121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #10465

Expansion of the ME/MET Capstone Course from One to Two Quarters

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Expansion of the Capstone from One to Two Quarters

Abstract

The Engineering & Design Department at Eastern Washington University (EWU) has traditionally taught the Senior Capstone course for the Mechanical Engineering (ME) and Mechanical Engineering Technology (MET) in a single 10-week quarter. Traditionally the course was more of a production run where students are required to design and produce a total of 15 fully functioning products. This was a good approach to the course when the students were a mix of MET and applied technology students. When the ME degree was added to the program in 2010, the course shifted more to a research and development focus than production. It requires one single functioning prototype instead of 15, and has ME and MET students working together since a separate capstone course was created for the applied technology students. This has definitely increased the complexity of the projects and made it easier to reach out to assist local industry. In order to successfully complete these projects, students must spend a lot of time on research and design before they begin building their working prototype. This was not the case when the course was more of a production run.

While it was possible to run the course as a one quarter as a production run, it is much more challenging to do so for a research and development one. Time constraints on parts availability and shipping, availability of the sponsoring party (if any), availability of some off campus facilities, the need for training etc., proved to be considerable when the course was run in the Spring of 2013. The successful projects were those that got started a quarter earlier (due to the initiative of the students themselves) while those that waited till the beginning of the spring quarter were under a lot of pressure and were not as successful. This led the faculty members to consider making the capstone course a sequence of two courses over two quarters instead of just one. This paper examines the factors that make a project successful through a careful examination of a couple of successful ones (that had started in the Winter quarter) and a couple of not so successful ones. The fact that some students took the initiative to start a whole quarter earlier allowed a pilot run. Faculty met regularly with the students and provided all the support needed. The authors came to the conclusion that the single quarter, 7-contact hour course is not sufficient and does not provide enough time to properly conduct research, design, order the necessary parts, get the adequate training (when needed)and test the product. This course needs to be changed, starting the academic year 2013-2014, into a two quarter, 8-contact hour course sequence.

Background

EWU is a regional university located in the eastern part of Washington. It has been offering a BS in Mechanical Engineering Technology for many years and has recently started offering a BS in Mechanical Engineering. Over the past two decades, more and more engineering and engineering technology programs have a required senior capstone course as part of their curriculum. The capstone course is a project-based course whose primary objective is to complete a large project, where students learn in the process and are evaluated based on their qualitative and quantitative contribution[1]. Before the addition of the BS in Mechanical Engineering in 2010, the capstone project was more of a production run than a research one. This is because the students enrolled in the MET program are typically the hands-on type. The project consisted of designing a prototype and producing 25 pieces, the number dropped down to 15 after a few years and remained so until 2009. The teams also included some construction management students. Typical projects included solar ovens, composite skateboards, and even a working sterling engine that functions off the heat of a hot cup of water. The project was done during one quarter (ten weeks) from start to finish. The focus was more on the production and not so much the research. Most of the effort went towards organizing the production runs as well as a focus on quality control of the 15 or 25 pieces required. While successful, these types of projects seem to be lacking the research component, but given the mathematical background of the students, it was the appropriate choice.

Since the addition of the ME degree in 2010, an effort was made to shift the focus from a production run course to more of a research oriented one, and this for both the MET and ME degrees. The teams are chosen as a mix of ME and MET students, each having slightly different, but complementary set of skills. Instead of 15 pieces, the students are required to create one working prototype or even a solid proof of concept depending on the project. However the project is usually much more complex from a technical point of view and the amount of background research much more involved. The program was run for the MET students one year before the creation of the ME program as a pilot program. The responses from the students were positive and the course rather successful. The same was done after the creation of the ME program and in addition the students were encouraged to seek industry sponsored projects. While some projects were successful, others were not as much[2]. The main challenge encountered was the lack of time, ten weeks seems to be short especially when one takes into account the response time from the company or sponsor and the time needed to ship or obtain necessary parts or services. Even when the project is not sponsored the time allocated is not sufficient and the students do not have enough time to perform research and execute the project. After consulting with the ME/MET department's IAC (Industrial Advisory Council), it was determined that the capstone course is to be offered over a two quarter period (2 credits in the winter and 3 in the spring) as opposed to a single 4 credit one. The IAC, a committee made out of representatives from the local industries, meets semiannually with the ME and MET faculty to discuss any pertinent issue including curriculum development and project collaboration. This change was implemented in the 2013-2014 academic year.

Literature Review

Engineering capstone design experiences in US universities over the past couple of decades have shifted gradually to multi-course durations. Figures 1 and 2 below present data from three national surveys on the duration of engineering capstone courses. The earliest survey by Todd et al.[3], the first known survey of this kind, showed more one-semester capstones than two-semester ones, but more multi-quarter capstones over those lasting a single quarter. When looking at the data overall, and differentiating as either multi- or single-term (semester or quarter), the split was nearly equal. A decade later, studies by McKenzie et al.[4] and Howe[5] both showed more capstones spanning two terms over single terms. The results from these later studies are similar, showing multi-term capstones were more common at approximately a 2 or 2.5-to-1 margin.

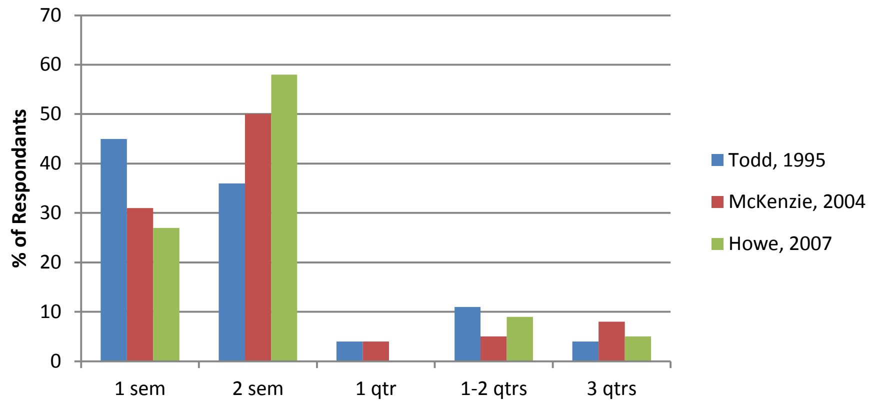

Figure 1 Distribution of engineering capstone course durations as reported from three national surveys from 1995 to 2007.

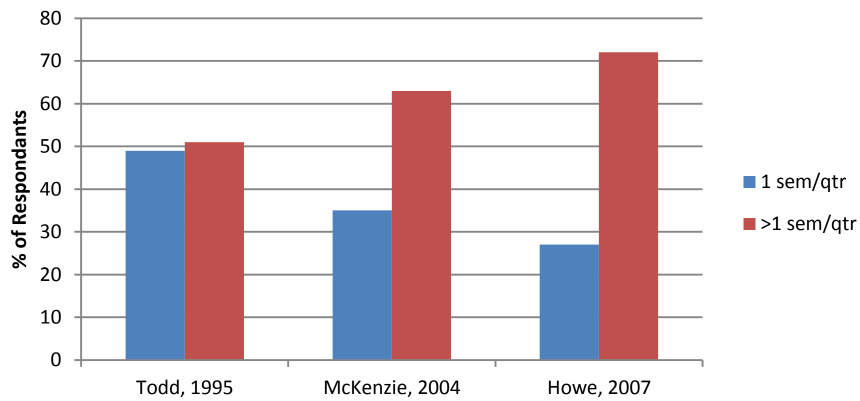

Figure 2 Distribution of engineering capstone course durations as reported from three national surveys from 1995 to 2007 presented as either single or multiple academic terms.

McKenzie[4] conjectured the shift to longer duration capstones was rooted partly in ABET changes over this time period. He stated that earlier ABET criteria required only conceptual design effort in capstones while later changes to the criteria required further prototype testing and design verification, for a more involved capstone experience. Dutson et al.[6] had also discussed this content-duration issue based on a review of the literature in 1997, in which they expounded briefly on the implications of capstone duration stating "*…construction and testing of prototypes and special equipment is generally not possible in shorter courses. The amount of detail required in paper designs and feasibility studies is also limited by the duration of the course*." Howe[7] showed that the breadth of content capstone courses had increased significantly over the decade since Todd's study[3], with Todd identifying nine major course topics in 1995 and Howe 24 topics in 2005, with increased emphasis on topics such as professional development and teamwork. Topics from Todd's study and Howe's study are given in Figure 3, taken directly from Howe[7].

1994 Survey Responses +		2005 Survey Responses (n = 343)	
Topic	%	Topic	%
Oral Communication	61%	Written Communication	87
Drawings/Creativity/Concept Generation	48%	Oral Communication*	83
Teamwork Essentials	44%	Engineering Ethics*	76
Planning/Scheduling	42%	Project Planning and Scheduling*	72
Engineering Ethics	40%	Decision-Making	68
Engineering Economics	40%	Teambuilding	66
Developing/Writing Functional Specs	36%	Team Dynamics	63
Safety in Product Design	33%	Engineering Economics*	61
Optimization	31%	Developing/Writing Functional Specs	56
		Safety in Product Design*	52
+most frequently taught topics from 1994 survey,		Leadership	50
as reported in *JEE* [3] (full list for 2005 survey)		Standard and Regulations*	49
*2005 survey topics repeated from 1994 survey		Drawings/Creativity/Concept Generation*	48
		Analysis Tools*	46
		Intellectual Property/Patents	45
		Prototyping and Testing*	37
		Optimization*	34
		Sustainability	29
		Manufacturing Processes*	29
		Risk Assessment	29
		CAD Design and Layout*	29
		Product Liability*	24
		Quality Function Deployment*	17
		Other	13

Table 3: Topics Taught in Capstone Courses.

Figure 3 Evolution of topics in capstone courses, from Todd et al.[3] 1995 and Howe[7] 2005 (source: Howe[7])

The studies presented above show a trend toward longer duration capstone experiences with corresponding increases in content. There is a great deal of literature with very good discussions on the various content and organization of capstone courses, as well as the drivers involved – ABET, industry needs, evolving engineering specialties, program specialties and needs, etc.

There is little research, however, on the implication of capstone duration to its intended objectives, and there are contradictions in the findings that are available, as mentioned by Griffin[8]. For instance, Griffin[8] cites a study by Bateson[9] that purported students in yearlong classes outperformed their peers in similar semester-long courses, and going further saying that the shorter the course, the poorer the student results, with quarters resulting in the lowest scores. A study by Logan and Geltner[10], again highlighted by Griffin, reported, conversely, that students in shorter "compressed" courses had higher success rates over peers in longer duration courses. Griffin's interest in this topic was based on discussions at Georgia Tech on the merits of one- or two-semester long engineering capstone courses, as the faculty were divided as to the best choice. Griffin et al. conducted a study on capstone duration with the following research questions (among others): "*Do longer course offerings result in better outcomes?*" and "*How much faculty resources could be saved from adopting the shorter offering?"*[8]. The stated learning objectives studied were reported as technical writing skills, presentation skills, and technical analysis. The results of the study indicated that one-semester long capstones achieved the objectives and, subsequently, a shift was made from two- to one-semester capstones in 2003, a reversal of the current trend. It should be noted that capstone courses in the US vary considerably from school to school and even between departments and faculty within the same school, with many differences in objectives, needs, and resources. For example, the department at EWU University has always believed the role of the instructor to be that of a reference, facilitator and supervisor. Usually the instructor meets with the groups every time the class meets, requires weekly updates and memos on the project progress and assesses the final product.

The shift to a two-quarter capstone sequence at EWU follows the typical trend in the US of including more R&D types of projects, which span the full engineering design process – problem scoping through prototype testing. More professional development objectives are also being emphasized, such as more student presentations, project management, and teamwork.

Capstone Project Experiences at EWU

During the Spring 2013 Capstone class we had 25 ME and 13 MET students that worked on 7 projects. The complexity of the projects continued to evolve as they embraced the R&D focus of the course. The projects ranged in complexity from the analysis and construction of cross bows to the design and construction of both a functional windmill and a quadcopter. This paper examines 4 out of 7 projects as it focuses on the extreme cases, i.e. the best and the worst. The remaining projects were not as relevant in identifying the most critical factors to a successful Capstone project. Most of the projects were self-selected by the students although two were driven by customers – building a captive dual copter system suitable for use in Computer Science classes on controls and testing of seat frame models for Commuter Cars Inc. The students for the two most complicated projects approached the instructors at the end of fall term and the beginning of winter term so they did much of the design work during winter quarter in consultation with the instructors. This was a great opportunity to test the effectiveness of a two quarter capstone before actually implementing the changes. The success of these two teams drove us to act upon our feeling that expanding the Capstone course to two terms was in the best interest of the students.

Early on during the winter quarter, a group of students came to the faculty to ask about the possibility of starting their capstone project a quarter ahead of time since Capstone was run during the spring quarter only. The team was already formed and the project consisted of building a self-leveling quadcopter as shown in figure 4. The students were very enthusiastic about the project and did an excellent job presenting it to the faculty. No one received any extra credit for starting early, but the students met regularly as a team as well as with the faculty as if the course was actually in effect. The project involved a lot of electronics work and programming, an area where our ME/MET students have not had extensive exposure. Therefore, strict deadlines were imposed even during the winter quarter as part of accepting the project.

The extra time allocated to this project allowed the team to go beyond what can be expected from a team in nine or ten weeks. The students had enough time to research and optimize their design based upon the components that they could acquire with their limited budget. The students researched different quadcopter designs, available power sources, available motors and their technical specifications, propeller designs, and materials. They learned how to install and program the Arduino board necessary for the proper functioning of the quadcopter. They modeled all the parts using Solidworks and performed Finite Element Analysis on many parts, including the frame, legs and motor mounts. Data was collected on the lift produced by several combinations of motor and propeller. In addition, power consumption and power sources (i.e. batteries) were analyzed to produce the optimum power to weight ratio for this application. This allowed the team to make a much more informed decision on the components to use.

By the time the spring quarter rolled around, the team had a very clear idea of what needed to be done and how. The major decisions had been made and most of the parts ordered. The project was reduced to constructing the copter and testing it. Attention to detail was also increased, the team had the chance to professionally anodize the frame, add the school logo and generally speaking add more aesthetic details that made the final product look very professional. The experience as a whole was very successful and the extra ten weeks or so gave this team plenty of time to do the research, finalize the design process and start execution.

Figure 4 Quadcopter

Another team decided to create a power generating windmill based on a design that uses a ball like turbine instead of the more traditional radial blades. Here again, such a project would have probably been refused based on the fact that there is not enough time to design, build, and test the system in ten weeks. The windmill team was composed of 10 students that broke into two subteams. One subteam was responsible for design and fabrication of the generator from scratch while the other designed and built an Energy Ball style windmill and stand. This required a great deal of research by this group of ME and MET students since aerodynamics and the details of electric generation are not covered in our curriculum. By the end of the winter quarter, the team had decided on the general design criteria including the size and primary materials and had started building a small scale turbine prototype.

The windmill was fabricated from steel rather than the much more applicable composites due to the student's familiarity with the materials and ability to get donated steel. The generator was built around a donated car axle bearing and involved a great deal of problem solving during design and fabrication, particularly with respect to placement of the high field rare earth magnets. While the final product was not as efficient as the ones available on the market, the students nonetheless produced the turbine and the generator on time and under budget. The main reason behind the low efficiency of the turbine resides in the fact that heavy steel was used (as opposed to composite materials on the ones available in the market) and the generator could also have been designed in a more efficient way. This team had team dynamic issues – there were too many strong leaders and not enough followers so they did not reach their full potential, particularly with respect to their final presentation. This is an issue that the instructors believe can be addressed during the first term of the new two-term Capstone course.

Figure 5 The energy ball style windmill and coils mounted in the generator.

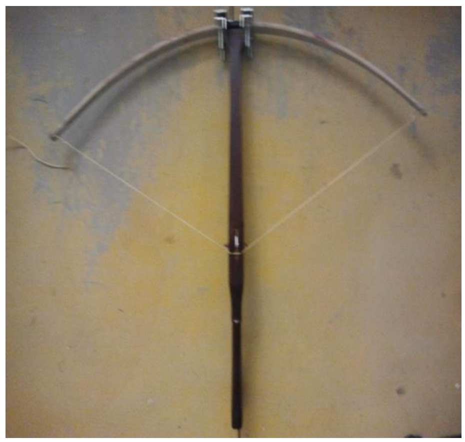

Figure 6 One of the two crossbows

Two of the teams that worked on their projects only during spring term were not nearly as successful as the two teams described above. The crossbow team was a group of friends that spent the first two weeks of the term defining the scope of their project as they all had different ideas, but wanted to work together. They selected the crossbow based upon the Finite Element Analysis that one of the team members had performed the previous term in the FEA course. At this point, they had to select and procure materials and develop the fabrication processes. They had all come into the course with different ideas and the stress of trying to complete the project in the short time remaining in the term meant that they never fully gelled as a team focused on a single project. As a result, by the end of the term, some of the team members were barely speaking to each other and their final paper and presentation were poorly coordinated. Once again, the instructors believe that more time to work on team dynamics and optimize the design before prototype construction would have resulted in a more successful project.

The captive dual copter project was proposed by the chair of the Computer Science department for use in his controls class. He had developed some conceptual drawings to define the scope of the project for the team. This team was an eclectic mix of students who did not find places on any of the other teams. They initially did a good job of organizing their efforts to examine design options so they could order materials and components. However, by the middle of the term they had fragmented based upon their competing demands – primarily another time intensive course and outside work. When this was combined with the 4-5 week lead-time for some of the components they lost focus and drive during the middle of the term. As a result they had a mad rush at the end of the term by part of the team to complete the project and consequently burnt out one of the motor controllers due to reversed polarity during testing. Once again more time would have permitted more emphasis on team effort and avoided the mad rush to complete this fairly straight forward project.

The final course grade is an average of the draft and final report, design review and final presentation, weekly reports, team evaluations, and a qualitative self-evaluation. In addition students were tested on engineering ethics and were required to submit a life-long learning portfolio. The strong and weak projects are chosen based on these parameters. These same tools are used with the two quarter method with a more formative approach during the first quarter and a more summative approach during the second quarter. The authors believe that these criteria reflect the nature of the course and are a good assessment tool.

Student Perceptions and Instructor Evaluations

We have continued the data collection and analysis that was presented last year[2] with the addition that we have analyzed the data for the ME and MET students as both separate groups and together as was done in the past. The results from the analysis of the most recent class during the Spring 2013 term are shown in Figure 7. Most of the scores have increased from the previous year as we have fixed the issues that we found the first two times that we taught the course in the R&D rather than the production mode. The three biggest findings from this data are:

1. There is still a significant disconnect between the student perceptions and the instructor evaluation for both team dynamics and lifelong learning.
2. The student perception in several areas was dramatically lower for the MET students vs. the ME students.
3. No assessment of accounting and cost control was done by the instructors other than checking the reimbursement forms for errors.

All three of these findings can be traced in part back to the very fast pace of the Capstone course during a single 10 week term. We believe that conducting the course over two terms will allow us to address these issues. During the 2014 Capstone session we will incorporate the following items into the course.

- We will provide team building tools so that the teams can overcome their differences and operate more efficiently. Several of the MET students felt that some of the ME students saw them as second class team members who were there to work in fabrication roles. Based upon the written comments this was a major reason for item 2 above.
- Spreading the lifelong learning tasks over 2 terms will allow the instructors to provide more input on the quality of the work (rather than just that it was completed) and to emphasize importance of this endeavor.
- During winter term we will have the students set up to use MS Project to track both project status and costs. It will then be second nature to for them to update during spring term when they are generally very busy with building and testing of their projects.

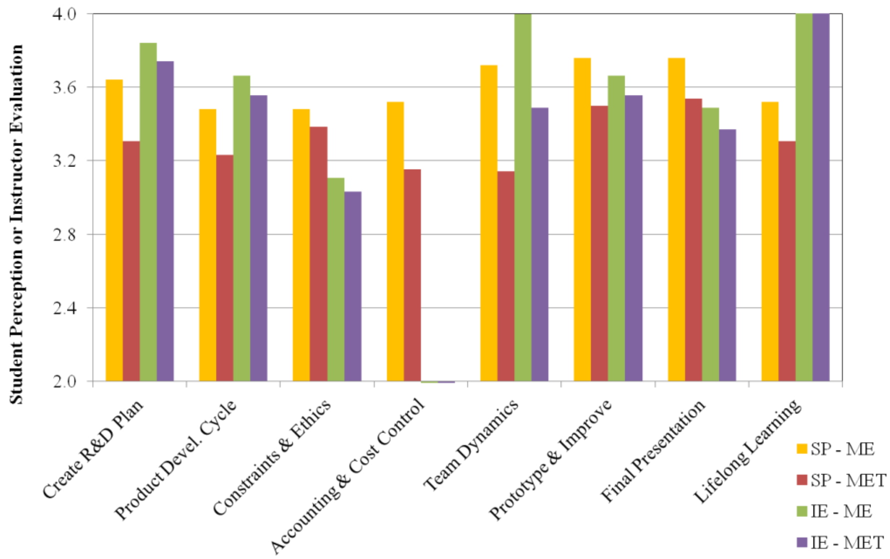

Figure 7 Student Perception (SP) and Instructor Evaluation (IE) of the Course Objectives on a 0 to 4 point scale (>95% is a 4 and 70% is a 2 for the IE) analyzed separately for the 25 ME and 13 MET students during the Spring 2013 class.

At the end of the capstone class we conduct an exit survey of the students to learn more about their overall perception of the program and their experience at EWU. The results of this survey are presented in figure 8 and broken out for the ME and MET students. We believe that the shift to a two quarter capstone course may help address the low scores for the first two items since we stressed how the capstone course simulated the workplace and they were definitely overwhelmed. The MET students scored Apply Math and Science lower than the ME students which is expected due to their less math and science intensive coursework. Discussion with several of the MET students indicated that the discrepancy in scores for Ethical/Social Responsibilities and Diversity is most likely due to the fact that several of them felt like they were seen as a second class citizen on their team by some of the ME students due to their different skill set. This is something that will be strongly addressed during the 2014 capstone course.

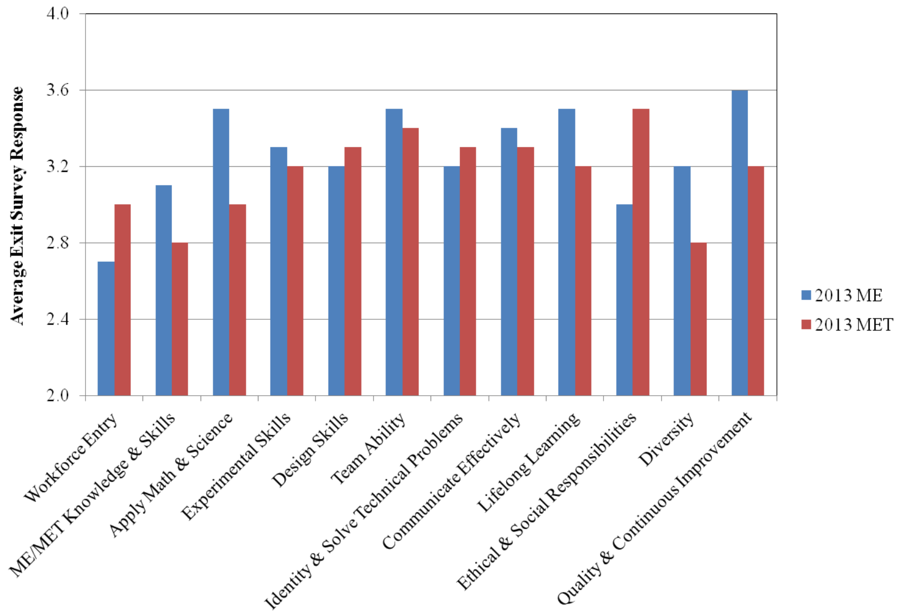

Figure 8 Exit survey results from the spring 2013 Capstone class.

Figures 9 and 10 show students perceptions and instructor evaluations data, respectively. The data was collected on a five point Likert scale and spans a total of five academic years, the first two have MET and applied technology students only while the remaining are a mix of ME and MET students. It is also important to note that prior to 2010-2011 the capstone course as more of a production run than a R&D one. Examination of these figures shows some term to term variability, but a general increase in the scores. Some of the low scores for the 2010-11 can be attributed to the change to the R&D focus in a course composed of mostly MET students, while those in 2011-12 are most felt to be due to a change of instructors midterm due to illness. The changes have not been analyzed for statistical significance.

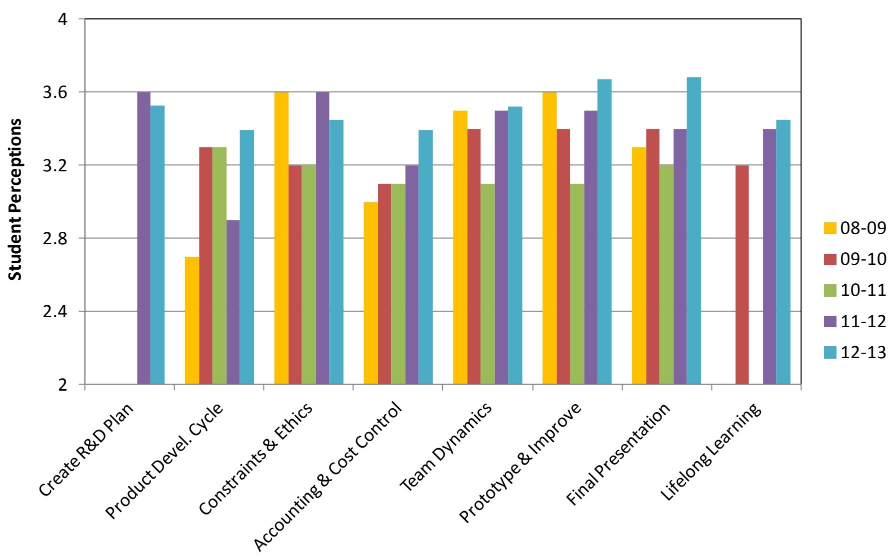

Figure 9 Student perception of how well the objectives were met by academic year.

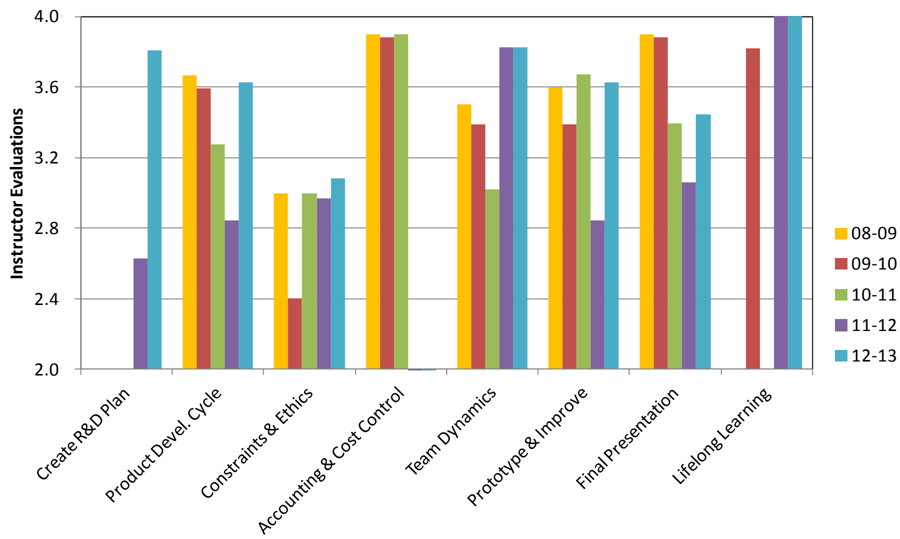

Figure 10 Instructor evaluations of student performance vs. the course objectives by academic year.

Discussion

It is clear based upon the results of the spring 2013 Capstone course that the nine to ten weeks allocated during a single quarter Capstone course is not sufficient to produce the high quality and thorough work expected of modern engineering students. To encourage research and a detailed design process requires at least an additional ten week quarter. It is important to note also that two quarters is not an excessive amount since the two teams which started early had just enough time to finish. The enthusiasm of the two groups of students allowed us to do a pilot run for a two quarter Capstone course before we could make the official change. In addition, our previous experience has shown that when working with industry-sponsored projects over one quarter there are many additional challenges including not having enough time for shipping parts or obtaining technical assistance[2,11]. Switching to two quarters will permit enough time to obtain the necessary parts and support.

Another advantage of having two quarters as opposed to one is the possibility of the instructor to monitor the project and the dynamic interactions between the students much better. There is much more room for adjusting or fine tuning the project as more progress is made. Often times, the initial idea or concept presented or sought must be modified or changed. With enough time these changes can be done in an efficient way without compromising the quality of the work. Furthermore, more peer evaluations can be performed so the students are aware of their standing in the team and have time to ameliorate their performances. Often times, poor performing students have used the argument that they were not aware that their performance was lacking since no feedback was given to them until it was too late to change. During the Winter 2014 term we have used the formative team evaluation process to assist individuals and teams in solving the issues around individuals who were not effectively contributing to the team during the first 4 weeks of the course.

Conclusions and Future Work

With double the amount of time allocated for the course more, better quality work can be expected from the students, making the Capstone experience much more relevant, challenging, and interesting. The plan is to require teams to finish their background research, initial design, and order their parts during the winter quarter, so that during the spring quarter, the students have a very clear idea of what needs to be done and have most if not all parts available. By giving the students twenty instead of ten weeks, not only will the quantity of work increase but also the quality.

We are conducting the ME/MET Capstone course over the winter and spring quarters of 2014. As part of this transition, we have formalized many aspects of the early research and development effort. In addition to the project proposal required previously, the teams will have to do a thorough literature review to determine what has been done previously and to more fully define the various constraints. This will lead into two rather than one design review – the first to their classmates and the second to the ME/MET faculty to get approval to start purchasing and fabrication of their project. They will also be required to track the project costs in MS Project and use a pay rate that they get to define which will help them focus on the fact that time is money.

Bibliography

1. Engebretson, A., & Meysenburg, M. (2003). Project-Based Courses. *Annual Midwest Instruction and Computing Symposium*. Duluth, MN
2. Weiser, M. W., Saad, H., Hossain, N. M. A. (2013) Incorporating Engineering Challenges into Capstone Design and Senior Project Courses, Paper 7199, *120th ASEE Annual Conference*.
3. Todd, R. H., Magleby, S. P., Sorensen, C. D., Swan, B. R. Anthony, D. K. (1995). A survey of capstone engineering courses in North America. *Journal of Engineering Education*, (84)2, 165-174.
4. McKenzie, L. J., Trevisan, M. S., Davis, D. C., and Beyerlein, S. W. (2004). Capstone design courses and assessment: A national survey. *Proc. American Society for Engineering Education Conf.* Salt Lake City, UT.
5. Howe, S., (2008). Focused follow-up to 2005 national capstone survey. *Proc. American Society for Engineering Education Conf.* Pittsburgh, PA.
6. Duston, A. J., Todd, R. H., Magleby, S. P., Sorensen, C. D. (1997). A review of literature on teaching engineering design through project-oriented capstone courses. *Journal of Engineering Education*, (86)1, 17-28.
7. Howe, S. (2010). Where are we now? Statistics on capstone courses nationwide. *Advances in Engineering Education*, (2)1, 1-27.
8. Griffin, P. M., Griffin, S. O., Llewellyn, D. C. (2004). The impact of group size and project duration on capstone design. *Journal of Engineering Education*, (93)3, 185-193.
9. Bateson, D. J. (2000). Science achievement in semester and all-year courses. *Journal of Research in Science Teaching*, (27)3, 233-240.
10. Logan, R. & Geltner, P. (2000). The influence of session length on student success (Research Report 200.4.1.0). Office of Institutional Research, Santa Monica College.
11. Saad, H.S., Weiser, M.W., (2013) Partnering with Industry on Mechanical Engineering Capstone Projects, paper IMECE2013-66092, ASME 2013 International Mechanical Engineering Congress and Exposition, San Diego, CA, Nov. 15-21