Practical Senior Design Considerations

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Abstract

The author has recently been given responsibility for overseeing a senior design project (capstone design) course, typically with 50-60 students, divided into teams of four to six students to produce a design meeting certain objectives. This paper discusses some of the elements in a capstone, with a focus on pragmatic aspects that may be helpful to other faculty members. These will include prior semester preparation, team selection, and team effectiveness. Problems that can arise with teams are also presented. Methods used for team selection are reviewed, and apparent grading differences are discussed. The issues of "social loafing" and peer evaluation are described. Especially noteworthy in this course was an apparent issue with gender. When final grades were submitted and tabulated, the author was surprised to find a disproportionate percentage of the women students receiving very low, even failing grades. These results were unexpected, especially when noting prior academic performance. In addition, some male students with otherwise stellar grades received very low grades in the course. This paper addresses the approaches reviews made by the author to understand both proximate and ultimate causes and to seek ways to minimize problems in future semesters.

Keywords: *Design, Teams, Gender.*

1. Introduction

The author has recently been given responsibility for overseeing a senior design project course, typically with 50-60 students, divided into teams of four to six students to produce a design meeting certain objectives. Each team has a faculty mentor who not only oversees each team's performance and mentors them, but also is responsible for assigning grades. In that first semester, a number of issues arose that required changed approaches. This paper is intended to provide a pragmatic look at the issues, identify some short- term "fixes" put into place for the second iteration, and introduce areas the author will research in the future.

2. Course Context and Objectives

The senior design course, or capstone course, is required by the engineering accreditation body, or ABET. As they state, students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints. [1] Thus, this is a requirement for engineering programs. The exact approach may vary from program to program. Examples can be seen at many universities. [2] – [5]

Each program must develop key student outcomes, as well as program educational outcomes. The mechanical engineering program at the University of Texas at El Paso (UTEP) has three program educational objectives. One is especially pertinent to the discussions herein, specifically "Our graduates excel as engineers with solid technical skills, strength in design, and an ability to work with complex engineering systems." It should be expected that the capstone course builds on expected student outcomes embedded in earlier courses. It begins them down the road to life-long learning by requiring them to undertake activities outside the traditional classroom. [6]

3. Course Format

The course is the second of a two-semester sequence in engineering design in the curriculum. The first is ME 4336, Principles of Engineering Design, and the course discussed herein is ME 4366, Senior Design Project. In the first course, students are exposed to some fundamental design approaches and considerations. Then, about half way through the course, they are expected to create teams and to select projects and mentors. They then begin work on the project, beginning with conceptual issues and problem definition. Examples of projects conducted for the Fall, 2013, semester are as follows: Design of low-cost water filtration system; ACL Simulator design and analysis; Knee joint simulator; Transportation Vehicle and Thermal Water Extraction System; Cooling System Design for UTEP's High Pressure Combustor; Design of Novel, Efficient, Durable Thermal Control Systems, Design of a low-cost prosthetic foot; Design of a low-cost prosthetic arm; and Thermoelectric exhaust waste heat recovery.

4. Course Management

The course has an instructor (in this case the author) who manages the course and oversees it. Each team has a faculty mentor, and the overall instructor is available to help them as needed. For this course offering, the transition between courses was excellent. The instructor for the first course provided the author with a notebook including the list of team members, projects, mentors, and several pages of initial work by each team.

The grading structure in this first effort was perhaps a little looser than it should have been. However, each mentor was charged with providing a grade for their team for the entire semester. Further, they were charged with providing their assessment of the individual contributions to the team performance. This was calibrated somewhat against the peer evaluation forms submitted by the students evaluating other members of their team. There was at the end of the semester a presentation on the team's design work made to the entire class and to numerous faculty members. Subsequent to that, a full paper describing outcomes of the project and design was submitted and reviewed. This approach inadvertently placed some constraints on the final grade, for once a percentage of effort had been assigned to the success of the team, it was really impossible to change individual grades based on the presentation and writing due to the assumption that their contribution was the same level as it was for the creation of the design. In addition, faculty members were given free rein to establish their own expectations and standards for the project.

5. Expected Outcomes

Since this design project is the culmination of the entire curriculum, students should have been exposed to concepts needed to be successful designers. To reinforce these elements, students are asked to post discussions on a number of key topics, including innovation and interdisciplinarity, identification of customers and their needs, sustainability, life cycle assessment, ethics, uncertainty in design, and other issues. In addition, they are asked to prepare a brief essay on a contemporary topic where engineers can make a difference and another essay and activity using tools that will help in lifelong learning.

6. Innovation and Teams

Teams are used in the design projects for several reasons, notably because graduates working in industry will be expected to work in teams. Beyond that, there are numerous advantages to teams, including enhanced solutions and improved innovation. It has been noted [7] that diversity on a team leads to significantly better ideas and solutions. Tools of ideation [8] are further enhanced by well-structured teams.

Unfortunately, most programs do not specifically prepare students to work on teams, leading to real problems in the senior design course, but also in the graduate's career. Most faculty members have never received training in teams themselves. In fact, even the reward system in many universities strongly favors senior authors and principal investigators on projects and often does not recognize fully other contributors to the publications or proposal writing.

There are numerous studies of team behavior. Unfortunately, these have not usually informed instruction in team behavior in engineering programs. One very recent study [9] makes this point very strongly. An excellent summary of helpful approaches in engineering design teams and project management is available [10].

Team skills should be nurtured intentionally from the beginning of the freshman year. This can be accomplished by inclusion of special activities embedded in at least one course each semester. Further, students who are engaged in collaborative learning [11] and project-based learning [12] will practice team behavior in those efforts. There are numerous elements with which students should become familiar, including at least assuring input from everyone, using techniques to achieve consensus, setting high standards, brainstorming, and using techniques to consolidate ideas and select those to be pursued further.

The most common concern about teams is unequal contribution from team members. While some of this concern is based on the view of the individual as the key contributor, it is indeed true that phenomena such as "social loafing" do exist. Therefore, there needs to be constant evaluation both of team behavior and individual member participation. During the first semester, a standard methodology for peer evaluation was used, with students asked to evaluate the other members of their team on four dimensions.

The single most frequently cited negative behavior on teams is the issue of "free-riders," or those who not do their full share of the team's work. The literature in studies of teams performed by the psychology community uses the term social loafing, which is further denoted by the student working less on team projects than he or she would as an individual. Yang and Yan [13] noted that social loafing was a major cause of conflict between team members. One of the most effective means of ameliorating the effect of social loafing is the use of evaluation tools [14]. As will be noted, a biweekly evaluation of individual contributions was added this semester, although it was too cumbersome and is being modified. This process is intended to decrease the social loafing and intervene early if needed.

Teams are expected to develop some maturity in tackling design problems. They need to understand the process of identifying alternatives and selection of the best choice. The author has had students express concern that they did not immediately jump to a solution, not realizing that time needed to be spent identifying the real problem, design expectations, and potential solutions. Exposure to the concept of the fuzzy front end [15] is also helpful.

7. Issues and Problems

Teams were selected using the following criteria where possible: gender, grade point average, and ethnicity. Since the institution is 80 percent Hispanic, the latter was sometimes hard to achieve. In addition, there were only seven women students and ten teams, so seven of the teams had a single woman student.

When final grades were submitted and tabulated, the author was surprised to find a disproportionate percentage of the women students receiving very low, even failing grades. These results were unexpected, especially when noting prior academic performance. Further, some students with previously excellent grades received very low grades for the course. To help review the issues, the incoming GPA’s of the students in the class were determined and correlated with proposed grades.

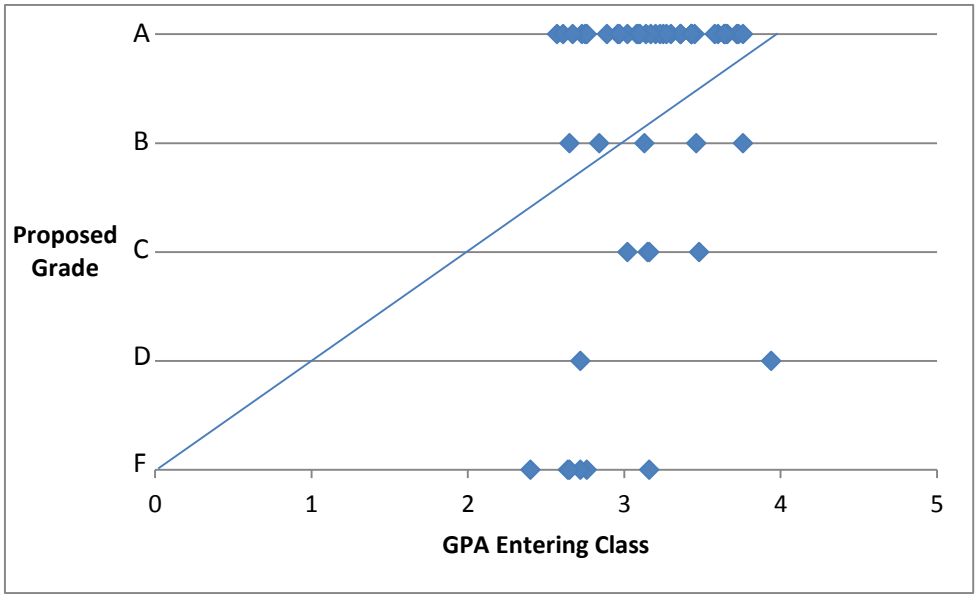

Figure 1. Proposed Grades in Course Related to Incoming Student GPA

Figure 1 reflects an attempt to understand the backgrounds of the students in the course. The graph displays the grades that were recommended for the students by their faculty mentors plotted against the Grade Point Averages (GPA's) entering the course. Those data points that are above and to the left of the diagonal line received grades higher than their incoming GPA, while those below the line represent grades lower than their prior GPA. There are several points that can be noted from the graph, two of which are especially significant. First, there is the obvious clustering of the large numbers of students who received an "A" in the class. These reflect the fact that many of the faculty mentors assigned a grade of "A" to everyone on the team without any differentiation. The second thing is a very large number of people in the course who received grades significantly below their incoming GPA. The most notable single data point indicates a student who had a 3.94 GPA coming in and received a "D" in the course. While it does not show in the individual data points, the young women who were originally assigned a grade of "F" are in the group to the right of the diagonal line. There are a few things to acknowledge when looking at this data. First, there are students who manage to negotiate through courses where they are individuals and who do not fully understand the material. Second, there are some people at the opposite end who relish working in teams and perform at a higher level. After lengthy discussions with departmental leadership, it was agreed that if students reach the final semester of their degree program, having been prepared by "us" then there is no reason they should receive a very low or failing grade. The program should have prepared them to be able to develop excellent designs. Therefore, these low grades are primarily, we believe, a failure of us to fully prepare them. There is also the fact that different faculty members have different standards, and that must be partly represented in these results. Considerable time was spent to adjust grades, but this episode clearly identified a need to find and solve root causes.

In looking at the gender question, the topic of implicit bias was reviewed. [16] Other terms for implicit bias include unconscious or unintentional bias. We are not aware that we are engaging in what are called microaggressions, aimed at women in non-traditional fields like engineering, all the time. The differences in our attitudes, responses, reactions toward women are small, but they add up over time to create real, large barriers to women's success and advancement. Women are just as "guilty" of this bias as men are, since the bias is rooted in the stereotypes in our culture, not our gender. Most often, implicit bias is what fuels things like evaluating women more harshly than comparable men (there is actually a large body of research on evaluation bias, in fact). [17] An interesting anecdote may be revealing. The department administrative assistant was the point of contact for student teams to seek funds for pursuing their design and testing. Interestingly, in all cases, the person approaching her for the funds was a woman. Much more

work needs to be done to better understand the specific issues at play here, but it is clear that some underlying forces are at work.

8. Conclusions and Future Directions

During the second offering of this course for the spring semester of 2014, some changes were made to try to avoid the same problems that occurred the previous semester. Unfortunately, the issue was complicated by a really poor transition in a somewhat longer time scale. This time the teams were allowed to self-form with no consideration for the makeup. Even worse, the teams were not selected in the previous semester nor did they begin work on their projects. To further complicate matters, this meant that they faculty mentors were not engaged with teams at all. It took considerable time to sort through all of that and get everyone placed on teams. In the initial listing presented to the author, a number of students had no team affiliation, and some students were on multiple teams. In addition, some of the faculty members had as many as five teams signed up when they had agreed to handle no more than two. The author also was approached by many of the students who did not wish to work with other students. Some of these objections were on personal bases because of conflicts in the past, but most of the complaints centered on the possibility that someone might lower their grade level. Therefore, this entire process started off on a bad footing, and it is not yet clear what the final outcome will be. Recall that one of the big benefits of teams is the ability to have more innovative approaches by having a diverse group of students. Unfortunately, that entire aspect was lost, so there is some concern by the author that there may be less creativity in the design process.

In moving ahead there are a number of steps that are proposed some of which took place immediately and some of which will be done in future offerings. For this second offering, some of the changes that were made include the following:

- Peer evaluation of other students by each other was dropped. This will be considered for reinstatement in future semesters, but with the bad start to the semester it was felt that this was a wise choice.
- A manual was developed for faculty members and students to delineate what is expected in the final product. A brief report form was developed for the faculty mentor to furnish to the overall instructor on a biweekly basis his or her assessment of performance of the entire team and most specifically of individual contributions. The idea here is to catch problems at an early point and be able to intervene to help people who are not participating, as well as to help the entire team. It turns out that methodology developed was somewhat cumbersome. It is being reviewed for future implementation to simplify a bit and also allow inputting of the information directly to a data base on the web as opposed to individual pieces of paper.
- Faculty mentors are being asked to define common objectives and standards (although a full transition will take a while).

Changes planned for future semesters include, among other likely steps, the following:

- Departmental plans to assure that some design experience occurs in every semester will be fully implemented
- The biweekly reporting process will be refined and feedback assured
- Teams will be selected early in the first course and begin working with their mentors (in fact, the author will intervene in that process, even though he does not teach that first course.)
- As teams are selected earlier, the experience will move toward becoming a true two-semester design experience
- Grades will be monitored and tracked for each class to see if issues have been removed

Two years ago, the department instituted a review of the courses within the department in the tracks in which they existed. This will be continued on a regular basis to not only assure that design is embedded in the curriculum but also to acquaint newer faculty members with the expectations from each course feeding into subsequent courses. The tracks are materials, manufacturing, and mathematics; solid mechanics and design; thermo-fluids; dynamics and controls; and instructional labs and facilities.

The author will lead a further research effort to study possible implicit bias in teams and to develop strategies to eliminate problems. These strategies will likely have several steps, including possibly means to sensitize faculty and students to the problems and being vigilant. Literature reviews will be expanded to better understand the marks of an effective team and to develop means to create an environment where teams reach those objectives. This is expected to lead to further team training earlier in the curriculum. The department is intentionally moving toward using project-based learning in all required undergraduate courses. This effort will of necessity require understanding of both team behavior and grading, so the two efforts will provide many opportunities for synergies.

One positive outcome of these problems that surfaced in this course offering is a change in the departmental views of course ownership. It has been this author's view that commonly one faculty member is responsible for the course, and other faculty members do not feel an obligation to be engaged. Even if a few faculty members serve as project mentors, others do not feel an obligation to be engaged. This is despite the fact that this is the culmination of a curriculum designed by the faculty and therefore in which they should have real interest. As a result of discussions, the department head has now mandated that during annual evaluations and planning, each faculty member must specify a minimum of two design projects for which they would be willing to serve as a mentor in the upcoming year. This not only gives an enhanced number of projects from which students can select, but it also means we are moving toward full participation from the department. The author believes that this full ownership will not only improve this course, but it also means that the other improvements suggested will be easier to implement.

It is hoped that identification of specific problems and potential solutions will not only help make the course better but also provide helpful insights to others teaching such courses. The author intends to pursue further research into team behaviour and effectiveness following industrial and organizational psychology directions and research. [9]

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