AC 2007-732: SENIOR DESIGN PROJECTS IN MECHANICAL ENGINEERING – ACTIVE INVOLVEMENT OF INDUSTRY PARTNERS AND ADVISORY COUNCIL

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Senior Design Projects in Mechanical Engineering – Active Involvement of Industry Partners and Advisory Council

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Introduction

Like most other programs, the curriculum of the Department of Mechanical Engineering at the FAMU-FSU College of Engineering is capped with a one-year senior design project in which the students work in teams to design and implement products or systems under the sponsorship of an industrial partner. It has been recognized that capstone design courses represent an excellent vehicle to round out a good engineering education and they provide the appropriate platform for students to apply design thinking and transition into a professional career[1]. Many universities have adopted this model for their engineering curricula[2,3,4]. At the FAMU-FSU College of Engineering this course was first introduced in Mechanical Engineering as a one-year sequence within an integrated curriculum in the 1999 academic year.

Our core Mechanical Engineering curriculum culminates in a two-semester capstone design project experience allowing the graduating class to work on relevant engineering projects by applying the knowledge acquired in the preceding years. In addition to the application of traditional engineering skills and knowledge, many important elements of engineering training are seamlessly integrated into the senior project, including teamwork, technical communications, and project management. This two-semester format provides the opportunity to define projects spanning a full product design cycle, starting from problem formulation, to concept generation and selection, design, and prototype implementation. The course is conducted not in traditional "lecture" format but through frequent 'design reviews' or 'staff meetings', emulating the real-world project practice the students are likely to face upon employment.

In order to provide projects that closely simulate the industrial environment, we work with the Mechanical Engineering Advisory Council (MEAC) and other industry contacts to identify partners who can sponsor high-quality and engineering-relevant projects. Industrial involvement to the program has been excellent since we initiated the new format in 1999-2000. We have increased the external-supported projects from 12% in 1999-2000 to more than 80% in the past three years. Moreover, we have integrated effectively the capstone experience in our continuous assessment process by involving industrial project sponsors and MEAC members in the annual project review as external evaluators.

At the end of the school year the capstone course concludes with a one-day review event including final presentation and open house. All teams make presentations describing their projects and the results obtained in front of students, faculty and external sponsors. Following the presentation, students showcase their projects with posters and the actual hardware built by the teams. During the review session, external sponsors and MEAC members are invited to serve as panel judges and give feedback not only to the student teams about their projects, but also to the department on any strengths and weaknesses of the curriculum as observed by them from the capstone design review. The capstone open house is followed by a two-day MEAC semi-annual meeting where the feedback from industry is further discussed and plans are drawn to integrate into the capstone course and the curriculum in general. This tightly interwoven relationship between the capstone course, curriculum evaluation, and MEAC participation has served the department well in many fronts: continuous improvement of the capstone course and curriculum, harvesting of relevant projects for the capstone course through strong industrial involvement, and expanded career opportunities for our graduates.

A recent article by the authors describes our overall capstone experience, including the evolution, format and mechanics of the senior design project course[5]. The current paper will deal with aspects of the involvement of the industry sponsors and MEAC, such as project harvesting, reconciliation of learning objectives, corporate buy-in, effective feedback, etc.. In particular, this paper will expand on some of the feedback received from the MEAC in the last 2 or 3 years on how to better incorporate systems engineering (SE) to the capstone design course and the curriculum in general. To that end, we will present some of the observations from the MEAC as well as our own as to why SE needs to be introduced, and how to best accomplish it. We will summarize the results of the two-day forum held at the FAMU-FSU College of Engineering in January 2007, in which industrial partners and MEAC members gave us guidance on how to best introduce SE to the curriculum.

Senior Capstone Experience

The current capstone experience includes two parts: First, the "Engineering Design Methods (EDM)" course introduces subjects relevant to the design such as team dynamics, the design cycle, cost analysis, concept generation and selection, technical writing/presentation, etc.. This course runs concurrently with the first semester of the two-semester "Senior Capstone Design" course, although at some point this course will be moved up to the junior year. The capstone project course is entirely project-based and very few lectures are used to introduce the projects and guide the teams through the design cycle.

Since its inception in 1999 the senior design course has seen steady growth in enrollment as well as in industrial participation. Since the capstone course is a required part of the curriculum, enrollment perfectly tracks graduation numbers for the department. We are now graduating over 60 students each year, with that number expected to increase to 80-85 over the next 2-3 years. Of further significance is the growth in industrial participation. When the course was started in 1999 we had only 2 projects (12%) sponsored by an outside industrial partner. We have consistently increased that percentage and today we are running close to all projects with an industrial sponsor (close to 90%). We feel this is the limit and will not try to achieve 100% of industrial sponsorship. There are many instances of valuable projects that we would like to pursue with the class that do not involve industry, such instances include service-oriented projects (community-based), projects involving spin-offs from research activity by our own faculty, or student-based organizations such as SAE or ASME.

Project Harvesting

Since the entire pedagogical premise of the capstone experience revolves around engineering design projects, and great effort goes into mimicking as much as possible the conditions encountered by engineers in industry, the quality of industrially-sponsored projects is paramount. Very significant effort goes during the summer prior to the beginning of classes to "harvest" enough quality projects from industry to staff enough design teams including the entire graduating class.

The task of securing enough projects and corresponding funding to feed the capstone experience course, although always daunting, has become somewhat easier in recent years due to two important factors:

- Active involvement from the department's industrial advisory council (MEAC), which has been very proactive at helping us secure participation from divisions and engineers from their home organizations, and
- A significant fraction of "repeat business" with many companies returning in subsequent years to sponsor more projects after realizing the benefits of their involvement (new design ideas, building and testing of early prototypes, exposure to faculty and students, recruiting opportunities, etc.)

At this point we have a solid base of industrial partners to secure enough industrial projects, although every year we have some sponsors that cannot return, or are not in a position to sponsor. Coupled with steady enrollment growth, this makes project harvesting always challenging, so the department is continuously searching for new opportunities to partner with industry.

Open House

At the conclusion of the academic year the capstone course features a final review/open house for the teams to make presentations describing the project and the results obtained, as well having an open house with posters and the actual hardware produced by the teams. This open house is a very special occasion for the department as not only the sponsors travel to attend, but we also invite our entire industrial advisory board. These engineers and engineering managers from industry serve as a panel of judges and give feedback not only to the student teams about their projects, but also to the department on any strengths and weaknesses gleaned from the capstone design projects.

The open house is usually a very festive all-day event as the vast majority of students will be graduating within the following three weeks, and this is an opportunity to showcase their hard work on the projects and spend some quality time with teammates after sharing many hours of sacrifice throughout the year. We end the event in the early evening with an informal dinner for the entire class, faculty involved, as well as all industrial partners and advisory board members. We consistently manage to attract most of the industrial sponsors for this event, even when long travel is involved. This is a testament to the importance these sponsors place on working with our students.

Industrial Involvement

The selection of the sponsor (the person from industry that will interact with the students and act as "customer") deserves special attention. As important as defining good projects for the students to work on is the industrial liaison that will work with the students and serve as "customer". In a large class with only one faculty acting as instructor/coordinator, the quality of mentorship offered by our industrial partners is of critical importance for the success of the project. Having strong backing from management is not enough if the individual mentor does not "buy into" the concept of capstone project sponsorship. He/she needs to perceive the value of industrial involvement and the benefits of the student work, however minor they might be in the context of the organization's goals. These benefits could be direct, in the form of project results, data, or prototypes; but they could also be indirect, such as potential recruitment targets, image creation within the entire graduating class, or development of industrial-academic contacts. Once a good "mentor" is identified in industry, we do everything we can to retain that person for future years, and conversely, if someone does not get involved with the design team to the degree expected, we tend to avoid such sponsor in future years. Over the years, we have developed a very strong group of mentors.

Multi-disciplinary Capstone Experience

Another aspect in which we have had mixed success and much work remains to be done is in exposing our students to multi-disciplinary design. Many of the projects we harvest from industry are, by virtue of coming from the "real world", multi-disciplinary in nature. In particular, many projects are ideal platforms for the interaction between mechanical and electrical engineering students. Every year we make attempts to integrate ME and EE students in our projects. However, we have run into impediments to do it in a widespread manner as a result of institutional differences within our own college, and the disparity of curricular requirements among the different departments when it comes to capstone experience. To date, we have not been able to involve as many students from other majors as we would have liked.

Senior Capstone Experience and System Engineering Curriculum – Summary of Findings

Traditional engineering education is centered around the notion of exposing students to specific engineering 'sciences', with the addition of some design courses and/or "capstone" design experiences. Despite its importance, most engineering curricula do not include formal exposure to SE as practiced in industry. We convened a two-day forum (January 30-31, 2007) to elicit input from our industrial partners and some MEAC members to discuss the pros and cons and the feasibility of integrating more SE early into our undergraduate curriculum before the senior capstone design exposure. This section summarizes our findings.

Why Systems Engineering? – Observations from the Capstone Course

We have run the capstone design course under the same format since 1999, coordinating more than 100 student team projects during that time (most of them sponsored by industry), and nearly 400 students have gone through the program[5]. Overall, the program has been very successful at providing student with a very realistic experience in terms of defining engineering problems, following the design process under shifting requirements, practicing team dynamics, and gaining a general appreciation to how engineering is practiced in the "real world". Under our current curriculum, all students have been previously exposed to the fundamentals of the design process before taking the capstone course. During sophomore year in the "Introduction to Mechanical Engineering" course, they have seen the phases of design, and how to conceptualize and select among alternative designs. They have also been engaged in limited-scope design projects as part of some of the core courses throughout their sophomore and junior years.

We have observed that, in the context of the capstone project implementation, seniors seem to apply some of this knowledge very aptly. Students instinctively reach for their experience and promptly decompose the requirements and start conceptualizing possible design solutions. They also apply a more or less quantitative approach to select a preferred design solution (e.g., a selection matrix). However, at this stage their ability to create mathematical models to support the selection matrix is weak. Once a design has been selected, the next steps in the process reveal further weakness among the students. They generally show no tendency (unless steered by the capstone course instructor) to perform exploration of the "trade space" or system modeling to achieve desired design parameter optimization. On the contrary, many teams appear to follow a rather "unsystematic" approach once a perceived "adequate" design solution has been reached. This is also an observation that can be extrapolated to some extent, to engineering practice in general[6].

We decided to address this perceived deficiency and organized a forum/workshop with our industrial partners to discuss ways to better integrate the concept of SE into our curriculum (if needed). We want to take the industrial perspective into consideration before attempting a curriculum overhaul to accommodate more exposure to SE. This forum and its main conclusions are covered in the following sections.

Format of Systems Engineering Forum

The forum on SE mentioned above took place over two half day sessions. Participants included faculty from the Mechanical, Electrical, and Industrial Engineering Departments, and industrial partners representing Lockheed Martin, AFRL/Eglin AFB, and Talla-Tech (all strong project sponsors for our capstone design program). During the first day, faculty from Mechanical Engineering presented to the industrial panelists a summary of our integrated curriculum (so they understood its philosophy, contents, and constraints to change). The presentations on systems engineering (with case studies) were made by the industrial panelists not only to the faculty, but to the entire Mechanical Engineering senior class as well. This part of the forum was scheduled to coincide with class time for the senior design project course. This added a pedagogical component to the forum by exposing students to real-world examples of how SE is applied in industry for the design and engineering of complex systems. It also allowed for interaction between the students and the industrial panelists, leading to a series of fruitful questions and discussions.

Since all students in the senior class are working in teams on capstone design projects, many of them sponsored by the companies represented by the panelists, three teams were selected to make brief (mini-review) presentations. The students presented the project scope, briefly described their designs, and explained what aspects (if any) of SE had been applied on their specific projects. This interaction allowed the panelists to bring up other possible ways in which SE tools could have been used during the design process (the timing of the forum was such that most teams had concluded their design phase and were in the manufacturing and implementation phase).

During the second day of the forum, faculty and industrial panelists had a closed-door session (half day) to discuss the items on the agenda and exchange ideas as to what could be the best practice way to incorporate SE to the curriculum, and more specifically to the capstone senior design course. The discussion was freewheeling but structured around the following questions and topics:

<u>Sub-session I</u>: What is systems engineering?
- <u>Topic 1</u>: Based on the definition of "systems engineering" commonly used in industry, is this a skill that undergraduate students should have prior to their first work experience?
- <u>Topic 2</u>: How can we best encourage students to think "system" when engaging in the design activities of the capstone project course?
- <u>Topic 3</u>: What are the skills that define a good systems engineer?

<u>Sub-session II</u>: How to teach systems engineering?
- <u>Topic 1</u>: How did good systems engineers acquire their skills?
- <u>Topic 2</u>: Can students without any work experience and very limited project experience be given relevant projects/theses to apply systems engineering? Should systems engineering be treated as a graduate-level subject?
- <u>Topic 3</u>: What are good textbooks/materials to teach systems engineering?

A summary of the discussions and the main conclusions reached by the panelists will be given in the following sections.

<u>Summary and Conclusions from Systems Engineering Forum</u>

From the discussion prompted by the topics described above, it is obvious that consensus has been reached on a few points. Our intent here is not to include all aspects of the discussion at the forum, but rather concentrate on those points in which some consensus was reached by all participants. These conclusions give us a "minimum specification" for how to better integrate SE as part of a design component in our integrated curriculum. The main conclusions from the forum (in summary form):

- It is not practical or needed to achieve a comprehensive understanding of SE at the undergraduate level; it is sufficient to expose students to the concepts, language, and minimum toolset.

Given the constraints with most undergraduate engineering curricula, it was deemed impractical to introduce a full course on SE. Furthermore, it was generally agreed that it is probably unnecessary at the undergraduate level. The consensus recommendation was to introduce some basic concepts and language early in the curriculum. Many sources were mentioned as starting points for course material[7,8]. Built upon this early exposure, the consideration of fundamental SE concept should be stressed through all design-relevant experiences in the curriculum.

- Systems engineering (as a formal course subject) is best introduced at the graduate-level.

There was also a consensus in that the first course fully based on SE is best taught at the graduate level. If possible, such a course could be required at the MS level, especially for those who are inclined to join the industry workforce immediately after graduation. It could also be made a technical elective for seniors under certain circumstances.

- Any introduction of systems engineering at the undergraduate level needs to emphasize the importance of developing and exploring the “trade space” as part of the design process.

The desired outcome from introducing SE into our curriculum would be an improved design approach as observed during the capstone experience. Our objective is to inculcate the need to introduce quantitative models during the concept selection phase, and for the students to do a better job of exploring trade space aimed at optimizing design solutions.

Two other aspects that came out of the forum, not necessarily related to curriculum reform in our department, but worth mentioning as well:

- A good way of introducing SE into a department is to emphasize design-driven applied research among the faculty.

- A good SE foundation with the students will also accomplish the objective of encouraging “life-long learners” as many of the skills will help them tackle problems outside their area of competency.

Curriculum Action Plan

The agreed-upon action plan consists of rearranging the way design is taught in our curriculum. The integrated curriculum already includes plenty of design-relevant activities in the engineering core courses. But we intend to add more structure to the curriculum by having a design-specific “track” running parallel to the teaching of the engineering disciplines. This is a similar approach to the “design spine” already adopted by other institutions[9,10,11,12].

In our curriculum, we already have some exposure to design at the sophomore level in the course "Introduction to Mechanical Engineering". Students are taught the fundamentals of the design process, how to conceptualize possible solutions, and some basic tools for decision-making. In its present structure, our curriculum does not have any design-specific course in the junior year (currently overloaded with engineering core courses). On the other hand, there is an "Engineering Design Methods (EDM)" course in the senior year that runs concurrently with the first semester of the capstone design project. We propose to move up this course to the junior year and, at the same time, re-tool it to make more effective use of the credit hours. The plan is to include a brief introduction to SE in the EDM course in the junior year. We will initiate a "Professional Lecture Series" by inviting engineering professional to present realistic case-studies to our students in this course emphasizing on systems approach. This EDM course also includes a brief model on optimization, which can now be turned into a controlled example of how to explore and optimize in trade space during the design process in the new format.
As it is now, the curriculum would then conclude with a capstone design project experience in which we will track the benefits of curriculum change to include a design track reinforcing not only engineering science, design methods, but also now SE concepts and techniques.

Conclusions

The capstone senior design course in the Department of Mechanical Engineering at the FAMU-FSU College of Engineering has proven to be an excellent vehicle to educate our students in team-based design, and the application of engineering fundamentals to real-world problems. The program has evolved over the last eight years and reached a high level of maturity. In eight years we have worked over 100 projects and graduated nearly 400 mechanical engineering majors, while also involving nearly 50 students from other majors. A complete record of projects and their sponsors is compiled in the course website: www.eng.fsu.edu/ME_senior_design. This capstone course has allowed us to create a good foundation for attracting industrial partners that provide project ideas, funding, and mentorship to turn the experience into a much more realistic platform for educational delivery.

Following this success, it is logical for us to explore the possibility of integrating systems engineering concepts into the Mechanical Engineering core curriculum. With the help of our industrial partners we have created an action plan to further improve the teaching of design practices by introducing basic concepts of systems engineering as practiced in industry. We intend to introduce modifications to our curriculum over the next two academic years to ensure that our students receive a progression of design exposure from the sophomore year on, and culminating in the capstone design experience.

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