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Abstract

Modern approaches to design and manufacturing require that graduates of engineering and technology programs are capable of working as team members within design and manufacturing environments. This paper explores fundamental concepts of team based activities, functionally, and effectiveness. It details the implementation of a team design problem within a computer-aided design course at Purdue University. Included within the team design problem's description are project management techniques and student feedback.

I. Introduction

The continued growth and development of information technologies have presented tools and techniques that have the potential to revolutionize engineering design and data sharing processes. Manufacturing enterprises function in a world marked by strong international competition and diversity. Traditional approaches to design and development can fall short in environments and industries where fast product time-to-market is often the best strategy for the capturing of market shares. Still, customers demand high quality and any company that cannot meet their expectations can and will be replaced. Design processes that are responsive and concurrent are needed for higher-quality products and faster time-to-market.

Conventional design processes are often conveyed as being linear in nature with steps such as Problem definition, Conceptualization, Synthesis, Analysis, and Manufacturing (Ditier, 1983). When an individual or group in the process identifies a problem or change, the process is often restarted. This traditional approach to design presents several problems (Cralley & Rogan, 1987). First, upfront design and development, to include engineering drawings, often leave important individuals out of the initial design loop. Groups and/or departments ranging from production to customer service often do not provide feedback until the latter stages of the process (if they actually get to provide feedback) leading to an emphasis on lower cost instead of performance and manufacturing suitability. Second, conventional design processes usually lead to fragmented data. This promotes the traditional communication "wall" found between engineering and manufacturing with both parties developing their own data sets and criteria. This in turn leads to lost data and ambiguous design representation.

Philosophies such as concurrent engineering were established to meet the quality demands within the lifecycle of a product. Within conventional design processes, functionality is followed by manufacturing, then assembly, then serviceability (Bedworth, Henderson, & Wolfe, 1991). Each step is tackled sequentially with minimum information flow occurring between parties. "Concurrent engineering has as its purpose to detail the design while simultaneously developing production capability, field-support capability, and quality" (p 141). It involves the concurrent arrangement of design functions into one design team consisting of individuals that represent the life of a product (from concept to scrap). Linked with wide-area networks, concurrent engineering teams have the capability of communicating between widely dispersed locations. This technological enhancement promotes the removal of communication barriers that commonly exist when design departments and production facilities are geographically separated.

Concurrent engineering dictates that individuals possess solid teamwork skills. While many individuals possess natural traits that can facilitate group dynamics (e.g. leadership, writing, speaking, personality, etc.), the ability to work in a team is a learned skill. Current Accreditation Board for Engineering and Technology (ABET, 2004) and National Association for Industrial Technology (NAIT, 2003) accreditation standards stress the importance of teamwork, problem solving, and design. Specifically, the Technology Accreditation Commission of ABET requires that graduates: 1) attain "an ability to function effectively on teams", 2) attain "an ability to identify, analyze and solve technical problems", and 3) utilize the interpersonal skills necessary to work effectively in teams. Additionally, the integration of concurrent engineering strategies, design processes, and collaboration is important and relevant in technology curriculum models (Balamuralikrishna, Athinarayanan, & Song, 2000; Chen & Chen, 2004; Yang, Hsu, & Ching, 2002).

II. Purpose

The purpose of this paper is to describe an introductory computer-aided design course for engineering and technology students. Specifically, this paper describes how this course utilized a structured team design exercise to introduce students to the fundamentals of group problem solving, project management, and concurrent engineering. Within this exercise, students were required to formally structure and self-administer their respective teams. It was thought that well structured design groups with established rules, procedures, and member responsibilities would promote effective teamwork. In order to assess this hypothesis, the following research questions were proposed:

1. Would formally structured design teams promote individual participation?
2. Would formally structured design teams lead to an enjoyable and valuable design project?

III. Team Fundamentals

While the utilization of teams in industry is not a new phenomenon, the effectiveness of their use has been questioned (Bailey, 2000; May & Carter, 2001; Rafferty & Tapsell, 2001). Globig (1999, Fall) describes two types of teams: Team Waste and Team Synergistic. Team Waste meets once per week with the objective of updating teammates on the progress of individual functionality. Members within this type of team work alone and rarely communicate effectively. While better than pure sequential design (with no teamwork), team members still working in their own arenas "may be optimal in their individual domains but will seldom remain optimal in a combined domain which is a union-sum of those individual domains" (Prasad, 1996, p. 170). Team Synergistic, on the other hand, while formal in organization, does not actually have formal meetings. Team members work together everyday and are constantly sharing ideas and concepts. Constancy of purpose is the norm, not the exception. Members are comprised of individuals from a variety of departments to include design, engineering, marketing, production, and service.

The effectiveness of a team, especially one that is self-directed, is often dependent upon the attitude of its institution and the nature of its organization. Hitchcock and Willard (1995) list four important criteria for an effective team. First, team members must work together full time. As previously pointed out by Globig, teams that come together only to share information (i.e. Team Waste) are not as effective as teams that are consistently dependent upon every team members' efforts (i.e. Team Synergistic). Second, effective work teams must include interdependent employees. Often overlooked in the design cycle is the value that downstream individuals (e.g. service technicians, salespersons, customers, etc) can have in the development of an effective product. Traditionally, players such as service technicians and salespersons have their own organizational structures. This hierarchy is usually outside the flow of the design process and does not promote concurrent product design. Due to this, it is usually necessary to reorganize to promote the effectiveness of teams. Third, teams must manage themselves. Traditionally, a group of workers will have a formally assigned supervisor. This concept does not promote effective utilization of teamwork. Instead of one team leader, the roles of a leader should be dispersed throughout the team. Finally, teams should be directed from within, not from the outside. It is common to find work teams that must report to one external authority, especially for administrative actions such as sick leave, vacation, etc. While it is rare to find a team that does not have to report to some form of entity, most of the administrative responsibility of a team should be handled from within the team itself.

According to Bragg (1999), groups must have certain attributes that lead to success. One attribute is a reason to work together. Often, teams are formed for the sake of change. Without a reason to work together, teams are doomed from the beginning. Accordingly, a group should work toward a specific, clear objective. As identified by Pagell and LePine (1999), groups that work on novel problems are more likely to be successful than groups that work on mundane issues. Additionally, when individuals believe that group activities are better that working alone, team production will improve.

Bragg (1999) stresses that the composition of a team should be carefully considered. A common approach is to form teams with members that share common skill sets. Since this provides a group with a narrow range of expertise, this type of group naturally fails. When teams are formed, team members should have complementary skills. Katzenbach and Smith echo this principle (1993) when they define a team as a "small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable" (p. 45). Concurrent engineering teams are formed of individuals from all avenues of an organization. This provides a broad range of expertise and timely input to critical design information. When a group is formed, the group, not individuals in the group, should be held accountable for success or failure.

A common concern with group problem solving in an educational setting is allowing strong members of the group to do a majority of the work, with weaker students not performing their share. Groups should be structured to allow for equal participation from all members. According to Johnson and Johnson (1994), five essential elements are necessary to allow for true cooperative efforts: (a) positive interdependence, (b) individual accountability, (c) face-to-face interaction, (d) social skills, and (e) group processing.

While common educational methodologies either require students to compete for grades or to work alone to accomplish an educational goal, successful groups should have a positive interdependence, where the successful outcome of one group member is dependent upon the successful outcome of each group member. In addition, well functioning groups require all group members to be held individually accountable for handling their share of the load. Through design or through neglect, these two elements of cooperative learning are often overlooked when structuring group exercises. While neglecting these two elements can still lead to successful group outcomes, there is no assurance that all members of the group will benefit equally.

Johnson, Johnson, and Holubec (1993) describe three steps for structuring positive interdependence. First, groups should be presented with clear objectives and goals to accomplish. Assignments with absolute right or wrong answers, such as in mathematics and physics problems, make ideal opportunities for cooperative groups, but design problems can also be integrated successfully. The key to cooperative groups is the setting of clear and measurable objectives. Second, groups should have positive goal interdependence. This requires individual member objectives and goals to complement the objectives and goals of the group, and the goals of individuals should lead to the accomplishment of the group's goals. Finally, groups should focus on the accomplishment of individual objectives and make a point to reward or compliment members for accomplishing a task. Johnson et al. (1993) also describe several ways to structure individual accountability. First, groups should be small enough to allow individuals to contribute, but members should, at times, be individually examined. Additionally, individuals in a group should be required to share learning outcomes with other members of the group.

IV. Team Design Problem

The course presented in this paper, CGT 226 (Constraint-Based Modeling), is required for Computer Graphics Technology and Computer Integrated Manufacturing Technology students at Purdue University; it is an elective for Mechanical Engineering Technology and Industrial Technology students. In addition, 20 to 30 percent of students

Figure 1. Design Problem

Figure 2. Ideation Sketch

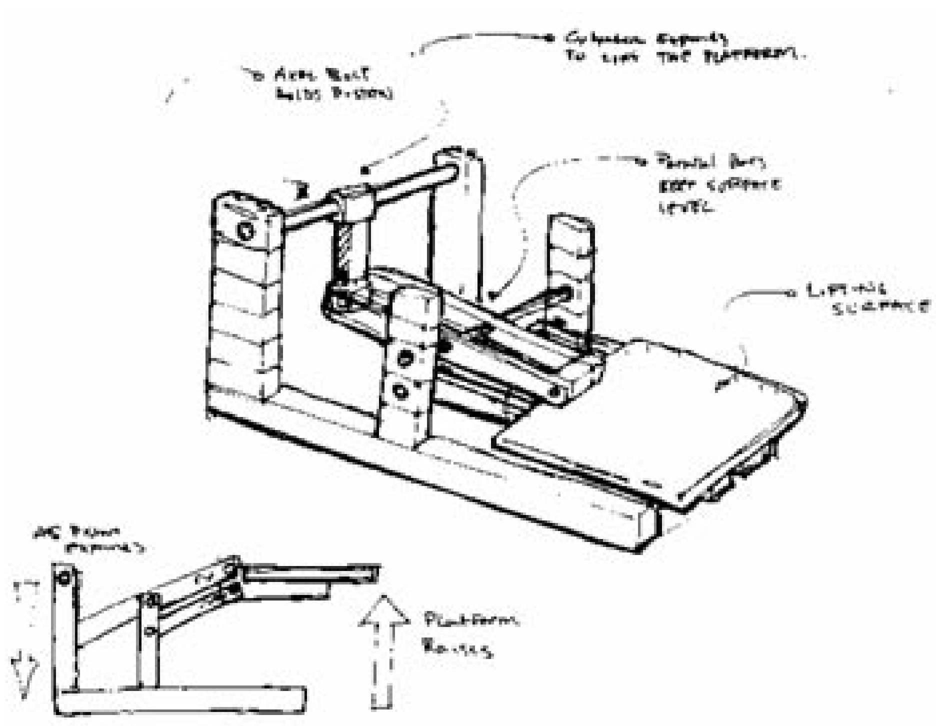


Table 1. Example of a Weighted Scoring Table

SPECIFICATION		CONCEPT 1		CONCEPT 2		CONCEPT 3	
		SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE
Weight	2	4	8	5	10	2	4
Color	1	3	3	4	4	4	4
Cost	4	4	16	4	16	3	12
Functionality	5	1	5	3	15	3	15
Total			32		45		35

within the course are from Purdue's Schools of Engineering. Students taking CGT 226 are required to complete an intensive team design problem. This project focuses on the incorporation of a high-end computer-aided design application (usually Pro/ENGINEER) and team design fundamentals within a formal design process. The design problem is typically changed every semester. Some past problems have included designing an adjustable basketball goal (see Figure 1), designing an aviation headset light, and designing a device for cracking pecans. The following criteria are utilized by the course director to select a problem: (a) a design that will incorporate multiple parts, (b) a design with parts that can be modeled by students within the course, and (c) a design that does not require complicated electronics.

Within the group design problem, students must follow a formal design process (Kelley, Newcomer, & McKell, 2000). Students are first presented with a design problem (i.e. a basketball goal) to include a limited number of required specifications and limitations. Students develop the problem by defining a problem statement and a complete list of design specifications. Design specifications are categorized and ranked in order of importance. Following the setting of the specifications, students must develop valid and distinct solutions through the use of ideation sketching (Figure 2) and brainstorming. For most design exercises, three solutions are required. A final concept is selected through the use of a weighted scoring table (see Table 1). After concept selection, students are required to model the design with the course's selected CAD application. A final assembly model and an assembly drawing with bill of material are created.

V. Group Formation and Project Management

As previously mentioned, students taking CGT 226 come from a variety of majors to include Computer Graphics Technology (CGT), Computer-Integrated Manufacturing Technology (CIMT), Mechanical Engineering Technology (MET), Industrial Technology (IT), Mechanical Engineering (ME), Aeronautical Engineering (AE), Industrial Design (ID) and Interdisciplinary Engineering (IDE). Two criteria are considered when assigning students to design groups: populating a group with a variety of student skills and providing each group with at least one "power" CAD user. Groups are formed around the fourth week of the academic semester. This provides time for the course's lab instructors to determine which members of the class will be strong users of Pro/ENGINEER (or any other selected CAD application). Lab instructors first form groups by distributing majors into each group. The objective is to distribute a least one CGT (or ID), one MET (or ME/AE/IDE), and one CIMT (or IT) major into each group. The purpose of this approach is to simulate a concurrent engineering approach to design with a variety of student strengths and skills. The instructor then determines that each group has one member apparently strong at modeling with a computer-aided design application. If not, the instructor reconfigures each group to meet this requirement.

Team development and organization are important considerations within each design project. Teams are required to be self-administrated and managed. When problems arise within a team, such as a group member not pulling his or her share of the load, the team (not the instructor) is responsible for finding and implementing a solution. When teams are formed and the design problem presented, the instructor provides a list of required tasks along with approximate times necessary to complete each task (see Table 2). From this list, each team assigns tasks for specific members to perform (see Table 3). Additionally, each team must develop a group mission statement and a set of team rules and polices. Examples of issues addressed within a set of rules include: (a) meeting attendance, (b) communication methodologies, (c) personal problem solving, and (d) member task requirements.

Under the criterion of managing their own design projects, using backwards planning techniques, teams are responsible for setting their own task due dates. Once set, each team is held responsible for completing each task according to schedule. As a reference for setting their due dates, teams are provided approximate completion times for each required task (see Table 2) and the project's final due date. The instructor also provides prerequisite tasks. Using this information and working backwards from the due date, a Gantt chart (Figure 3) and a PERT chart (Figure 4) are created to help manage the project.

The emphasis on formally managing the course's design projects serves three purposes within the goals of the course. First, students are introduced to real-world project management techniques that they can use throughout their programs of study. Since many students in the course have completed or will take a course in production management or production control, this provides a good balance between theory study and practical examination. Second, since the course's design project can at first seem overwhelming, task-scheduling techniques help to keep students on track toward producing a high-quality final design. Third, since all design projects require students to model multiple parts within a shared team environment, students have to formally organize their data sharing procedures.

VI. Findings

During the Fall 2001 semester, quantitative and qualitative approaches were utilized to derive team and individual opinions on the effectiveness of the design exercise. Three sections of CGT 226 were used for feedback (n = 47). At the end of the project, each team was required to detail in a formal report three positive experiences from the exercise (i.e. what they liked) and three negative experiences (i.e. what they didn't like). The purpose of this approach was to obtain valuable student and team feedback on ways to improve the exercise. Students also individually completed a questionnaire that was designed to measure the perceived effectiveness of their design groups. A Likert scale was utilized to measure

Table 2. Required Project Tasks

TASK NUMBER	REQUIRED TASKS		RECOMMENDED TIME TO COMPLETE TASK
1	Task due dates to instructor	NA	1-2 days
2	Group member duties	1	1-2 days
3	Group mission and rules	1	2-3 days
4	Problem identification statement	3	1-3 days
5	Ideation sketches	4	5-10 days
6	Weighted scoring table	4,5	1-2 days
7	Design for Assembly Analysis	6	1-2 days
8	Pro/E part models	7	5-10 days
9	Pro/E assembly drawing	8	2-3 days
10	Rendering	9	1-2 days
11	Abstract sheet/Notebook	9,10	2-3 days

Table 3: Team Member Responsibilities (Example)

TASK	ASSIGNED PERSONS
Setup Group Rules and Develop Mission Statement	Everyone
Assign Member Duties	Everyone
Develop Problem Statement	Jill, Jane, and Jack
Develop Ideation Sketches (Concepts)	Everyone (one concept each)
Produce Weighted Scoring Table	Joe
Design for Assembly Analysis	Jack
Model Parts in Pro/ENGINEER	Jill, Jane, and Joe
Develop Assembly Model in Pro/ENGINEER	Jack
Produce Assembly Drawing in Pro/ENGINEER	Jane
Rendering of Assembly	Joe
Project abstract	Jack
Design Format for Notebook	Jill

responses (1 Strongly Agree, 2 Agree, 3 Neutral, 4 Disagree, and 5 Strongly Disagree) to the following statements:

1. My group functioned well together.
2. All members of my group did their fair share of the assigned group project.
3. I enjoyed the group project.
4. The group project was a valuable component of the course.
5. Having task due dates helped to keep my group on schedule.
6. If I had a choice of doing a group activity or doing extra individual assignments, I would chose to do extra individual assignments.

A one-sample t-Test was used to determine degrees of significance for each question. The population value was set at 3.0 to reflect a neutral response. The findings from the student feedback reflected a positive attitude toward the team project. In general, students enjoyed the project, (M = 2.468, SD = 0.929), t(46) = -3.925, p = 0.000, and felt it was a valuable learning experience (M = 2.319, SD = 1.002), t(46) = -4.657, p = 0.000. When requested to state a preference between the group project and a similar individual project, there was no indication that students would prefer doing an individual project (M = 2.829, SD = 1.148), t(46) = -1.106, p = 0.315. The qualitative results mirrored the quantitative survey. One of the overwhelming positive responses derived from the group reports was the opportunity to apply a CAD application, such as Pro/ENGINEER, to a design problem. Students also liked the creative nature of the project and the ability to work with individuals from other majors.

There was positive feedback relating to team management of projects. Teams liked the fact that they were able to set their own due dates for subtasks of the exercise (M = 1.957, SD = 0.721), t(46) = -1.042, p = 0.000. There was some consensus for having less required due dates, though. Within the project, there were 11 tasks that had student assigned due dates. The qualitative feedback highlighted that students wanted some of the tasks combined into one due date

Figure 3. Gantt Chart

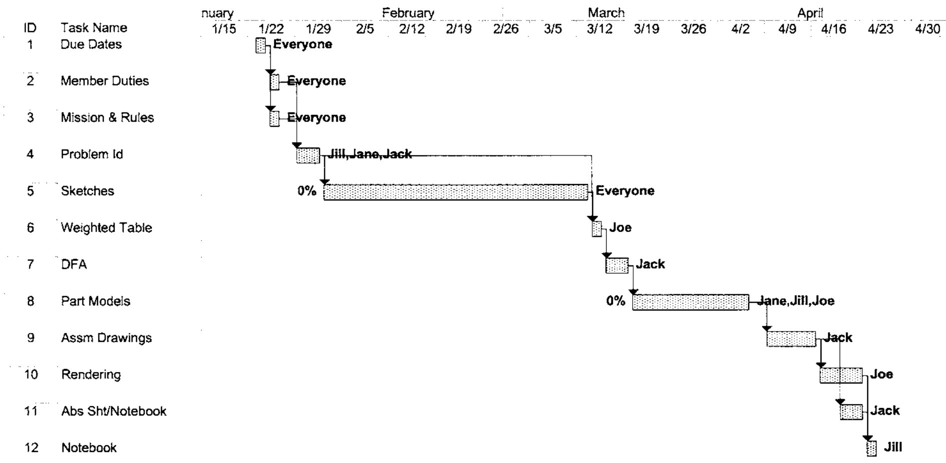
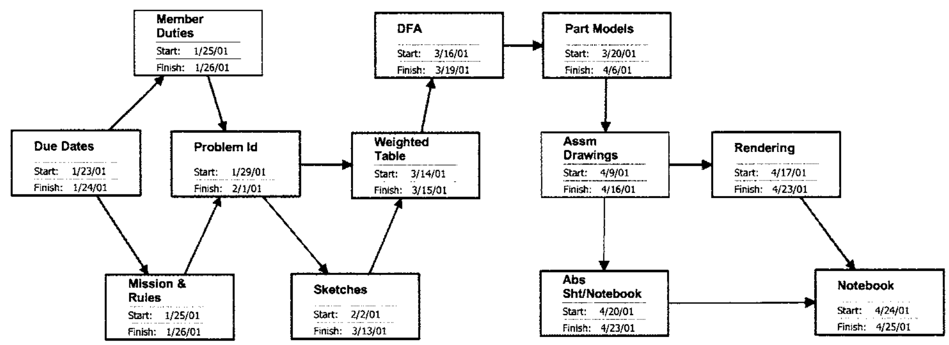


Figure 4. PERT Chart



with approximately five or six required due dates. While teams and students liked being able to set their own task due dates, there was some concern related to the use of project management tools to track task progress. The reports indicated that PERT and Gantt charts were not helpful in keeping their groups on schedule.

The design project was structured to promote a positive interdependence among group members. Generally, this structure appeared to be successful. The survey indicated that group members functioned well together, (M = 1.8511, SD = 0.5508), t(46) = -14.299, p = 0.000, and that all group members performed their fair share of the assigned tasks (M = 2.276, SD = 0.948), t(46) = -5.227, p = 0.000. One of the requirements established to promote positive interdependence was the upfront setting of individual responsibilities. Student qualitative feedback generally indicated that this requirement was helpful in completing the project tasks in a fair and equal manner. Of the fifteen teams that were evaluated, only one had a student that was negligent in performing individually assigned responsibilities. This team adequately managed this problem, ending in a successful final project.

Each team provided positive feedback on the management of the project. Within the course, students normally complete the team design exercise outside of formal laboratory hours. Most teams mentioned that they would like to see time set within formal class periods for team activities. One team mentioned that they would like to see a fewer number of individual lab assignments and more group exercises.

VII. Implications

One of the goals CGT 226 is to develop in students the ability to visualize and solve design problems using a formal design process. This goal is accomplished through individual laboratory exercises and a formal design project. Another goal is to develop in students the ability to implement basic principles team problems solving. This goal is accomplished through the utilization of a team design project. A subset of this goal is the ability to manage multiple team tasks through formal project management tools. This sub-goal is met through the utilization of management tools such as PERT and Gantt charts.

Within this course, students were required to manage their own individual course requirements (e.g. lectures, labs, etc.) and to participate within the management of their own design teams. The purpose for providing a team exercise instead of an individual design project is to provide a practical exercise were students must work together in a team environment. Student feedback seems to suggest that this objective was accomplished with student teams submitting viable and well-managed projects and designs.

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