IE Capstone Design Course with IE and ME Team Collaboration

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Abstract

This paper presents an overview of the capstone design course in Industrial Engineering at Mississippi State University, a required course for the Bachelor of Science degree in Industrial Engineering. In the course, students are formed into project teams, each of which selects one manufactured product to analyze as part of a comprehensive venture analysis.

The unusual aspect of this course, and the focus of this paper, is the collaborations between the Design of Industrial Systems course and three other courses, including one outside the Department of Industrial Engineering. The collaborative courses are the two required Industrial Engineering courses of Manufacturing Processes and Engineering Administration, plus Mechanical Systems Design, a required capstone design course in the Mechanical Engineering curriculum. The courses that collaborate with Design of Industrial Systems act as subcontractors.

The collaboration with Mechanical Engineering demonstrates the feasibility and benefits of cross-discipline teamwork, one of five undergraduate enhancement areas adopted by the College of Engineering in 1997. These areas are communication skills, global awareness, computing skills, entrepreneurial thinking, and cross-discipline teamwork.

Each collaboration is reviewed, with experiences gained and future plans presented.

I. Introduction

Design of Industrial Systems (DIS), IE 4915, is the five-hour capstone design course in the Industrial Engineering (IE) curriculum at Mississippi State University. In the course, students are formed into project teams with typically five to six students per team. Each project team selects a single manufactured product to analyze as part of a comprehensive venture analysis. The product must contain significant fabrication and assembly content as determined by the instructor.

Each member of a project team is responsible for two functional areas. Example functional areas are marketing, facility site selection, product analysis, and facility layout[1]. Ten to twelve functional teams are formed to provide a means for students who are responsible for the same functional area to work together. Each student is a member of two functional teams.

Portions of the required analyses in the DIS class are subcontracted to two other IE classes and a Mechanical Engineering (ME) class, as shown in Table 1. Overviews of the collaborations follow in sections IV through VII.

Table 1. Collaborative Courses.

Collaborative Course	**Responsibilities of Collaborators**
IE 3323 Manufacturing Processes	Determine the manufacturing method of fabricated parts. Select fabrication equipment and determine recurring and non-recurring costs of the equipment, including maintenance. Provide a detailed layout of the fabrication area. Determine fabrication staffing by skill type and shift.
IE 4513 Engineering Administration	Design the organizational structure for the venture, including all indirect labor and management staffing. Determine the annual cost of salaries, wages, and benefits for all employees.
ME 4443 Mechanical Systems Design	Analyze products for potential mechanical redesign considering such aspects as manufacturability, function identification, loading, consumer safety, marketing, reliability, performance, and cost versus value.

II. Course Expectations

The DIS course instructor acts as both the client and mentor to the project teams. The client is presented as a non-engineer entrepreneur. A client letter of authorization to each project team early in the semester informs the team of project parameters, expectations and deliverables. To provide a reasonable project scope for a sixteen-week semester, the client provides directions to the project team concerning product complexity, estimated product sales in the tenth year of operation, facility expansion considerations, client preferences for facility location and the number of sites to consider, and guidance on financing options to consider.

The deliverables from each project team include a project proposal, with budget, early in the semester, a detailed facility layout, a detailed financial analysis for the first three years of operation, and various functional area formal reports, progress reports, and memos. A formal oral presentation of project results is made at the end of the semester to a panel of practicing engineers for evaluation of the technical aspects of the project analyses.

III. Team Operation

The projects officially begin when the client letter of authorization is delivered to each team, which selects both a team leader and project manager. The team leader is responsible for all team activities and provides leadership as necessary to achieve team goals. The project manager, in consultation with the team leader as needed, is responsible for project scheduling, budgeting, and cost monitoring and reporting.

With instructor approval, each team assigns two functional areas to each team member. The team leader is responsible for two functional areas in addition to team leadership; project management is one of the two functional areas for which the project manager is responsible.

A key component of the course is a weekly project team meeting with the client/mentor to review project status. The meeting chair and scribe rotate among team members for leadership experience, and written agendas and minutes must be prepared each week.

The instructor assigns the same number of formal reports, progress reports, and memos to each member of a project team. The subject area of each report and memo depends on the student's functional areas.

IV. The Manufacturing Processes Collaboration

The Manufacturing Processes (MP) collaboration is the most extensive of the three collaborations, beginning with a joint laboratory period in week 3 to disassemble the product and ending with the MP final reports delivered in week 11. One MP team is formed for each DIS team, and a member of each DIS project team acts as the liaison to the corresponding MP team.

The DIS team is responsible for determination of make or buy decisions for all parts, although the MP team often influences these decisions. For example, the MP team may recommend that a part previously identified as a fabricated part be purchased instead. Resolving these questions is the responsibility of the DIS student who serves as the MP liaison.

The DIS project team provides a statement of work to the corresponding MP team in week 4. The statement includes a spreadsheet file parts list, with quantity per final assembly, specifications and a photo of each fabricated part, and expected production volume for each year of the first ten years of operation.

Each MP team provides an interim report in week 7 that includes the fabrication direct labor content per shift, the number of shifts for each production machine, and an identification of labor type for each direct labor employee in fabrication.

Each MP team provides a final report in week 11 that includes the fabrication direct labor content per shift, the number of shifts for each production machine, an identification of labor type for each direct labor employee in fabrication, the fabrication method of each fabricated part, specifications of fabrication equipment, recurring and non-recurring costs of the equipment, including maintenance costs.

A representative of each MP team is invited to participate in the DIS oral presentations to the external engineering panel at the end of the semester.

The schedules for this and other collaborations are shown in Figure 1.

V. The Engineering Administration Collaboration

The Engineering Administration (EA) collaboration begins about mid-term, its beginning triggered by the MP interim report and the completion of the preliminary assembly line design by the DIS team. As with the MP collaboration, typically there is one EA team for each DIS team. If enrollments in the two courses vary greatly, there may be two EA teams for each DIS team, in which case the EA teams provide competitive organizational designs. (EA is a required course for IE majors, but students from other majors enroll and participate in the collaboration with DIS.)

The inputs to the EA teams are: direct labor by skill level from MP and the DIS team, the marketing analysis performed by a DIS team member, and the tentative location of the facility for determination of labor rates.

There are two deliverables from each EA team to the corresponding DIS team: the recommended organizational structure for the venture, including all indirect labor and management staffing, and the annual cost of salaries, wages, and benefits for all employees.

A representative of each EA team is invited to participate in the DIS oral presentations to the external engineering panel at the end of the semester.

The schedules for this and other collaborations are shown in Figure 1.

VI. The IE and ME Collaboration from the IE Perspective

One MSD (ME) team is formed for each DIS (IE) team. In week four, the DIS and MSD teams meet to conduct a brainstorming session in which possibilities for product redesign are developed. The IE perspective is to approach possible redesign with a view to improving product manufacturability, decreasing product cost, increasing product quality, enhancing consumer product safety, and otherwise enhancing product appeal to potential buyers.

The DIS and MSD teams jointly develop a priority list of items to consider for product redesign. At the start of week six, each MSD team provides a schedule of deliverables to the corresponding DIS team. This is a statement of the redesign possibilities that the MSD team has agreed to investigate. The MSD team final report of redesign recommendations is delivered to the DIS team at the end of week eight.

The majority of the MSD team recommendations are not incorporated into the current venture analysis because of the need to perform activities concurrently, such as the design of the manufacturing processes. The recommendations, however, are presented to the external review panel and client for consideration if the client should decide to invest in the (hypothetical) venture. An MSD team member is invited to participate in the DIS oral presentations at the end of the semester.

The schedules for this and other collaborations are shown in Figure 1, with additional detail of the MSD collaboration given in Figure 2.

VII. The IE and ME Collaboration from the ME Perspective

The Mechanical Engineering capstone design course, Mechanical Systems Design (MSD), provides a team of four for each IE team in this product realization venture. This assignment's completion date is 3.5 weeks, when a letter of transmittal via a PowerPoint presentation is given to the MSD class.

The scope of the MSD class is indicated by the time line of Figure 2. The class starts with design projects and project concepts including: Gantt chart[2]; functional cost analysis (i.e., value analysis)[2, 3], manufacturing processes and economics[3]; design codes and standards; product literature. The design tasks are changed each term to assure inclusion of the creative, open-ended process; however, these tasks always include: gears (AGMA Standards), bearings, seals, shafts, springs (Marks H.B.), fits (Machinery's Handbook), motor selection (Grainger & Thomas Register), ergonomics (SAE Standards), pressure vessels (ASME Code). Grade points for each task are set by average time required from Gantt charts. All reports are via MathCAD.

Figure 1. Collaboration Schedule.

DIS = Design of Industrial Systems class (IE)
MP = Manufacturing Processes class (IE)
EA = Engineering Administration class (IE)
MSD = Mechanical Systems Design class (ME)

	Week Number															
Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
MP Collaboration																
Joint DIS/MP product teardown			Δ													
Statement of work from DIS to MP				Δ												
Joint DIS/MP product analysis meetings				Δ....	Δ											
MP interim report due to DIS and EA							Δ									
Fabrication design review with DIS and EA							Δ...	Δ								
MP oral presentations of final fabrication design											Δ					
MP final design review with DIS and EA											Δ					
MSD Collaboration																
Joint brainstorming meeting									Δ							
Statement of work from DIS to ME				Δ												
Schedule of deliverables from MSD to DIS						Δ										
ME final report due to DIS					Δ											
EA Collaboration																
Statement of work due from DIS to EA					Δ											
Direct labor and marketing plan due to EA									Δ							
Interim organizational design due to DIS												Δ				
Organizational design review with DIS												Δ….	Δ			
Final organizational design due to DIS														Δ		

The IE teams, the clients, arrange the initial meeting to introduce the ME team to the product, its functions, and its component parts. Also, the IE team initiates a brainstorming session to define potential tasks for the ME team with priorities assigned to the tasks. The ME team then meets with their instructor to review this list, to set reasonable goals based on schedule and resources, and to define a plan of attack.

The ME team completes a functional analysis, a first step in the value analysis process. Within ten days, the ME team formally responds to the IE team accepting responsibility for selected tasks and specifies deliverables with a schedule. Class periods are used for individual team meetings. Each team meets weekly with the instructor to assure significant successes within the resources and on schedule.

Figure 2. Mechanical Systems Design Schedule.

Activity	**Week Number** **1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17**
Task 1. Structural Des.: AISC Code/FEA	Δ…….Δ (weeks 1–3)
Cost/Management Perspective of Design	Δ…Δ (weeks 2–3)
Task 2. Product Evaluation of Pressure Regulator: Functions/Spring Design	Δ……..Δ (weeks 3–5)
Task 3. Product Realization: ME/IE Team	Δ…..………..Δ (weeks 4–8)
IE Product Introduction/Brainstorm/Action List	Δ...Δ (weeks 4–5)
ME Send Schedule/Deliverables List to IE	Δ (week 6)
Function/Safety/Ergonomics/Performance/ Manufacturability/Failure Analysis	Δ…...Δ (weeks 5–7)
Team Meets with Instructor	Δ Δ Δ (weeks 5, 6, 7)
Teams Give PowerPoint Presentations	Δ Δ (weeks 8, 9)
Task 4. System Design: Motor/Gearbox/Pump	Δ……..…………..…Δ (weeks 8–13)
Gear Design (AGMA)	Δ……Δ (weeks 10–11)
Bearing Selection/Shaft Design	Δ….Δ (weeks 11–12)
Lip Seals/O-Ring/Casting Design	Δ...Δ (weeks 12–13)
Task 5. Clutch Design/Ergonomics	Δ.…Δ (weeks 13–14)
Task 6. ASME Boiler & Pressure Vessel Design	Δ.…Δ (weeks 14–15)
Task 7. Legal Aspects/Patent Search	Δ (week 15)
Task 8. Ethics Case Study by Teams	Δ (week 16)
Final Exam (PowerPoint presentation of ethics case by teams)	Δ (week 17)

The objective of the ME team is to satisfy its client, who represents management and manufacturing, and the product user, the public. Each team has an opportunity to make "silk purses," but the materials on hand appear more like "sow's ears." Significant contributions have been made in areas of structural redesign, product safety, cost reduction, product performance, manufacturability, and consumer ergonomics, but each project has its unique opportunities.

VIII. An Example Collaboration

During the Fall 2000 semester, one of the DIS teams chose an electric leaf blower for its venture analysis, as shown in Figure 3. Product specifications are listed in Table 2.

Figure 3. Leaf Blower.

Table 2. Product Specifications

Motor voltage	120 volts
Motor current	7.5 amps
Motor frequency	60 Hz
Blower exit air velocity	110 mph
Blower exit air volume	280 ft^3 / minute

The product was disassembled in a joint meeting with the MP team in week three, with each component part identified by description and part number, photographed, weighed, and tentatively classified as to make or buy. The disassembly activity was also videotaped.

The leaf blower consisted of twenty-five parts, including packaging materials and the owner's manual. The DIS and MP teams agreed that six of the parts, all plastic, would be fabricated. A team recommendation to treat the blower motor as a purchased part was accepted by the client/instructor.

During week four, a joint brainstorming meeting was held by the DIS (IE) and MSD (ME) teams to familiarize the MSD team with the product and explore redesign opportunities. A typical format for brainstorming was followed (no censoring of ideas, e.g.). The resulting listing of potential redesign items is given in Table 3.

Table 3. Potential Redesign Items

Number	**Description**
1	Add plug attachment
2	Add lock attachment (nozzle to housing)
3	Smooth nozzle and blower tube finishing
4	Different types of materials/plastics for parts
5	Improve fan design (including jet fan idea)
6	Decrease fan weight
7	Absorber pad (notch instead of glue)
8	Motor (including brush) - weight, size, etc.
9	Handle on back of housing
10	Change nozzle (slide like telescope)
11	Decrease noise

Next the IE and ME teams chose the highest priority items from the ones listed in Table 3. Items selected for redesign priority were 1, 4, 5 and 8.

The ME MSD team provided a report of its recommendations in week eight. The report included numerous figures and drawings not reproduced here, but a summary of those recommendations is given in Table 4.

Table 4. Mechanical Engineering Redesign Recommendations

Item	**Recommendation**
Motor	Given the voltage and current of the motor, the calculated motor power is 1.21 hp. Test the motor for power utilization. If the actual power output is less than 1.21 hp, then a less powerful (and thus less costly) motor could be used.
Air intake system and fan design	Change the fan design so that the air that moves past the motor can be "pulled" from the top vents of the housing rather than "pushed" from the bottom intake of the blower. This design improves efficiency and simplifies the impeller by providing cooling of the motor with 100% of the air moving out of the blower instead of splitting the air intake flow into part for motor cooling and part for the blower outlet.
Plug attachment	Add an extension cord clamp to prevent the cord from being accidentally pulled from the plug. The current design of a loop on the back of the housing is cumbersome and could damage the extension cord. Eliminate the loop.
Blower tube connection	Add a blower tube locking mechanism so that the blower tube cannot become detached during operation.

IX. Summary and Future Plans

The collaborations provide valuable educational experiences and new cross-disciplinary perspectives to engineering students. Student surveys support this conclusion by the faculty involved. The students learn to support each other and to depend on the diverse knowledge and skills of the group in the open-ended product realization task. This forms an effective capstone for the prior years of preparation in both IE and ME.

The instructional effort to sustain the collaborations is significant and should be recognized by the administration. Furthermore, a weakness of the collaborations is that they depend greatly on the commitment and enthusiasm of the collaborative courses instructors. An overly turf-protective collaborative instructor can easily prevent a successful collaboration.

A collaboration with a new IE required course, Logistics Engineering, is scheduled to begin in 2001-02, and other collaborations are being considered. One with Civil Engineering concerning facility construction cost is a possibility, although the timing of this activity (late in the semester) may prevent this collaboration from being implemented.

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