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Engineering capstone senior design

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ABSTRACT: In this article, the author presents his experiences in the development and coordination of capstone senior design in a small engineering programme. The mechanical engineering programme at Indiana University-Purdue University Fort Wayne in Fort Wayne, USA, is relatively small and only undergraduate. Capstone senior design in the mechanical engineering programme at Purdue University, Fort Wayne has gone through several modifications and upgrades over the last few years. Before these changes, the capstone senior design programme was criticised by the ABET accrediting teams and was cited as weak. Because of this, the faculty developed and implemented a new approach, and structured new guidelines to strengthen the capstone senior design. This effort resulted in a much stronger capstone senior design, and the mechanical engineering programme was commended and praised in this area.

INTRODUCTION

The capstone senior design project is a degree requirement in any respected engineering programme [1]. In some programmes, the capstone senior design project is accomplished in one semester, while others devote two semesters to carry it out. The main objectives of the capstone senior design project are as follows:

- To apply knowledge learned in other courses;
- To enhance the thought and planning process;
- To expose students to a team design and implementation similar to that encountered in industry;
- To improve the written and oral communication skills of students.

The capstone senior design project in the mechanical engineering programme at Indiana University-Purdue University Fort Wayne in Fort Wayne, USA, has undergone several modifications and upgrades over the last few years. In the past, the capstone senior design project was accomplished in one semester, one faculty advisor was responsible for all the capstone senior design projects, the design projects were just designed on paper and most of the projects were completed by individual students, not by teams. This translated into weak senior design projects that resulted in a criticism by ABET accrediting teams.

Currently, there is a Capstone Senior Design Coordinator and each senior design project is carried out by a team of students and supervised by a faculty advisor in the relevant area. The capstone senior design project spans two semesters. In the first semester, the problem statement is formulated and basic conceptual designs are generated and then evaluated. The best conceptual design is then selected and a complete and detailed design is generated by the end of the first semester. In the second semester, a prototype of the finished design is built, tested and evaluated. The final report and oral presentation to faculty and students are required from all design teams at the end each semester. Some of the senior design projects are multidisciplinary. In addition, students are exposed to real life design problem experience by getting them involved to work on design projects provided and supported by the local industry or professional societies.

The most recent report by the ABET accreditation team did not list any weakness or concern in the area of engineering design. On the contrary, the mechanical engineering programme was commended and praised in this area. In this article, the author presents a brief background about the history of the capstone senior design in the mechanical engineering programme at Purdue University, Fort Wayne, and the measures that were taken to strengthen it.

HISTORICAL BACKGROUND

In the 1980s and early 1990s, the capstone senior design project in the mechanical engineering programme at Purdue University, Fort Wayne consisted of ME 463, a 3-credit hour course (one semester). The design projects were carried out through the analysis and synthesis stages only, and did not include building, testing or evaluation. All the senior design projects were advised by a single faculty member. This approach limited the diversity of subject areas covered. In addition, the design projects were performed by individual student rather than a team of students. This approach resulted in very weak senior design projects.

The ABET accrediting team that visited the programme in 1993 has criticised the mechanical engineering programme in the area of design. The following is an excerpt from their report:

> *The overall treatment of engineering design does not appear to be consistent with the requirements incorporated into the 1993-94 ABET engineering criteria … As a result of the deficiency cited in this statement, an interim visit in the fall of 1996 may serve as the basis for consideration of an extension of the period of accreditation of this program to the year 2000*.

In the aftermath of that ABET report, the faculty of the mechanical engineering decided to introduce some changes to their senior design approach in order to eliminate the deficiency cited by the visiting ABET accrediting team. The changes included an expansion of the senior design course from one semester (ME 463) to two semesters (ME 487 & ME 488), to offer two different sections (solid mechanics and thermal). In the first semester (ME 487), both sections, solid mechanics and thermal, are to be handled and advised by one faculty only. In the second semester (ME 488), each section is to be advised by one faculty member in the relevant area. The idea behind this expansion is that students finish the design on paper in the first semester (ME 487) and build, test and evaluate the design in the second semester (ME 488). The Department would support the design projects by contributing $100 per student.

This design plan was provided to the visiting ABET accrediting team in 1996 and was scheduled to be implemented in fall 1997. The visiting ABET accrediting team was not happy with the plan and the slow pace of change. The following is an excerpt from their report:

> *The course that is intended to provide the meaningful, major design experience is ME 463. The design plan provided at the beginning of the visit, which presents the coverage of the design topics throughout the curriculum, states that this course designs are intended to be carried out only through the analysis and synthesis stages, and not include construction, testing or evaluation. This approach does not appear to be consistent with the goal of providing a major, meaningful design experience to the students … This course is scheduled to be expanded to two semesters in 1997-1998, and this expansion seems to be a necessary step toward being able to provide a meaningful, major experience to the students. It also seems essential that other faculty become more directly and actively involved in the course, in addition to the person who is assigned the primary responsibility. At the present time, it appears that the requirements are not being met for ABET engineering criteria, section IV.C.3.d.*

The author joined the mechanical engineering programme faculty at Purdue University, Fort Wayne in fall 1997. The senior design course expansion was then implemented. The design projects were a mixture of individual and team projects. All projects, solid mechanics and thermal, were advised by one faculty member in the solid mechanics area. In spring 1998, two sections of ME 488 were offered (one was solid mechanics and the other was thermal). The senior design thermal section of ME 488 was assigned to the author. As expected, the designs that were supposed to be completed on paper in the first semester (ME 487) were not finished and had major fundamental errors. It is believed that this result is expected when the advisor of the design projects is responsible for eight to ten design projects and half are not in his/her area of expertise. Because of this, the thermal section senior students spent the first month or month and a half to fix and complete their designs.

As a result of this experience, the author recommended that ME 487 (the first senior design course) should be divided into two sections, one solid mechanics and the other thermal, and each section was to be advised by a faculty advisor in the relevant area. The author also recommended that all projects should be team projects and that no individual projects were to be allowed. These recommendation was agreed to by the faculty and the Chair of the Department. In addition, some effort was undertaken to improve the quality of the design projects by seeking local industry sponsorship and support. These steps paid off. The mechanical engineering programme was praised for these improvements by the visiting ABET accrediting team in fall 1999, who commented:

> *The department is to be particularly commended on the progress made in introducing engineering design to all levels of the program and implementing a hands-on design experience. In particular, it is noted that a number of the capstone design projects now have support from local industry. The program can take pride in the fact that one such project has resulted in a design that has resulted in a patent application*.

ADVANCEMENT OF THE CAPSTONE PROJECT

The approach described above has improved the engineering senior design experience for students in the mechanical engineering programme at Purdue University, Fort Wayne. However, the arrangement of two sections (solid mechanics and thermal), plus the involvement of two faculty members only, still limited the diversity of the subject areas covered. In 2001, at the urgent advice of the author, a committee was formed to address this issue and others such as multidisciplinary design projects.

The committee consisted of four faculty members: two were mechanical engineering and two were electrical engineering, and was chaired by the author. The committee developed new guidelines for the capstone senior design courses that included the creation of two new courses (ENGR 410 and ENGR 411) for the multidisciplinary senior design projects; the formation of a multidisciplinary committee to handle multidisciplinary design projects; the involvement of most, if not all, of the faculty in advising the design projects; and the assignment of a faculty member to coordinate these activities.

The objectives are as follows:

- To apply knowledge learned in other courses;
- To enhance the thought and planning process;
- To expose students to a team design and implementation similar to that encountered in industry;
- To improve the written and oral communication skills of the students.

The courses involved are namely:

- ME 487 and ME 488 are the mechanical engineering senior design sequence courses;
- ECE 405 and ECE 406 are the electrical engineering senior design sequence courses;
- ENGR 410 and ENGR 411 are interdisciplinary senior design activities open to students from both programmes.

Concerning the project teams:

- There must be at least one multidisciplinary project every year (ENGR 410 & 411). Enrolment in ENGR 410 & 411 is subject to the approval of the Senior Design Coordinator. Excellent academic standing is required for enrolment. These projects are advised by a committee consisting of two faculty members: one each from ECE and ME;
- All senior design projects must be performed as teams. No individual projects are permitted. Each project is advised by one faculty member from the relevant discipline;
- The minimum size of any team in the ECE and ME senior design sequences is two;
- The minimum size of any multidisciplinary team (ENGR 410, ENGR 411) is four; the team(s) should include students from both programmes (ie ECE and ME).

Proposing Projects

Project suggestions may come from a number of different sources such as:

- Senior design students;
- Faculty members;
- Industry.

Project suggestions must meet certain criteria in order to be accepted as a potential design project. Each project must be sufficiently complex, yet simple enough to be accomplished within the allocated time to the project team, with the understanding that a worthwhile product or at least a functioning prototype would result from the project. All project proposals must be directed and discussed with the prospective team advisor. The final decision, to accept a project proposal or not, will be made by the advisor.

Course Activity

The course activities for the first semester (ECE 405, ME 487 and ENGR 410) are as follows:

- All students enrolled in these courses shall attend common lectures arranged by the Senior Design Courses Coordinator. Failure to attend these lectures is subject to a penalty as outlined below under *functions of the Senior Design Courses Coordinator*;
- The first activity entails the formation of project teams. Shortly after that (two weeks into the semester), each team is required to develop a problem statement and a written project plan that covers the activities planned for the entire semester;
- Each team must accomplish certain milestones, like brainstorming, conceptual designs, evaluations of concept, and detailed design of the selected concept before the end of the first semester. Deadlines for these milestones are set through discussion between the advisor and project team. These deadlines are to be included in the written project plan mentioned above;
- Near the end of the semester, each team is required to produce a written report and give an oral presentation. The due date for the written report and the date of the oral presentation are set by the Senior Design Courses Coordinator.

Table 1 shows a timetable that outlines the deadlines by which a specific milestone must be completed. This is based on a fall semester. It should be noted that each student is required to submit a weekly progress report.

Table 1: Milestones deadlines (ECE 405, ME 487, ENGR 410).

Date	Period	Milestone
8/25	–	First class meeting. Finalise the design teams.
9/8	2 weeks	Problem statement to be submitted. Start brainstorming.
9/24	2.5 weeks	Finish evaluating the ideas that were generated using brainstorming; 3 to 4 conceptual designs to be submitted.
10/13	2.5 weeks	Summary of the evaluation of the 3 or 4 conceptual designs to be submitted. A conceptual design and a back-up are to be selected.
11/24	6 weeks	Detailed design of the selected concept that includes a full and complete analysis, calculation and evaluation with all computer generated drawings is due.
12/3	1.5 weeks	Final report due.
12/9-12		Oral presentations.

The course activities for the second semester (ECE 406, ME 488, and ENGR 411) are as follows:

- Teams should complete their projects by implementing what they have designed in the first semester; ie building, testing and evaluation, and demonstration of the end products. Deadlines for these milestones are set through discussion between the advisor and the project team;
- Two weeks into the semester, each team is required to submit a measured parameters statement to identify various parameters that need to be determined, as well as the method of measurement. This measured parameters statement includes all the parameters/quantities that are needed to be obtained during the testing process in order to be able to evaluate the success of the design after it has been constructed;
- Near the end of the semester, each team is required to produce a final written report and give an oral presentation. These submission dates are set by the Senior Design Courses Coordinator.

Table 2 is a timetable that outlines the deadlines by which a specific milestone must be completed. This is based on a spring semester. It should be noted that each student is also required to submit a weekly progress report.

The functions of the Senior Design Courses Coordinator include:

- Being in charge of the weekly common meeting hour;
- Send a memo to the engineering faculty requesting the titles and brief descriptions of any project they would like to supervise. The faculty member should indicate if the prospective senior design project is being supported by outside funding;
- Publicise all the prospective senior design projects received from the faculty. Students should be encouraged to go and discuss the prospective projects with the relevant faculty advisors;
- Students who are not successful in signing up on a project with an advisor will be assigned faculty advisors by the Coordinator through a fair mechanism such as lottery. This

will be carried out in the first week of classes (ECE 405, ME 487 and ENGR 410) during the common meeting hour;
- Give lectures that cover the following topics (EE 405, ME 487, and ENGR 410):
  - Formulation of design problem;
  - Brainstorming of conceptual designs;
  - Evaluation of conceptual designs;
  - Initial design, modelling and simulation, iteration and development of an acceptable design.
- Arrange for at least four lectures to cover the following areas, which will provide the students with (ECE 405, ME 487, and ENGR 410):
  - Understanding professional and ethical responsibilities;
  - Knowledge of contemporary issues;
  - Recognition of the need for life-long learning;
  - The broad education necessary to understand the impact of engineering solutions in global and societal contexts.
- Conduct the course survey (feedback) at the end of each semester;
- Arrange the time and the place for the oral presentations of all teams at least one month in advance (both semesters);
- Attend all the oral presentations;
- Coordinate the evaluations of the presenters by the attending engineering faculty members (ie distributing the evaluation forms to the attending engineering faculty members before the presentations and collecting them afterwards), then calculate the average based on a maximum possible points of 15;
- Figure out the average for each student and submit the grade to the Registrar office.

It should be noted that the author has been coordinating this activity since the implementation of this plan (fall 2002).

Table 2: Milestones deadlines (ECE 406, ME 488, ENGR 411).

Date	Period	Milestone
1/12	-	First class meeting.
1/26	2 weeks	Measured parameters statement that includes all the parameters/quantities that are needed to be obtained during the testing process is due.
3/22	8 weeks	A working prototype is to be completed by this date.
4/19	4 weeks	Testing and evaluation of the prototype is to be completed by this date. The design team must submit the data/results of their tests, discussion/ evaluation, plus details of the procedure used in their testing. The team must arrange for the advisor to test their prototype within a week of this date.
4/28	1.5 weeks	Final report is due.
5/4-7		Oral presentations.

With regard to team advisors:

- A committee of two faculty members, one ECE and one ME, shall be assigned by the Chair to serve as advisors for the multidisciplinary project. A major task of this committee is to secure outside funding for this type of project;
- Each of the remaining projects shall be advised by an individual engineering faculty;
- A faculty member is not permitted to advise more than one team in any given academic year;
- When a team of students agree to work on a senior design project with an advisor, the faculty member shall send a memo to the Coordinator indicating the title of the project and the names of the team members;
- The team advisor shall follow the grading scheme outlined below. The advisor has control over 85% of the grade. This portion of the grade covers all the activities listed in the *Grading of the Projects* section, except for oral presentations. The other 15% is assigned by the courses Coordinator based on the average of the evaluations of the presentation by the attending engineering faculty;
- The team advisor shall forward, to the courses Coordinator, his portion of the grade (ie 85%) for each student in the team by the deadline set by the courses Coordinator.

Grading of the Design Projects

It should be noted that it is not necessary that all students in a given team receive the same letter grade. The teams' advisors/ Coordinator shall follow the grading scheme outlined below.

The grades of those students enrolled in ECE 405, ME 487 and ENGR 410 shall be based on the following distribution:

- Problem Statement: 10%;
- Progress Reports: 5%;
- Conceptual Designs (CD): 15%;
- Evaluation Summary of CD: 10%;
- Final Design: 35%;
- Final Report: 10%;
- Oral Presentation: 15% (NB The oral presentations portion of the grade (ie 15%) shall be assigned by the courses coordinator based on the average of the evaluations of the presentation by the attending engineering faculty minus any penalty (up to 5%) for failing to attend the common lectures.

The grades of those students enrolled in ECE 406, ME 488, and ENGR 411 shall be based on the following distribution:

- Measured Parameters Statement: 10%;
- Progress Reports: 5%;
- Building Prototype: 15%;
- Testing and Evaluation: 40%;
- Final Report: 15%;
- Oral Presentation: 15%.

THE DESIGN PROCESS

The design process that students follow in their capstone senior design projects is the one outlined by Bejan et al and Jaluria [2][3]. The first essential and basic feature of this process is the formulation of the problem statement. The formulation of the design problem statement involves determining the requirements of the system, the given parameters, design variables, any limitations or constraints, and any additional considerations arising from safety, financial, environmental or other concerns. The second step in the design process is the generation of conceptual designs employing the well-known brainstorming technique. In this step, the configuration and

main features of the system are given in general terms to indicate how the requirements and constraints of the given parameters will be achieved. The conceptual design may range from a new idea to available concepts applied to similar problems and modifications in existing systems.

The selected conceptual design leads to an initial design that is specified in terms of the configuration of the system, the given quantities from the problem statement and an appropriate selection of the design variables. Next comes the modelling and simulation of the system. Modelling involves simplifying and approximating the given system to allow a mathematical or numerical solution to be obtained. The results from the simulation are used to determine if the design satisfies the requirements and constraints of the given problem.

Recently, El-Sayed presented an educational design process that covers several capstone design essential topics [4]. Some of these topics include: the engineering design process, teamwork, brainstorming, conceptual designs, proposal writings, ethics, project management, and design reports and presentations.

SPONSORSHIP OF SENIOR DESIGN PROJECTS

The cost of constructing a prototype of a finished design is usually high. This is especially true when the design projects deal with practical and real life problems [5]. For small undergraduate engineering programmes with limited resources, such as this one, the high cost of building these projects tends to cause a problem and hampers the selection of good quality capstone senior design projects. This problem becomes more pressing when the senior design projects are multidisciplinary in order comply with the Accreditation Board for Engineering and Technology (ABET) accreditation criteria, which require that graduates of engineering programmes possess *an ability to function on multi-disciplinary teams* [6].

The author recently reported on the need for outside support of capstone senior design projects [7]. Whenever it is possible, the students are exposed to real life design problem experience by getting them involved and work on design projects provided and supported by the local industry and professional societies, such as the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). Types of the design projects that the local industry is interested in include a completely new design to perform specific task(s), modify or improve an existing design, and solving problems in some industrial operations. Additionally, the ASHRAE funds capstone senior design projects that involve ASHRAE-related topics.

The ASHRAE has a programme called Undergraduate Senior Project Grant Programme that provides funding (grants up to $5,000.00) for undergraduate engineering senior design projects and technical school projects. These grants are made for the school for the support of the materials required for the project and not for funding school overhead costs, faculty or student salaries. The author has been very successful in obtaining these types of grants. Six grants from this grant programme have been obtained since the year 2000, as follows:

- Refrigeration System for a Small Compartment ($1,775.00), 2000;
- Thermosiphon Heat Recovery System ($3,155.00), 2001;
- Preheating System for the Incoming Cold Water of a Residential Hot Water System ($1,835.00), 2001;
- Experimental Apparatus for Demonstrating Air Conditioning Processes ($4,990.00), 2003;
- Experimental Apparatus for Demonstrating Solar Water Heating Concept ($4,145.00), 2004;
- Design and Construction of a Heat Pump Unit for Lab Use ($3,794), 2005.

It should also be noted that the ASHRAE's sponsored senior design projects have resulted in laboratory experimental apparatuses that are currently being used to support instruction in four thermal engineering courses [8][9].

CONCLUSION

A capstone senior design experience of a small engineering programme is presented. Several changes and improvements that were implemented to strengthen the capstone senior design over the years are described in detail. A comprehensive new plan for the capstone senior design that was recently formulated and implemented is also presented. The new approach provides the senior design students with diverse choices for their design projects. This is accomplished by involving the entire faculty and local industry. The feedback from students, faculty and industry has been very positive. Most importantly, this capstone senior design was highly praised by the ABET team who recently (1st week of October 2005) evaluated these engineering programmes, which were described by the ABET reviewers as follows:

> *The two-semester senior design course sequence is particularly well organized and run to ensure that all students demonstrate a thorough engineering design process in preparation for professional practice.*

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