct result of switching to capstone design projects that were predominantly industry sponsored. Some of these problem areas included; underestimating the teaching workload for the capstone design faculty in this new environment of industry sponsored projects, team sizes being too small, a small but vocal minority of students strongly desiring to design and develop their own products, having very limited interdisciplinary participation, and receiving pressure from industry to further improve the intellectual property agreements. Continuous improvements to these particular deficiencies as well as other new problems that have occurred over the past six years are described in this paper.

Capstone Design- A Process:

One can consider capstone design as a process, where the input is a project description and the outputs are functioning hardware and software that meet specification, and the accompanying documentation. The goal of an accomplished process is to always produce repeatable and successful results. It was felt that the best methodology by which this goal could be achieved by the I/UCPC and the capstone design faculty was to implement continuous and evolutionary improvements. This entailed determining the key barriers preventing total success, discussing ideas for their removal, and then implementing these ideas. It is important to understand that this is a continuous process, and that there is always a need for improvement and innovation. Initially there were only a few faculty members involved with the teaching of the capstone design course sequence and initiating improvements. However, as the size of the mechanical engineering student population increased at CU (much greater than the national trend), and the capstone design teams advised by a single professor decreased, the number of faculty associated with the capstone design program grew to be approximately ten. Three years ago, a design faculty quality circle was formed. The concept of quality circles is a relatively old one, and is reputed to have started in Japan approximately 30 years ago. The mission of a quality circle is to determine process deficiencies and implement related improvements. The design faculty quality circle met at least once per term to discuss and resolve problems that were adversely affecting the results produced by the capstone design teams.

Resolving Some Problems during the First Three Years:

The actions that were implemented to try to resolve the early problems mentioned in the Introduction section are described directly below. Some 'solutions' were relatively easy to put into place and were quite effective. Others required years of 'tweaking' to make them effective.

Capstone Design Faculty Advising Workload: Prior to the initiation of industry sponsored projects to the capstone design course, teaching and advising 10 design teams per semester was considered to be the equivalent to teaching one course. The same teaching responsibilities were then used for the first year of the new industry sponsored projects program. However, the time required by the faculty to adequately advise industry sponsored projects increased dramatically. In fact this advising time nearly doubled when compared to the time required for the previous program. Thus, it was determined to add more capstone design faculty through the use of adjunct professors, additional permanent faculty, and the 'volunteer' efforts of other interested design faculty in the department. This reduced the ratio of design teams to faculty advisor per semester to approximately six. This is still a relatively high number compared to that of other schools with similar programs.

Team size:
It was decided to accept only a certain number of industry sponsored projects such that there would be approximately five students per team. It was seen that the workload for a team having four members was a bit high, particularly if one of the members was not totally engaged. Later experience also showed that six students per team was a bit high, particularly for the types of projects that were typically obtained from industry. Additionally there were two SAE teams, one developing a Baja vehicle and the other a Formula racing car. Neither of these teams performed all that well in national competitions, with each barely finishing in the top half of the competition. Thus, it was decided to have one SAE team, a Formula team, with twice the number of students participating on this team. This change resulted in a better design environment and the team placed in the top 15% during the most recent SAE competition.

Some Student Preference for Self Selecting Projects- A New Entrepreneurship Program:
It was felt that the preference on the part of some students for self selected projects could be changed from a perceived negative to a positive for the capstone design program, via the use of an entrepreneurship track. After numerous meetings with the highly rated entrepreneurship faculty in the CU business school, a plan was developed to create a mini, multi-disciplined entrepreneurship program. The entrepreneurship track within the capstone design course would provide an opportunity for students to develop a new product of their own choosing, in conjunction with a team of business students. This innovation to the I/UCPC program was initiated five years ago in conjunction with the business school. The first requirement for mechanical engineering students to participate in this mini-program was to convince other students in the class to work on their entrepreneurship team, such that a team of at least four engineering students was formed. The next requirement was that at least one member of this entrepreneurship team must commit to take the 'Creating a Product Plan' course offered in the Spring term by the business school. Additionally, the design faculty must agree that the defined entrepreneurship project had significant design challenges.

The engineering students on the entrepreneurship team must then convince a significant number of business students (4-6) in the 'Business Product Feasibility' class, offered in the Fall term, to work on their idea, and in fact, form a multi-disciplined team with them. In order to do this, the engineering students presented their product ideas to the business students at the start of the Product Feasibility class. By the end of week two of the first semester, the multi-disciplined entrepreneurship teams are formed. If the product idea is not accepted by the business students, the engineering students associated with this idea are then re-distributed to the other existing industry sponsored teams. The established entrepreneurship teams then meet on a regular basis (typically, once every other week).

The design reviews for the entrepreneurship teams are conducted by the design faculty. Occasionally, the mechanical engineering department's industry advisory council reviewed the product design and business plan for one or more of these teams. Periodically, a design and business review was conducted by a local, successful entrepreneur, who also has an engineering background. At the end of the first term, the product idea must be shown to be feasible from both an engineering and business point of view. If not, the engineering part of the team is dispersed and redistributed to the other design teams. If feasibility is shown, the mechanical engineering part of the team remains in tact while the business students on the team during the second term come from the next business class, i.e. 'Creating a Product Plan'.

To date, three of these multi-disciplined teams have won the business school's annual competition for best product plan. There have been at least 7 transitional patents that have been filed by these teams. This relatively successful program has fully satisfied the need for those mechanical engineering students who strongly desire to design and develop products of their own choosing.

Intellectual Property Agreement: A new intellectual property agreement was established with the sponsoring company obtaining all of the intellectual property developed on the project. An increase in the base price for project sponsorship also occurred with this new agreement. This agreement was put into place, in part, as a result of some mild pressure exerted by the department's industry advisory council on the technology transfer officers. Additionally, there were new and more enlightened personnel hired to operate the university's technology transfer office.

Additional Problems Occurring Over the Past Four Years:
Over the past four years there have been new and repeated problems that have detracted from the complete success of the capstone design program. Some examples of these additional and/or repeated problems have been;

a. Students lacking support to perform finite element analyses (FEA), computational fluid dynamics (CFD) analyses, design circuits, develop data acquisition code, etc.
b. Some student teams not having sufficient time for more than one design iteration (two attempts at success).
c. Poor writing skills on the part of some students.
d. Ordering materials and parts for projects was cumbersome and time consuming.
e. Not having some multi-disciplined teams containing mechanical engineering and electrical engineering students.
f. Not stressing the importance of the roles of team officers and team leadership.
g. Not obtaining the necessary participation level of some industry mentors.

Attempts to reduce the severity of some of these problems are described below.

The Need for Extra Support to Student Teams in Specific Areas: - FEA, CFD, and data acquisition software consultants were hired by the I/UCPC to aid students use available FEA, CFD, and data acquisition software. The consultants gave detailed instruction to the students, ultimately allowing the students to be self sufficient. The consultants were upper level graduate students who have commensurate experience with these tools. Additionally, there were personnel within the Integrated Teaching and Learning Laboratory at CU that helped the capstone design students resolve instrumentations and data acquisition problems related to their projects. There are a few other improvements in this overall area that are planned in the very near future such as; easy to use CFD tools with consultants and guidebooks, turnkey data acquisition systems with very understandable user manuals, and the availability of an experienced and student friendly machinist in the mechanical engineering department.

Team Leadership: - All teams select team officers consisting of a captain, a treasurer and a scribe at the beginning of the first semester. Lectures on leadership, team dynamics and the roles of team officers were given to the class. The scribe takes meeting notes and distributes them to the team within one day of each meeting. The team captain acts as the team liaison to the industry mentor, and makes sure that all team members are fully engaged. The treasurer tracks the project budget, and handles the purchase of most materials, parts, etc. required by the team. Each team had the option of changing the scribe and/or the captain at the end of the first semester. At times, the faculty advisor initiated a change.

Purchase of Parts, Materials: - Purchasing parts for projects was a very loose and cumbersome process. Funneling all purchases through one program administrator was very inefficient. In addition receipts students obtained for small purchases were lost or not submitted. Large purchases, in particular, took a long time to complete. It was decided to give each team a charge card with a spending limit of $1000. This limit could be increased with the permission of the faculty advisor and accompanying minimal documentation. The team treasurer was the only person on the team that was allowed to use the charge card. Each treasurer must take an on-line exam to demonstrate that they are familiar with the usage rules for the card before they can receive the card. This card qualification process takes about two weeks. All purchases made on the card require receipts and these are regularly reconciled. An administrative support person spends about four hours per week helping students in this regard and makes sure that all records are kept in a professional manner. The administrator also rates the performance of the team treasurers and transmits this to the appropriate faculty advisors.

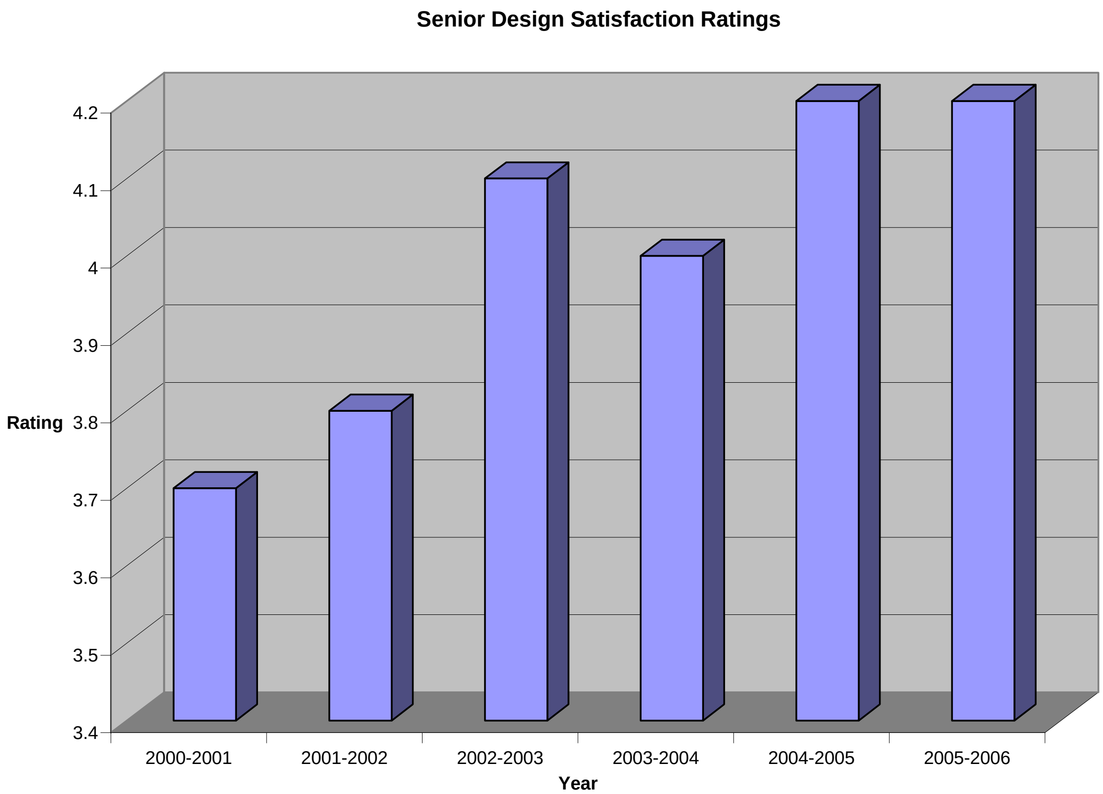
Participation of Industry Sponsors: - It was observed that those teams that were actively supported by their industry mentors typically ended up with a better end product. The number of meetings between the industry mentor and the team was one measure of the industry mentor's participation level. Data was taken at the end of Spring 2004 semester to see if team performance, as measured by the satisfaction rating of the industry mentor, correlated with industry mentor participation. This result was that there was a reasonable correlation between mentor involvement and project success. It is now strongly recommend that the industry mentors meet with their team at least every other week.

Multi-disciplined collaboration: - Almost all development projects in industry are implemented via a multi-disciplined approach; mechanical engineers, electrical engineers, software engineers, materials and manufacturing personnel, etc. all working on the same team. Furthermore, engineering team representatives also meet with marketing, sales, finance, and other personnel on a regular basis. Creating this type of environment at CU has been near impossible. The engineering departments have their own capstone courses with their own unique schedules. For example, electrical engineering and chemical engineering have a one semester capstone course. The chemical engineering course is a paper study, with no hardware being built. The computer science department has a team/project selection process that is typically completed within the first week of the first semester. There have been a number of projects within the mechanical engineering department (I/UCPC), that have an electrical engineering content of some complexity. In these cases the mechanical engineering teams have been able to describe the electrical systems and interfaces needed for the successful completion of their projects. Typically the captains and faculty advisors of these teams would meet with electrical engineering design faculty and students to try to convince them to form a team partnership. The sponsorship fees for these types of projects were shared on a pro rated basis with the electrical engineering program. As a result of these efforts there have been one or two projects of this nature each year for the past few years. The partnership between the business school and the mechanical engineering department has been described earlier in this paper.

Time for More Design Iterations: - It was seen that most of the capstone design teams had time for just one design iteration. Thus, after the initial design was built and tested and found to have flaws, analyses were then performed resulting in a redesign. This redesign was then tested and while it performed better than the initial design, it still was shy of meeting all specifications. It was anticipated that one more design iteration would result in many more projects being totally successful. Thus, it was determined to establish a schedule that would allow this to happen. The student teams clearly needed to accomplish more during the first semester. As such, a new path was taken that required all teams to have their design drawings totally completed, and all parts ordered or in hand by the end of the first semester. All ordered parts had to have an expected arrival date before the start of the second semester. Additionally, it was expected that some preliminary testing of some design subassemblies could be completed by the end of the first semester. This change has led to an improvement in overall team performance.

Results:

Some results have been obtained that show an overall improvement in the capstone design program. One of the metrics used to show program improvement is the change in the average of all of the ratings received from industry sponsors each year. This average rating has improved from 3.7 to 4.2 over the past six years. A 4 rating corresponds to the sponsor being very satisfied with the project results. This is shown in the figure below.



A team of mechanical engineering and business students has won the award, given by the business school, for the best business plan, for each of the past three years.

An excellent sense of community has developed amongst the faculty teaching the capstone design course. The use of the quality circle format has enabled the identification of relative weaknesses in the program and then a means for their correction.