Embedding Engineering Management into Product Design Education

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Abstract — This paper first discusses the evolution of the Introduction to Engineering Design and Graphics course (ED&G 100) at the Pennsylvania State University from a skill development course to a product design oriented course. Then, it focuses on embedding engineering management subjects to the course due to new needs and necessities. Project management, teamwork training, motivation and decision-making are some of these subjects. The progression of embedment over three-semesters is presented along with brief design project explanations. Unsolicited student comments that are collected during teaching evaluations are also presented as an indication of improved student satisfaction.

Index Terms — Engineering management, and product design education.

I. Introduction

An integrated project team (IPT) is a multidisciplinary, relatively autonomous, project oriented work team [1]. IPTs are used in industry, not only to increase productivity in solving problems but also to form and sustain strategic capabilities through employee learning. New product development is one application area where the utilization of IPTs is regarded as critical to the formation of strategic product development capabilities [2,3,4]. To prepare students for similar problem solving responsibilities and to foster engineering principles learning, a comparable approach to IPTs is currently used for several sections of the ED&G 100 course at the Pennsylvania State University.

ED&G 100 is a first year engineering course with an enrollment of more than 400 students each semester. The major course objective is to develop sound problem solving skills early on in the student's education. This is accomplished through skill development focused on two design projects. The first design project involves building a weighing system using strain gages and beams. After a series of guided, hands-on experiments and lectures on the mechanical behavior of materials, four-person design teams are asked to build a weighing system that can accurately weigh objects within a specific weight range to a specified resolution. Team performance for this design project is measured via design demonstrations, and an evaluation of each team's design report.

During this project, a laboratory book [5] is used which includes experiments involving electrical resistor measurement, strain gage applications, and Wheatstone bridge circuit construction. Teams complete experiments by following step-by-step instructions from this book. In general, the weighing system design project is received as a natural conclusion to these experiments by most students.

The second project, which is industry sponsored, is utilized to create an atmosphere of "an actual working environment" for students via a real design project. Therefore, every semester a different industry sponsor is recruited to present a design problem, and determine deliverables. In general, these design projects are open-ended in nature; and clearly they don't come with step-by-step instructions. Thus, despite efforts to improve motivation via design competitions, the projects may become a source of frustration for freshmen engineering students who are typically new to dealing with open-ended problems. Common student complaints are that the projects and lectures are unclear or unorganized, workload is unbalanced that they are given too much work to do in a very short time, and even that they do not know what the next step in their solution should be.

Similar problems and potential solutions have been presented by others. Koen [6] noted that by omitting intermediate deadlines faculty might be enforcing the increased effort exponentially as the final deadline approaches. This increased effort in a short time, generally creates disputes about unbalanced contributions to the team project, which inevitably decreases team motivation. However, adding more faculty imposed deadlines takes away from students learning to run their projects. Thus, student-developed schedules have been advocated as a solution [7,8]. However, student-schedules alone are not sufficient deterrent to team disputes.

The focus of this paper is (1) the evolution of the ED&G 100 course from a skill development course to a product design oriented course, (2) "unplanned" embedment of engineering management subjects to the course due to its new needs and necessities over a three-semester period. Unsolicited student comments collected during teaching evaluations are presented as an indication of improved student satisfaction.

II. Evolution of the Course

ED&G 100 course was originally a skill development course with over half the course dedicated to manual graphics instruction and about 25% dedicated to laboratory skills such as instrument use, experimental data acquisition and analysis, and report writing. During the 1980s graphics instruction was reduced to make room for computer literacy: introductory programming and exposure to the early CAD software. In 1990, programming was dropped; and in 1991, the first solid modeling software, Silver Screen, was adopted and used until 1998, when IronCAD was introduced. Also in 1991, with NSF funding, a design project was introduced. The design curriculum has slowly taken over the course and the name was changed form "Engineering Graphics and Communication" to "Introduction to Engineering Design" in 1995. The conception of design imparted to students in the course also changed during the 1990s from something both challenging and motivational to something very relevant and focused on real problems in industry and the public sector. In 1998, Engineering Design and Graphics Program was one of the recipients when Penn state won the Boeing Engineering Educator of the Year award [9] for a proposal entitled "Industry-Led Design."

The course now has two design projects, a technology push project based in the strain gage that has its origins in the laboratory curriculum developed in the late 1970s and a market pull project usually from industry. Occasionally the second project is in the public sector. Documentation of the second project is now web based.

In hindsight, the changes seem to have happened slowly but they have been far reaching and graphics is now only about 15% of the course with perhaps 20% devoted to CAD. Of what has been lost, there are a few casualties that stir second thoughts. The lab-based curriculum used to be rather more extensive and it is hard to give up any of that. Also, tolerancing is not taught by all instructors and probably should be, but curricular time is at premium and the students sometimes complain of the workload.

On the other hand, because of its renewed importance we now see that design should be taught in order to establish competencies for the next design course rather than just a motivational tool or for professional orientation. Thus, looking ahead we can identify many needs. Some of these needs are relevant to engineering management (project scheduling, staffing, budget and risk management, development processes and organizational structures, application of codes and standards, and product planning.) The following section summarizes the embedment of several engineering management topics to design curriculum over the course of three semesters.

III. Embedding Engineering Management to Design Education

The embedment of engineering management topics to design education was not planned and implemented in steps over three semesters. Rather, it has been a progressive chain of observing problems, and implementing remedies in successive semesters in search for an improved way of teaching product design, or engineering design in general, via open-ended problems. This unique experience is discussed below in three phases involving three different design projects: (1) Kimberly Clark product design project, (2) Marconi Communications product design improvement project, and (3) Hazelton campus solution design project.

Phase I: Kimberly Clark Product Design Project

During fall semester 2000, Kimberly Clark presented the problem of revisiting the "single-season" product business, to define the product execution and corresponding automated process design for a business proposition. Key deliverables were a market analysis and a prototype of the product; a description of the manufacturing process needed to mass-produce the product, and an in-depth analysis (with CAD drawings, documentation, etc.) of one of the components of the manufacturing process.

After design project 1 was completed, students were asked if they wanted to change their teams, which were originally formed by students. Only two teams out of each section responded as they did. After reshuffling team members only in those teams, the design project was introduced. To guide these design teams, product planning, identifying customer needs, product specifications, concept generation and concept selection were introduced [10] as major components of the development process. Several intermediate deadlines and a project deadline were determined to set a moderate pace. Critical path method (CPM) was also introduced, and students were encouraged to plan and complete development activities to meet the deadlines. Furthermore, they were told that after the project they would be evaluating each other for their contribution to the design process, and that project grades would change subject to contribution.

Design project performance was evaluated by peer design evaluations and design report assessment. The weights of these assessments were 25%, and 75% respectively. Peer design evaluations were done during the in-class design competition. While a team was presenting, remaining teams evaluated their design. It was observed that students took evaluating peers very seriously, hence a meaningful design discussion after every presentation surfaced. During this peer evaluation and peer critiquing time, integrity and ethics were strongly emphasized.

Despite the fact that most students received the competition environment very well, and one of the teams won the overall competition out of 112 teams, some performance limiting issues have been observed. Teamwork ineffectiveness, miscommunication, and inefficient use of time were among these. As a set of remedies for these problems, a team building activity and teamwork skills interventions were added to the course, and the course was run including these during spring 2001 semester.

Phase II: Marconi Communications Product Design Improvement Project

The second project for the spring 2001 semester was sponsored by Marconi Communications Inc. The objective was to design a shipping crate to house the Marconi Communications BXR-48000 switch, which weighs 700 lbs and has dimensions of 73.5 x 21.2 x 23.62 in. The crate is for use during manufacture of the switch and shipment to the end user. Other design requirements for the crate included the ability to maneuver the crate with only two people without using a forklift and the ability to reuse the crate. The design project and its objectives were conveyed to all teams at the same time. Each team was given eight weeks to develop their design solution. All teams were instructed to act during this time as if they were companies competing to get Marconi's shipping crate business with their solution.

For this project, teams were formed randomly. Randomly selected one half of the teams were given three two-hour high performing team skills training, while others were provided engineering problem solving assistance as is typically provided for the ED&G 100 students. The training offered to the randomly selected sample of eight design teams was varied, and in general, it became more complex with each intervention. A brief description of the content of each intervention is described below.

Intervention 1— Earthquake Exercise: The first intervention consisted of a simple earthquake exercise used to demonstrate that individuals working in teams typically perform better than individuals working alone on the same task. This intervention was conducted after the design project was given to the design teams. The teaching point reinforced was that teams produce better results than individuals.

Intervention 2 — Role Playing of Group Development Stages: The second intervention was conducted during the fourth week of the final design project. During this intervention stages of group development were introduced—forming, storming, norming, and transforming/high performing. Following this introduction, each team was asked to develop a role play scenario depicting a specific stage of development, i.e. one team developed a scenario and acted-out the forming stage, one team role-played the storming stage, one team role-played the norming stage, and finally, the other team role-played the transforming/high performing stage. Though initially uncomfortable with the notion of role-playing, the student teams performed well and their role-plays were consistent with the stage of group development that they were required to act-out. The teaching point reinforced was that teams undergo a tangible, somewhat predictable developmental process and that at times group development is uncomfortable.

Intervention 3 — After-Action Reviews (AARs): This intervention was conducted during the seventh week of the final design project. Design teams were led in a brief discussion of the theory, and execution of AARs. The discussion included the introduction of a 3-step method to (1) review & analyze what went well, (2) review & analyze those things that did not go well, and (3) offer recommendations & suggestions for improving those things that did not go well during team projects. After the discussion of the AAR process, student teams were then required to conduct an internal AAR to evaluate their own team's performance up to that point of the design project. The students valued the opportunity to engage in meaningful team analysis using the 3-step AAR method. They reported their findings to other groups and, predictably, came to understand that other teams shared similar problems and successes. The teaching point reinforced was that self-assessment is a useful technique for monitoring and improving the performance of teams.

Design team performance was measured using team quizzes, design demonstrations (during which designs were evaluated by peers), and an evaluation of each team's design report. The grading weight of the team quiz was 5%. 25% of the remaining 95% of the project grade (23.75%) was allocated as the weight of the peer design evaluation, and 75% of the remaining 95% of the project grade (71.25%) was assigned for the design report assessment. These weights were used to establish a project grade for each design team. However, for each team member's grade, the other team members were asked to rate the contribution of that person to the team's design solution. Their contribution grade was then used to establish a multiplier to determine their project grade.

A team quiz is an assessment during which a set of questions is answered by a team of four in 15 minutes. Only one member would need one hour to solve the same set of questions. The time allowed for completion of the team quiz was adjusted based on the group size. However, for absent/late members, no time adjustment was permitted. The purpose of giving team quizzes was to help students learn that they are interdependent, and hence it was added as team building activity. Three quizzes during project 1 and two team quizzes during project 2 were given throughout the semester. It was observed that on team quiz days attendance improved, and students showed effort not to disappoint their teams.

Major product development process components were introduced as was done the previous semester. In addition, they were asked to study the development process of at least two companies via an Internet search before identifying the activities they will schedule using CPM. The objective was to have teams adopt their own design process, and define relevant activities.
Despite the initial complaints for changing their teams by randomization before the final project, students were not vocal about team related problems throughout the project. The intervention topics were appropriate - - particularly the earthquake exercise and the AAR exercise. Some unsolicited comments indicated that interventions were not given early enough for them to use effectively. Some resistance was encountered during the role-playing intervention from a few

students with statements such as: “Why are we learning this stuff? or “We don’t want to be leaders, we want to be engineers!” Furthermore, it was observed that separating the design teams for giving training only to one half of the teams raised questions, and made them uncomfortable.

Phase 3. Hazelton Campus Solution Design Project. This project involved the solution to a handicapped access need at the Penn State University’s Hazelton campus. This campus provides residence hall accommodations for 485 students. In addition, the hall’s food court provides meals for resident students, faculty, staff, and visitors. The food court building and residence halls are located near the main entrance of campus, at an elevation ranging approximately 1575' to 1600' above sea level. All other campus facilities are located at an elevation of approximately 1710'. Getting from the lower portion of campus to the upper part is accomplished by either walking directly up a steep pathway, which is not compliant with the Americans with Disabilities Act Accessibility Guidelines (ADAAG) for slope and design—or directly on the main road, which is non-compliant for slope. Driving is an option but parking is limited. In order for the campus community to be able to access the facilities without having to drive, finding a solution that offers flexibility, convenience, ease of use, and accessibility for people with disabilities was the design task. Thus, teams were required to design a mechanical, manual, or service system that will provide access for people with disabilities and the non-disabled population.

Project deliverables were traffic analysis, CAD drawings, projected costs (construction and operation), a scale model prototype, and design documentation. For this project the performance was measured using team quizzes, peer design evaluations, and design report evaluations. The weights of these grades were 5%, 23.75% and 71.25% respectively, as was previous semester.

During this phase, team formation, peer evaluations within teams, determination of project due-dates, and timing and topic of teamwork interventions were modified. Teams were formed to have teams with similar average GPAs because a study of the previous semester’s results showed the average team GPA to have a significant effect on team performances [11]. After studying the product development process students were encouraged to set their own intermediate due-dates. The final project due-date was set to be the in-class design competition date.

The peer evaluation within teams was done for both design projects. Since teams were not changed for the second project, the individual contribution values calculated after design project 1 were not revealed until teams were done with the second round of peer evaluations. Instead, a half an hour class period was dedicated for them to discuss their performance and how to improve performances individually and as a team. However, last day of the class, each student was given his peer evaluated contribution value, and teams were encouraged to discuss the values if anyone thought there was an unfairness.

Team skills interventions were conducted for all teams 4-times for 2-hours each for a total of 8-hours starting earlier in the semester in comparison to previous set of interventions. The type of training offered or order of delivery during this intervention series was modified. Following the earthquake exercise, the AAR training was presented. Then personality type training was offered. This intervention briefly introduced the personality type theory followed up with a confidential on-line questionnaire [12]. The questionnaire categorized students into 4 groups as guardians, artisans, idealist, and rationalists. This categorization was based on dimensions of extroversion and introversion, intuition and sensing, thinking and feeling, and judgment and perception. Learning about their personality type created a discussion environment for the effect of personality type on project performance.

Role-playing was replaced with strategic planning intervention. During this intervention, importance of planning one's life and the efficient use of time for becoming higher achievers were discussed. Students were encouraged to apply these same principles to their design project.

IV. Results

Overall, after the embedment of various engineering management topics and relevant activities, a decrease in student complaints was observed. Although it is not possible to identify the isolated effect of each of these embedded topics and activities, an aggregate indication of student satisfaction is presented in Table 1. The information given in Table 1 is compiled from the unsolicited comments relevant to design project 2 collected during teaching evaluations for the course over three semesters. In the table, the number of positive comments and that of negative comments are categorized into various themes relevant to design project 2, such as organization, clarity, teamwork, and the amount of work.

Table 1 also shows the overall quality of instruction and overall quality of the course as documented by the teaching evaluations.

Table 1. Compiled Unsolicited Student Comments About Design Project 2.

Focus of comments	**Design Projects**					
	Kimberly Clark Project Phase I - Fall 2001		**Marconi Comm. Project Phase II - Spring 2001**		**Hazelton Campus Project Phase III - Fall 2001**	
	Negative Comments	**Positive Comments**	**Negative Comments**	**Positive Comments**	**Negative Comments**	**Positive Comments**
Organization	**8**	**0**	**4**	**0**	**3**	**0**
Clarity	**8**	**0**	**2**	**0**	**4**	**0**
Teamwork	**0**	**0**	**0**	**7**	**0**	**14**
Project overall	**12**	**2**	**2**	**8**	**4**	**12**
Amount of work	**10**	**0**	**25**	**0**	**16**	**0**
Design lab time	**3**	**0**	**0**	**0**	**5**	**0**
# of evaluators	**51**		**58**		**88**	
Overall quality of instruction	**5.82/7**		**5.97/7**		**6.26/7**	
Overall quality of the course	**4.91/7**		**5.26/7**		**5.58/7**	

It is clearly seen that both the quality of instruction and the quality of the course have improved. Since the instructor is not changed from one semester to another, these improvements are explained with the embedment of engineering management topics to the original engineering design curriculum. Nevertheless, compiled unsolicited student comments show an increase in the number of positive teamwork relevant comments and in the number of positive design project relevant comments.

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V. Conclusion

The paper discusses the progressive chain of observing problems, and implementing potential solutions in successive semesters in search for an improved way of teaching product design via open-ended problems. The implementation of potential remedies resulted in an embedment of engineering management topics and relevant activities to the course, such as team building (team quizzes), teamwork skills training, project management (identifying activities, determining due-dates, and CPM), and motivation (peer evaluations within teams). Although it is not possible to identify the isolated effect of each of these, an aggregate indication of student satisfaction is presented in Table 1. Overall, it is observed that student satisfaction relevant to the quality of instruction and the quality of the course has increased. This is attributed to the embedment of engineering management topics and relevant activities to the engineering design curriculum.

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