Integrated product and process design in a capstone senior design class

Bahram Asiabanpour & Vedaraman Sriraman

Texas State University-San Marcos
San Marcos, United States of America

ABSTRACT: In this article, the authors present a capstone senior design class that was designed for manufacturing engineering students at Texas State University-San Marcos, in San Marcos, USA, with funding from the Society of Manufacturing Engineers – Educations Foundation. The course was unique in that students experienced most of the aspects of the design/development cycle, including product design, prototyping/verification, manufacturability analysis and the design of manufacturing systems for the mass production of the product. Student teams were also required to develop cost estimates and plan for the raw material required for production. Project management tools were utilised to plan the activities for the semester, as well as to provide updates to the class on the conformance of the project to initially established timelines. At the conclusion of the projects, students made formal oral presentations to their peers, faculty and industry guests. The article concludes with a discussion of the results of a formal course evaluation that was conducted by an educational testing and evaluation firm.

INTRODUCTION

In autumn 2000, a new undergraduate degree in manufacturing engineering was initiated at Texas State University-San Marcos, in San Marcos, USA. Curriculum development efforts for this programme were driven considerably by a study conducted by the Society of Manufacturing Engineers (SME), entitled *Manufacturing Engineering for the 21st Century* [1]. Other criteria included that laid down by the Accreditation Board for Engineering and Technology (ABET). The SME study identified communication skills, teamwork, project management, business skills and life-long learning as some key competence gaps in recently graduated engineers. ABET criteria maintain the following:

> *… students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political* [2].

While most SME's gaps and ABET's engineering practice criteria can – and must – be assimilated throughout the four-year curriculum, the capstone senior design course provides the most appropriate framework for simultaneously addressing practically all of the gaps and criteria.

A survey of recent research in the area of capstone design courses revealed the following. Several universities have redesigned senior capstone design courses to address key skill deficiencies of the engineering graduate [3-5]. These articles generally focused on the university-industry relationship. Marin et al highlight the role of the industrial affiliate, the use of state of the art tools for students, and the effect of a new capstone design course on the marketability of graduates [6]. Farr et al introduced a framework for the engineering capstone design course with an emphasis on three key elements: student preparation, project selection and instructor mentorship [7]. Latcha and Oakley have reported that their capstone design projects are limited to a specific market: the toy industry [8]. Cooperative learning instructional activities in a capstone design course was a concept that was first introduced by Pimmel [9]. In this approach, there is major emphasis on students' involvement in class lectures and project discussions. Finally, Griffin et.al have shown the impact of group size and project duration on capstone design [10].

All of the above articles have pointed out very important and critical issues for the capstone design course. However, none have addressed the issues of having students experience the entire product cycle and the incorporation of business plans. Therefore, while the best practices of other efforts were adopted, the aforementioned issues were unique to this work.

The goal for the capstone design course at Texas State University was to provide teams of students with the opportunity to work with open-ended design problems wherein most of the aspects of the product development cycle, including product design, prototyping/verification, manufacturability analysis, and the design of manufacturing systems for the mass production of the product, were experienced.

The course was taught for the first time in autumn 2003. Based on preliminary results and outcomes, this course was modified for the second offering, which occurred in autumn 2004. The major modification was the inclusion of a formal class evaluation by an external evaluation and testing service. For the third offering of the course, the plans are to involve local industries by having them supply and supervise design projects.

CLASS DESCRIPTION

Since this course is at the senior level, students would have had most of the background (ie in materials, design, manufacturing, quality, engineering economics, *hands-on* fabrication skills, etc) prior to taking this course. However, a brief review of some of the topics considered crucial for conducting a successful project were presented. Some topics include project management, cost estimation, business plans and manufacturability analysis. The textbook by Ulrich and Eppinger on product design and development was used as supplementary material for the early phase of the course [11].

Also, in this class, guest speakers occasionally presented lectures. These speakers were usually outstanding researchers from academia or practitioners from industry. Guest speakers presented talks on topics such as creative product design and cost modelling. In those cases, the class schedule was adjusted to accommodate the schedules of the guests.

PROJECT STEPS

In the first two weeks, each student was tasked with identifying a new customer need or an existing product that was in need of redesign. This could be accomplished with the participation of an actual local company/industry. However, in the first offering of the course, the *problem* was internally generated. In the third week of the classes, every student presented a problem/need and his/her approach to the solution of the problem/need. In week four, students formed teams of 4-5 students each. Based on their interests and feedback from the instructor, they choose one of the projects as their team project.

Subsequently, as the course progressed, the teams finished each stage of their project every week. Upon receiving feedback from their instructor, teams dynamically made adjustments to their products/plans. In fact, despite major differences in their final products, all teams followed a common timeline and procedure.

Tables 1 and 2, and Figures 1, 2 and 3, illustrate some of the steps for one of the projects.

Table 1: Example of a customer needs list.

	Customer Statements	Interpreted Customer Needs
1	I use a wireless keyboard and mouse	Chair is compatible with wireless components
2	My neck hurts after sitting in a chair for a long time	Chair promotes good posture
3	Needs leg rest	Chair has an optional ottoman
4	I would like to have cushioned arm rest	Chair is comfortable
5	I like adjustable chairs	The chairs reclining position is adjustable
6	Needs a place for a drink	Chair has built in cup holder
7	Light weight	Chair can be easily transported
8	I need a place to put my notepad	Storage areas are provided
9	The keyboard height should be adjustable	Chair is comfortable

Table 2: Example of concept selection.

	Concept Variants					
Selection Criteria	A	B	C	D	E	Ref.
Comfort	+	+	+	0	0	0
Mobility	-	0	0	+	-	0
Storage	-	+	0	0	+	0
Manufacturing Ease	-	-	-	-	-	0
Ease of Handling	-	0	0	0	-	0
Durability	0	0	0	0	0	0
Sum +'s	1	2	1	1	1	
Sum 0's	1	3	4	4	2	
Sum -'s	4	1	1	1	3	
Net Score	-3	1	0	0	-2	
Rank	5	1	2	3	4	
Continue?	No	Yes	No	No	No	

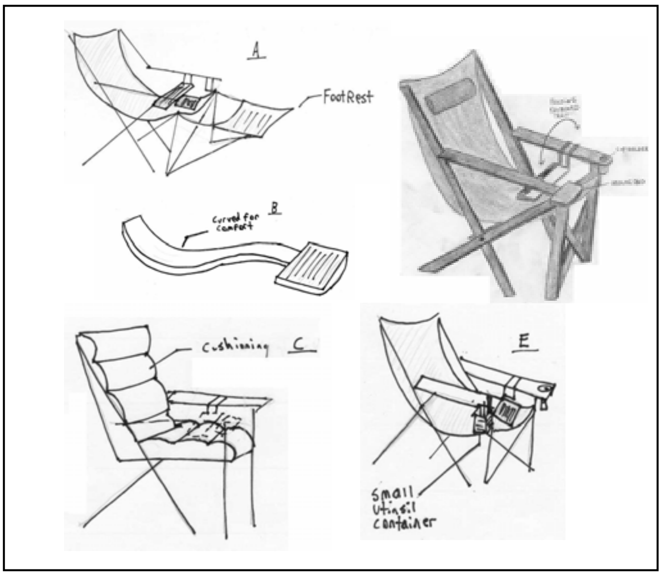

Figure 1: Concept generation.

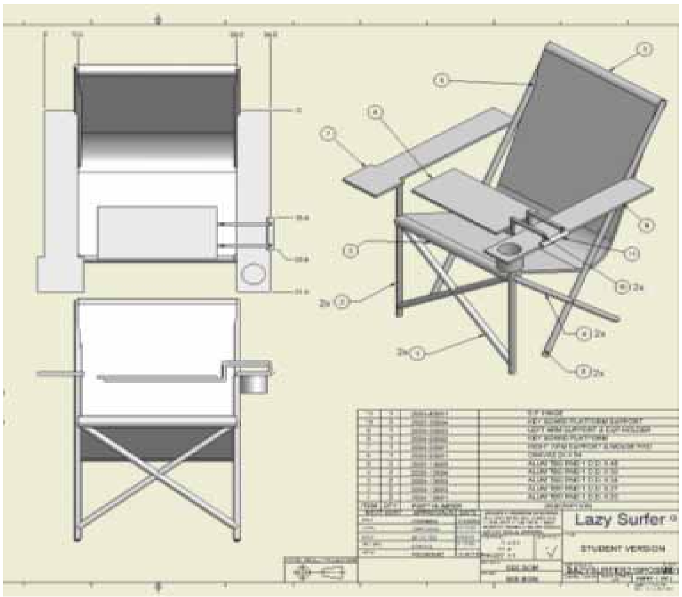

Figure 2: Parts and assembly design.

BUSINESS PLAN

One of the aspects of the capstone design course, which has rarely received enough or any attention in similar courses at many other universities, is the product business plan. In most cases, the issue of the business plan simply translates into cost estimation. Thus, in other efforts, students merely go through the exercise of constraining expenditures within pre-established budget caps.

Figure 3: The final prototype.

In the capstone design course at Texas State University, students take a significant step beyond cost estimation. They prepare a business plan. In this plan, based on some assumptions in regard to annual mass production volume and item price, and on an estimation of investment costs, operating expenses, tax and other related cash flows, students provide a realistic profit projection plan for the next 1-10 years. The whole notion is that, besides being proficient in design creativity, students also must be able to present a convincing case for potential investors.

STUDENTS' EVALUATIONS

Different evaluation criteria were utilised for gauging team and individual performance. For the team performance, teams were evaluated based on the quality of their work, reports and presentations on a weekly basis by the instructor, as well as a final evaluation that was undertaken by a panel of experts (other departmental faculty and guests from industry). All students within a team received the same grade for the project.

The only exception was in the case of unusual problems or misconduct by a student. These exceptions were judged by confidential peer evaluation. When needed, individual conversations with team members at the end of semester enabled the instructor to gain additional insights into an exceptional situation.

Weekly individual homework and quizzes, presentations, as well as a final examination, enabled the instructor to gauge students individually.

Table 3 provides some of the projects that were undertaken in autumn 2003 and 2004.

BEST DESIGN CONTEST

In order to stimulate a healthy competition between student teams, a *best design* contest was held at the conclusion of the projects. A panel consisting of departmental faculty and industrial advisory committee members ranked student teams based on oral presentations. The panel also offered improvement suggestions to the student teams and the course professor.

Table 3: Examples from the 2003 and 2004 projects.

No.	Project Title	Final Product
1	Design of an entertainment centre that is easy to assemble and disassemble.	
2	Redesign of a modular C-clamp.	
3	Design of a *Lazy Surfer Chair* with a built in keyboard and mouse.	
4	Design of a lightweight key chain with the University logo.	
5	Design of an integrated laptop case that can be unfolded to be used as a computer desk.	
6	Design of a lighting kit that will be adaptable to most standard power drills.	

COURSE EVALUATION

To evaluate the learning experiences of the students involved and to determine whether this course was fully functioning as a *capstone experience*, a formal course evaluation was conducted by an external source. Keith Research and Evaluation, a private educational testing firm based in Austin, Texas, USA, was hired. This evaluation was conducted in two steps as follows:

- Step 1: Students were asked six quantitative questions with possible answers ranked between 0-10 (rank 0 for not at all successful and 10 for extremely successful). The questions in this step probed their knowledge at the beginning of the semester.
- Step 2: At the conclusion of the semester, students were asked the same questions as in step 1. Additionally, at this point, some qualitative questions were asked as well.

A numeric ID was assigned to each student. Therefore, both surveys (beginning and end of the semester), as associated with each student, were studied together.

The Manufacturing Engineering Program Coordinator, the faculty member teaching this course, and the external researcher met on different occasions to:

- Discuss the goals of the evaluation;
- Review the class syllabus;
- Identify the content focus of the study;
- Determine the method by which data would be gathered;
- Establish data collection timelines.

Based on these sessions, an evaluation instrument was developed. Quantitative questions mainly dealt with topics such as understanding product and process development, design for manufacturing and assembly, writing, presentation and project management skills.

The following is a brief overview of the evaluation results. Results indicated that student comprehension improved from the beginning of the semester to the end of the course in all areas evaluated on the survey. More specifically, tests of statistical significance indicated improvement in performance in the following areas:

- Understanding product and process development;
- Solving design problems;
- Estimating product and production costs;
- Technical writing;
- Oral presentations;
- The ability to work in teams.

Furthermore, factors were identified that influenced students' learning. These details may be found in ref. [12]. Figures 4 and 5 illustrate some of the survey results.

SUMMARY

A senior design course that was designed to students with Manufacturing Engineering majors at Texas State University-San Marcos is described in this article. The course presented students with an opportunity to solve open-ended design problems wherein students experienced the entire product cycle.

These learning experiences enabled the student to see the *big picture*, ie see how background in several technical content areas such as mechanics, materials, process, tool design, automation, applied statistics, etc, was essential to the solution of real world problems.

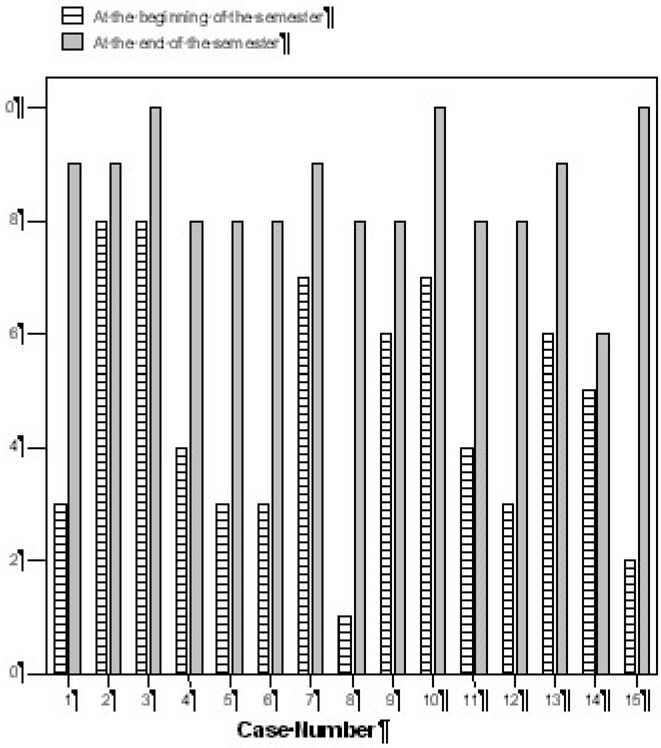

Figure 4: Understanding product and process development – putting it all together.

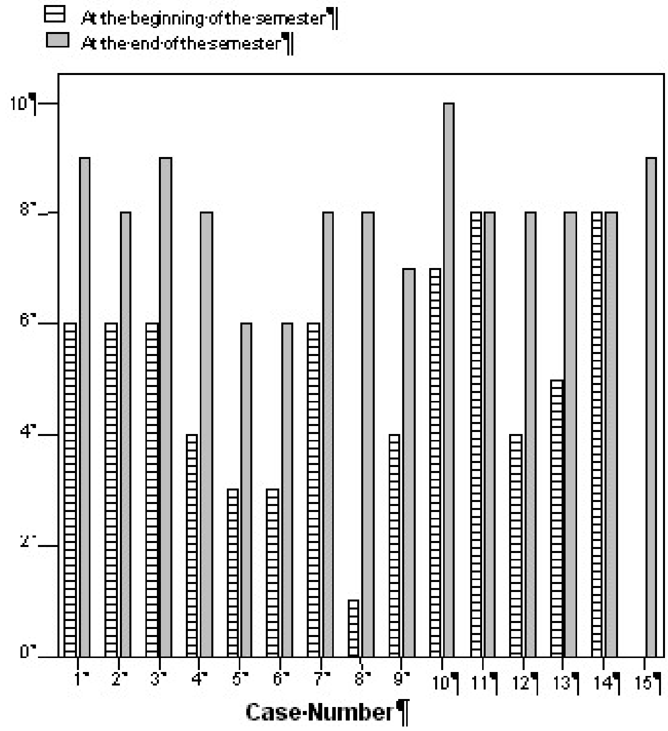

Figure 5: Solving design problems or design for optimum part manufacturing and product assembly – operating with incomplete data or with many unknowns.

The first offering of the course revealed that students' interest levels were very high. The course also prepared students for an engineering career by enabling them to hone their skills in engineering practice-oriented topics, such as communications, project management, teamwork and business plans.

During the second offering of the course, a formal course evaluation indicated that students improved from the beginning of the semester to the end of the course in all areas measured on the survey. In particular, improvements were significant in the following areas: understanding product and process developments, solving design problems, estimating product and production costs, technical writing, oral presentations, and the ability to work in teams.

The experience of other educators strongly suggests that involving industrial partners in these courses enriches the quality of educational experiences [3-5]. Thus, industry partners have supplied projects and served as liaison engineers with whom students could interact.

For the third offering of this course, which will occur in autumn 2005, design projects will be solicited from industry. Each design team will then have an industrial project and an industrial mentor to guide activities throughout the semester.

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