Teaching Integrated Product and Process Design

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Abstract – This paper presents a capstone senior design class that was designed for Manufacturing Engineering students at Texas State University-San Marcos with funding from the Society of Manufacturing Engineers – Educations Foundation. The course was unique in that students experienced most all aspects of the design/development cycle to include product design, prototyping/verification, manufacturability analysis, and the design of manufacturing systems for the mass production of the product. A team based approach was used wherein some members of the team played the role of "design engineers" and some played the role of "manufacturing engineers." Student teams were also required to develop cost estimates and plan for the raw material required for production. Project management tools were used to plan the activities for the semester as well as to provide updates to the class on conformance of the project to initially established timelines. Finally, students made formal oral presentations to their peers and a cross section of faculty and industry guests.

Introduction

In Fall 2000, a new undergraduate degree in Manufacturing Engineering was initiated at Texas State University-San Marcos. Curriculum development efforts for this program were driven considerably by a study conducted by the Society of Manufacturing Engineers (SME) entitled "Manufacturing Engineering for the 21st Century" [1] and by the criteria laid down by 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 competency gaps in recently graduated engineers. ABET criteria [2] maintain that "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." 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.

Several universities have redesigned senior capstone design courses to address key skill deficiencies of the engineering graduate [3], [4], and [5]. The goal for the capstone design course at Texas State was to provide teams of students the opportunity to work with open-ended design problems wherein most all aspects of the product development cycle to include 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 Fall 2003. Based on preliminary results and outcomes this course is being modified for the second offering which will occur in Fall 2004.

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 [6] was used as supplementary material for the early phase of the course. Table 1 illustrates major class activities on a weekly basis. The only flexible component of this schedule was in regard to the guest speakers. These speakers were usually outstanding researchers from academia or practioners form the industry. Guest speakers presented talks on topics such as creative product design and cost modeling. In those cases the class schedule was adjusted to accommodate the schedules of the guests. The following table provides specifics:

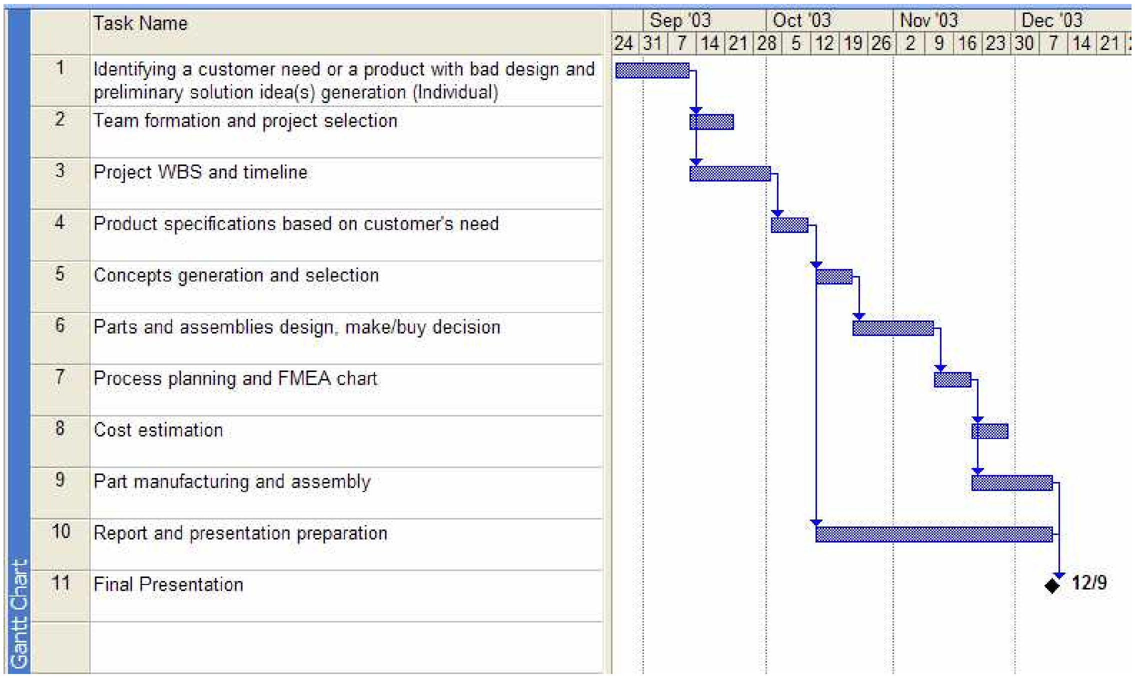
TABLE I
CLASS ACTIVITIES

Week	Lecture Title	Description	Presentation
1	Introduction, survey, quiz, and concurrent engineering.	Explain class procedure, anonymous survey (including data such as GPA, analysis software and programming knowledge, and work experience), anonymous background quiz, and lecture in concurrent engineering concepts. Reviewing previous projects.	
2	Identifying customer's needs, design, and creativity.	Lecture on identifying customer needs, good design vs. bad design, creativity and innovation.	
3	Team working.	Lecture on team working and leadership including meeting checklist, team fail and success factors, and team manager and members responsibilities.	All students: Present an example of a product with bad design and idea(s) for solving the problem (3 minutes).
4	Project management.	Lecture on organization types, work breakdown structure (WBS), Gant chart, critical path calculations, and MS Project software review.	Teams managers: Introduce projects titles, and teams members (3 minutes).
5	Defining product specifications and quality function deployment (QFD).	Lecture on defining product specifications (customers needs to technical metrics) and QFD and case study.	Teams managers: Present project WBS network and other project related activities (5 minutes).
6	Concept generation and selection.	Lecture on concept generation and selection.	Teams managers: Present product specifications and other project related activities (5 minutes).
7	Design for manufacturing and assembly.	Lecture on manufacturing processes (review), design for manufacturing (DFM), design for assembly (DFA) and case studies.	Teams managers: Present on concept generation, selection and other project related activities (5 minutes).
8	Robust design and design of experiments (DOE).	Lecture on design of experiments techniques and a hands-on class exercise.	
9	Rapid prototyping and failure mode and effects analysis (FMEA).	Lecture on available rapid prototyping facilities and in FMEA, with real industrial examples.	All students: Present parts and assembly design, bill of material, DFM/DFA rules used in design, and other project related activities (10 minutes).
10	Cost estimation	Lecture on cost estimation of the product in case of mass production.	Teams managers: Present on processes and materials considered for parts/assembly fabrication (5 minutes).
11	Exam		
12-15	Guest speaker or no class		
16	Final presentation	A panel of experts from university faculty and industry judged the projects. The best team was presented with a honor certificate.	All students: Final presentation (12 minutes each team)

Projects 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. Figure 1 illustrates a general Gantt chart for a project.

FIGURE 1
GENERAL GANTT CHART FOR TEAMS' PROJECTS



Tables II and III and figures 2, 3, and 4 illustrate some of the steps for one of the projects.

TABLE II
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 long periods of time	Chair promotes good posture
3	Needs leg rest	Chair has 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
10	Needs a massage option	Chair is comfortable
11	I like chairs that have wheels	Chair can be easily transported
12	Needs good back support	Chair promotes good posture
13	Options for both left and right handed people	Chair is comfortable for both right and left handed people
14	Chair needs to look good with the rest of my furniture	Chair is aesthetically pleasing
15	I like a chair that reclines	Chair is comfortable

FIGURE 2
CONCEPT GENERATION

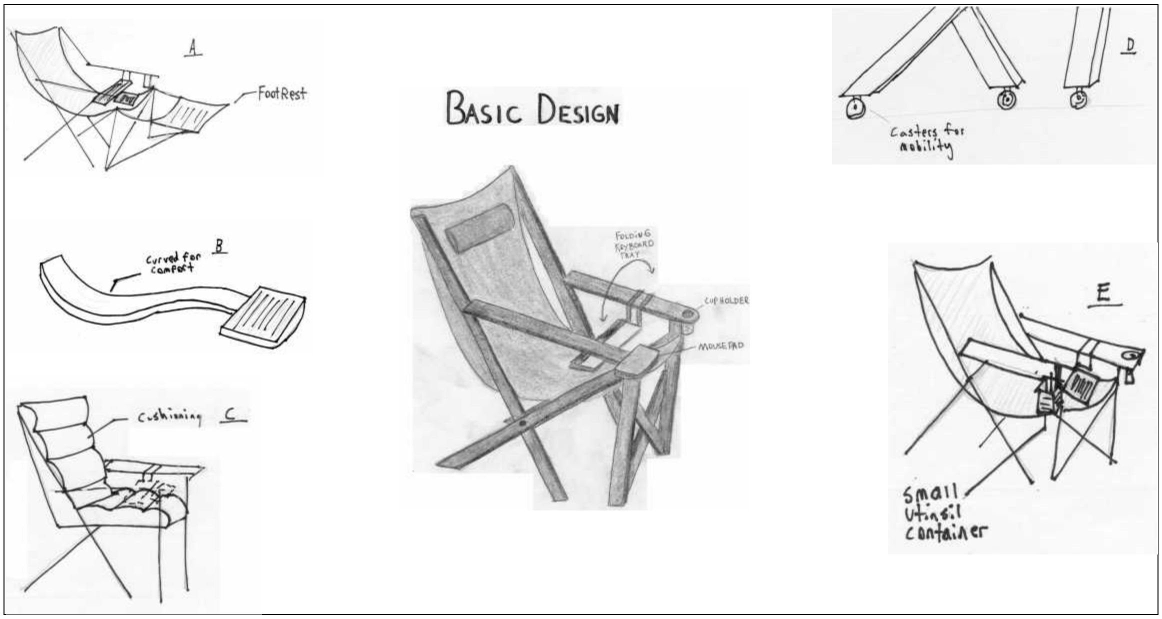


TABLE III
CONCEPT SELECTION

	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 3
PARTS AND ASSEMBLY DESIGN

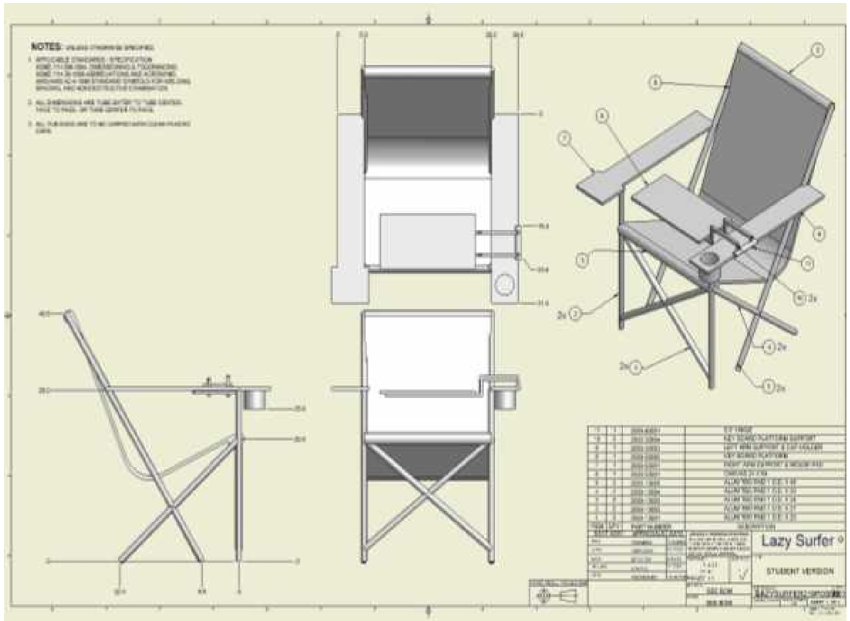


FIGURE 4
FINAL PROTOTYPE

Table IV provides a list of the various projects that were undertaken in Fall 2003.

TABLE IV
TEAM PROJECTS

Team #	Project Title
1	Design of an entertainment center that is easy to assemble/disassemble.
2	Redesign of a modular C-Clamp.
3	Design of a Lazy Surfer Chair with built in keyboard and mouse.
4	Design of a lightweight key chain with the university logo.
5	Design of a child proof and durable humidor.
6	Design of a hammock that is easy to assemble/disassemble.

Student Evaluations

Different evaluation criteria were utilized 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). All students within a team got 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, and a final exam enabled the instructor to gauge the students individually.

Summary

A senior design course that was designed for Manufacturing Engineering majors at Texas State University-San Marcos was described. The course presented students 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", i.e. 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. The first offering of the course revealed that student interest level was 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, team work, and business plans. The experience of other educators [3], [4], and [5], strongly suggests that involving industrial partners in these courses enriches the quality of educational experiences. Thus, industry partners have supplied projects and served as liaison engineers with whom the students could interact. For the second offering of this course, which will occur in Fall 2004, the following are being planned – a) formal, detailed evaluations of the course to determine the effectiveness of the described approach, b) solicitation of projects from the industry.

References

[1] Society of Manufacturing Engineers, "Manufacturing Engineering for the 21st Century, Volume IV – Manufacturing Engineering Plan: Phase I Report, Industry Identifies Competency Gaps Among Newly Hired Engineering Graduates, The Next Step – Partnership With Schools," *Society of Manufacturing Engineers and SME Education Foundation*, 1997.

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[5] Thigpen, L., "The Capstone Design Experience in Mechanical Engineering at Howard University," *Proceedings of the 29th ASEE/IEEE Frontiers in Education Conference,* November 10-13, 1999.

[6] Ulrich, K., *Product Design and Development*, McGraw-Hill/Irwin, Second Edition, 2003.