AC 2010-487: IMPACT OF TEAM AND ADVISOR DEMOGRAPHICS AND FORMULATION ON THE SUCCESS OF BIOMEDICAL ENGINEERING SENIOR DESIGN PROJECTS

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Impact of Team and Advisor Demographics and Formulation on the Success of Biomedical Engineering Senior Design Projects

Abstract

A major senior design experience is a requirement of all ABET-accredited undergraduate biomedical engineering (BME) programs. At the University of Virginia, this experience is implemented in the form of a team-based, year-long Capstone design course. Student teams work on a diverse set of real-world BME problems and are advised by different cohorts of research faculty, clinicians, and/or industrial advisors. Our study addresses whether or not team and advisor demographics and formulation impact project outcomes in terms of success metrics, defined here as grant applications, conference proceedings, peer-reviewed publications, patent filings, national or university-level awards, and technology licensing. Our analysis spans five consecutive years of the Capstone design course, in order to determine which factors contribute to the success of a Capstone project. Aspects of student team demographics and formulation considered include: team size, gender, and grade point average (GPA). Advisor demographics considered include: number of advisors per team, affiliation, degrees, and experience. Data is presented as (average total number of successes/team ± SEM).

Our results indicate that the number of student members on a team impacts Capstone project success as defined by our metrics. Both teams with 3 and 4(+) students generated significantly more total successes per team ((2.3 ± 0.61) and (2.5 ± 0.71), respectively) than teams with only 2 student members (1.2 ± 0.24) ($p \leq 0.05$). The average total number of successes/team generated by teams with only one student member was also notably lower (1.5 ± 0.18) than that of larger teams, although this comparison was not statistically significant. In addition, for students working individually, their cumulative GPA entering Capstone was found to correlate with the success of their Capstone projects. For example, students with a GPA of 2.8 or below produced a significantly lower amount of success outcomes than students with a GPA of 3.6 or above ((0.20 ± 0.20) vs. (2.0 ± 0.32), ($p < 0.03$)).

The results of our study indicate that advisor demographics are also important contributors to the success of a Capstone project. For example, the number of advisors/team appears to impact Capstone project success. Teams with 3 or more co-advisors produced significantly more total successes per team (3.7 ± 0.81) than teams with only one advisor (1.4 ± 0.18) or two co-advisors (1.6 ± 0.25) ($p < 0.005$). Capstone advisors are selected from a variety of disciplines, and advisor affiliation was found to impact project success. Interdisciplinary advisors generated the most successes/team, as compared to teams advised only by advisors of a single affiliation, i.e. BME, industry, nursing, etc. Teams with industrial advisors performed significantly better if also co-advised by at least one advisor with a different affiliation than industry (i.e. BME) ((2.1 ± 0.17) vs. (0.44 ± 0.17), ($p < 0.001$)). Teams with advisors possessing different types of degrees generated more success/team than teams with a single advisor or multiple advisors possessing the same type of degree.

Our findings indicate that a variety of aspects of student team and advisor demographics impact the generation of Capstone project success outcomes. The results of this study enable us to make

recommendations with regards to the formation of Capstone student teams and the selection of Capstone advisors for upcoming years, in order to optimize the chances for successful outcomes.

Introduction

A major design experience is a requirement of all ABET-accredited undergraduate engineering programs[1]. For the biomedical engineering (BME) program at the University of Virginia, this design experience is implemented as a team-based, year-long (two semester) Capstone design course taken in the fourth and final year of undergraduate study. Students enrolled in this course work on a diverse set of BME design projects and are advised by varying combinations of research faculty, clinicians, and/or industrial advisors. Students may elect to work individually or as part of a team of their classmates, and thus team sizes can range from one senior undergraduate student to four or more seniors. Although a student may be the sole senior BME undergraduate working on a particular project and therefore classified as an "individual" for the purposes of this study, the student is in fact part of a broader team. A student working individually will at the very minimum have an additional team member (i.e. an advisor) and may also work with graduate students, postdoctoral fellows, inter-departmental collaborators, and underclass undergraduates on his or her project.

The project selection process for BME Capstone at the University of Virginia affords students considerable flexibility in how they are assigned to their particular projects as well as how teams are formulated. In our experience, maximizing student enthusiasm and buy-in for their projects from the start of the course correlates with student performance and effort, and thus we have devised a system for project selection which takes into account both student and advisor interest levels[5]. In the months prior to the start of the Capstone course, the instructors compile a descriptive list of potential projects which is distributed to Capstone students at the beginning of the course. A "BME Capstone Project Fair" is held one week later, where all potential advisors and students gather to interview one another for the various projects. After the Project Fair, students indicate their interest level in each project using a numerical ranking system (i.e. 1 = extremely interested, 4 = not interested in project). Students are also asked to indicate their top two project choices and to describe the reasons for their interest in the projects (i.e. previous experience in the area, relation to career goals, etc.). Advisors also submit their preferences for particular students based on the interviews at the Project Fair. The BME Capstone instructors then consider the surveyed information to optimally match students and advisors. Throughout the years of BME Capstone at the University of Virginia, most students are assigned to his/her first or second choice of project.

During the implementation of any Capstone senior design course, a number of key issues, such as the determination of appropriate team size and the selection of advisors, are key considerations. Although the determination of the optimal group size has been the subject of many studies, there is still little consensus on the impact of group size on project work and team performance. For instance, the size of the group has been shown to negatively correlate with the quality of the output[2]. However, in a different study, groups of two to eight members were evaluated and found to have no significant difference in performance[3]. Of particular relevance to this study, Griffin showed that industrial and systems engineering capstone students preferred working in smaller teams (5-7 students) rather than in larger teams (8-10 students) and were

more likely to agree that they worked well as a team and managed their time efficiently[4]. Although there has been much investigation of optimal group size (mostly from a sociological and behavioral standpoint), further work is needed to investigate the impact of team size on additional project outcomes.

Since biomedical engineering is a multi-disciplinary field, at our institution students work on a wide variety of real-world BME problems and are advised by many different types of faculty and/or industrial collaborators. Therefore, in this study aspects of advisor selection (i.e. number of advisors per team) are also investigated to determine whether advisor demographics impact the outcome of a project.

The methods for the establishment of Capstone design student teams and their advisors have been described for numerous engineering programs[4-8]. For example, current practice at one BME undergraduate program is to form gender- and academic ability-balanced teams of four students[6]. This protocol for team formulation was cited to anecdotally improve team effectiveness[6], but a thorough investigation of team formulation's impact on team effectiveness and success is still needed. To this end, in this study we address whether or not certain aspects of team and advisor demographics and formulation impact team effectiveness in terms of success outcomes, defined here as grant applications, conference proceedings, peer-reviewed publications, patent filings, national or university-level awards, technology licensing, and final Capstone grades. Our analysis spans five consecutive years of the Capstone design course at the University of Virginia, in order to determine which factors contribute to the success of a Capstone project. Aspects of student team demographics and formulation examined include: team size, gender, and grade point average (GPA). Advisor demographics considered include: number of advisors per team, affiliation, degrees, and experience. To the best of our knowledge, this is the first study to investigate the impact of numerous aspects of team and advisor demographics and formulation on Capstone senior design projects and to provide clear guidance on team formulation and advisor selection for BME Capstone senior design.

Methods

Data Collection

Surveys were developed for faculty and industrial advisors involved in all past five years (2004-2009) of BME Capstone senior design at the University of Virginia. Advisors were asked to report on the success outcomes previously described which were generated from the projects they advised. In the event advisors were unavailable, former BME students were also contacted to collect data on their Capstone project so that the response rate was 100%. At the University of Virginia, there are two full-time BME Capstone instructors who were able to supply and validate data on student demographics and project outcomes. Data was collected for a total of 168 teams (228 students).

Statistical Analysis

An unpaired student's *t*-test was used to test for differences between two groups. Statistical significance was asserted at a p value < 0.05. Data is displayed graphically as average total number of successes/team + SEM, and n represents the number of Capstone teams.

Results

Analysis of Yearly Successes

We hypothesized that the total number of successes of Capstone teams (including grants applied for and received, conference proceedings, peer-reviewed publications, patent filings, national or university-level awards, technology licensing) would increase as the years of implementing BME Capstone at the University of Virginia progressed, and instructor experience increased. To test this hypothesis, for each year of the BME Capstone senior design course the total number of successes per team was determined (Figure 1). We found that year 2 had a significantly higher average total success/team as compared to year 3. There was a major increase in number of students and team numbers from year 2 to year 3 (Table 1), which might explain the significant decrease in the average successes per team. Specifically, the larger class size may have reduced the oversight provided to each team by the Capstone instructors because their energy, time, and effort were spread across many more teams. As the enrollment reached more of a steady state for years 3 to 5, there is a trend towards an increasing average for total successes/team (Figure 1).

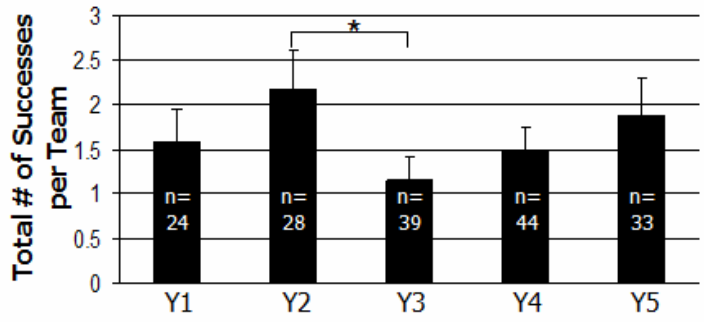

Figure 1. Analysis of yearly successes during the past 5 years of BME Capstone at the University of Virginia. *p = 0.03.

Year	Number of Students
1	35
2	48
3	74
4	65
5	61

Table 1. Number of students enrolled in BME Capstone per year.

In addition, we were interested in examining the distribution in the types of successes to determine if there were any trends among the years. For each year, the distribution of the distinct types of success metrics was analyzed (Figure 2). For the majority of the years, conference proceedings and grant applications comprised a large portion of the success metrics generated in a given year. The rarer success metrics included publications and provisional patents, which could be due to the fact that many BME Capstone projects are brand-new projects when assigned to the students and are at early stages even after a year of Capstone work.

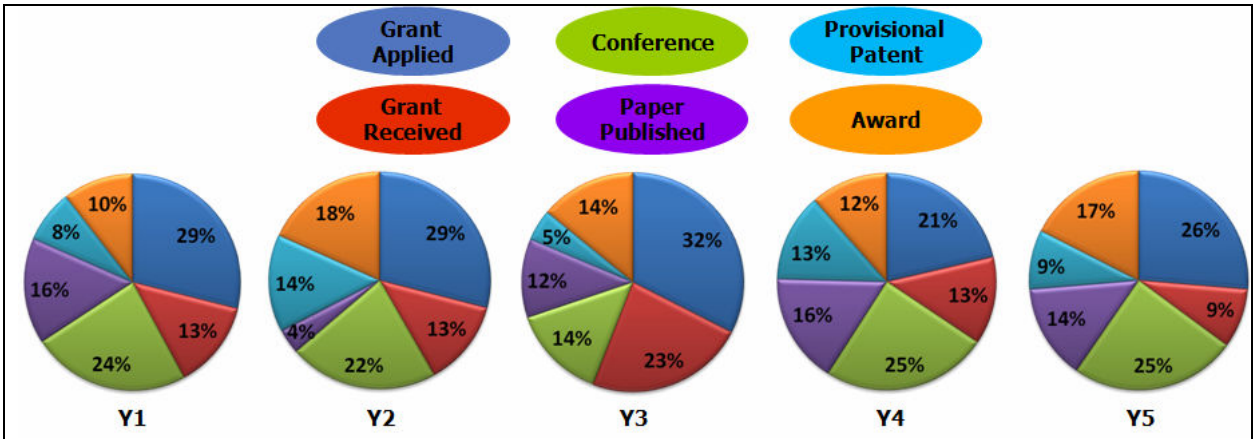

Figure 2. Success Distributions for BME Capstone at the University of Virginia.

Impact of Team Formulation on Capstone Design

Although more students have elected to work as individuals or pairs on their Capstone projects over the past 5 years, our results indicate that larger teams (maximum of 5 members) tend to be more successful (Figure 3). There is a significant improvement when just one undergraduate student member is added to a student pair, and comparing pairs to teams with 4(+) members we also see a marked improvement. Although the difference between teams with only one undergraduate student and the larger teams was not statistically significant due to large variation within the data, a noticeable trend exists where larger teams generated more success outcomes.

For teams with two or more members, teams were categorized as all male, all female, or mixed gender teams. Although there was no statistically significant difference among the groups, groups with mixed gender members tended to generate more success outcomes (Figure 4).

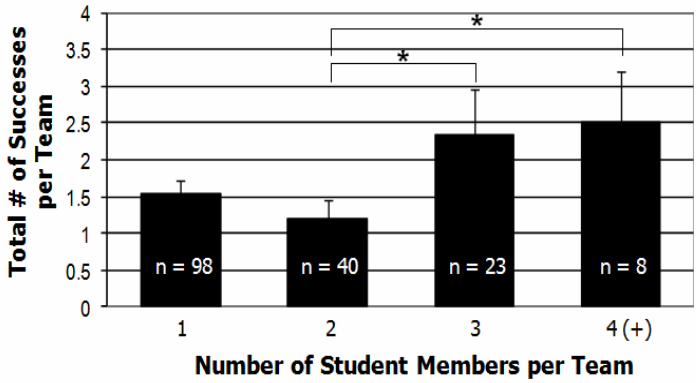

Figure 3. Impact of team size on the generation of success outcomes. *$p \leq 0.05$.

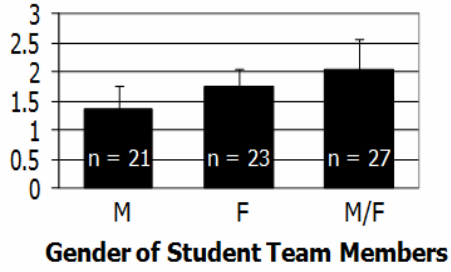

Figure 4. Impact of gender on the generation of success outcomes.

Since GPA is used in some engineering Capstone programs to form academically ability-balanced student teams[6], we were next interested in determining whether GPA is an important aspect to consider when formulating Capstone teams, in terms of generated success outcomes. Capstone teams were categorized according to the 3rd year cumulative GPA of the student members. A high or low GPA was defined as being either above or below the average GPA for

BME students for their particular year, which was usually around a 3.4. We found that teams with all high GPA members generated more success outcomes than those with all low GPA members, as expected. Teams with at least one high GPA member did just as well as teams with all high GPA members. In teams with one student, the number of success outcomes did not seem to be impacted by whether the student had an above or below-average GPA. Also, individuals with higher GPAs favored working on their own.

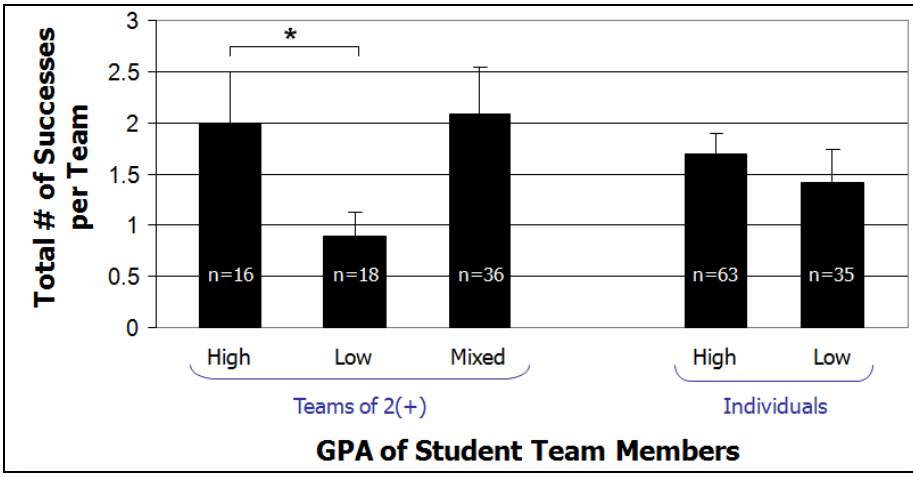

Figure 5. Impact of the 3rd year cumulative GPA of student team members on the generation of success outcomes. *$p = 0.04$.

Although there did not appear to be a significant difference in success outcomes generated for teams composed of either a low-GPA individual or high-GPA individual (Figure 5), we wanted to investigate GPA as a predictor for success in Capstone in more depth. For BME 4th year undergraduate students working individually (i.e. the sole 4th year BME undergraduate on the team), their 3rd year cumulative GPA was found to positively correlate with the generation of success outcomes (Figure 6). (Note that the lowest GPA bin (2.0 – 2.4) data is skewed by an outlier.) Although only the comparison between the range of 2.4 – 2.8 and 3.6 – 4.0 GPA was statistically significant, lower GPA individuals tended to have less success, at least according to the metrics examined in this study.

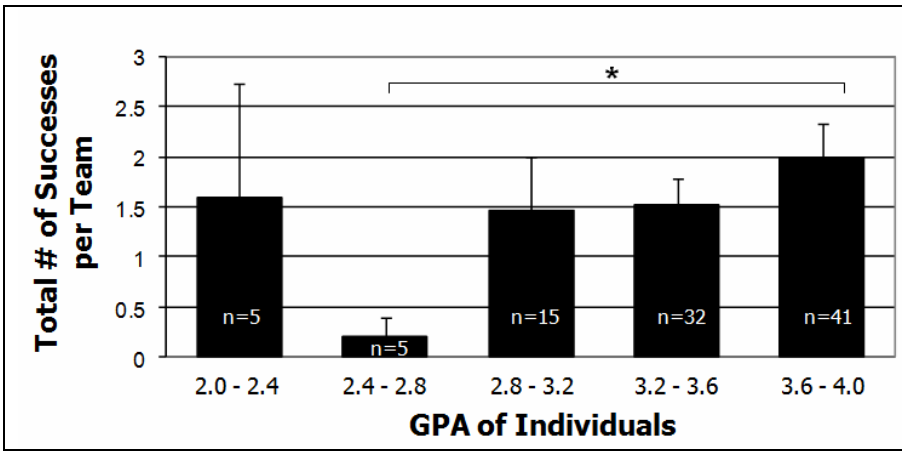

Figure 6. Correlation of 3rd year cumulative GPA of students working as individuals on Capstone projects and the generation of success outcomes. *$p <$ 0.03.

Impact of Advisor Demographics and Selection on Capstone Design

We hypothesized that the number of advisors per team had an impact on the team's success (i.e. more advisors per team, more resources, experience, advice, etc. may be available). We found that teams with 3 or more advisors had significantly more successes than teams with a smaller number of advisors (Figure 7).

BME Capstone projects at the University of Virginia can involve advisors from a variety of disciplines and academic affiliations. Because of the advantages interdisciplinary collaborations offer (i.e. multiple perspectives, variety of experiences and resources, etc.), we hypothesized that having advisors with different types of degrees on one team would lead to more successes. For each team, the advisors were classified as individual (meaning there was just one advisor), uniform degrees (meaning all the advisors had the same type of degree), or mixed degrees (if the advisors had different types of degrees, such as a Ph.D. and a M.D.). Indeed, teams with advisors of mixed degrees tended to have more success outcomes per team (Figure 8).

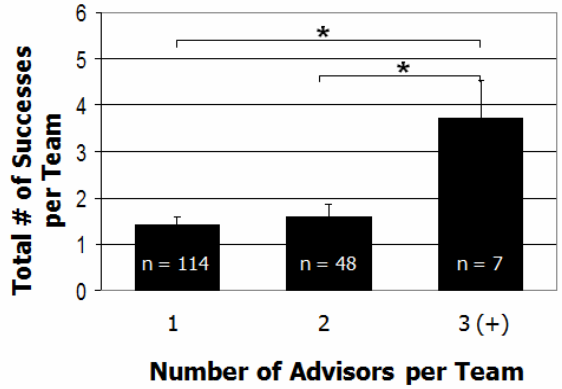

Figure 7. Impact of the number of advisors per team on the generation of success outcomes. *$p < 0.005$.

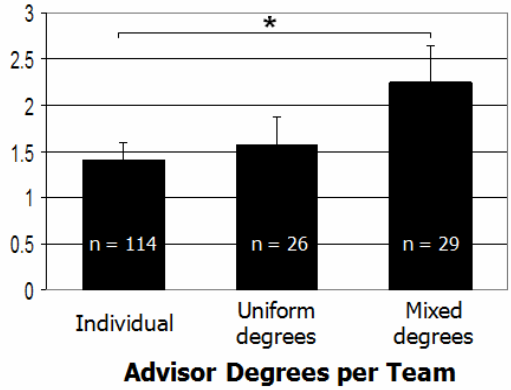

Figure 8. Impact of the degrees of the advisors on the generation of success outcomes. *$p < 0.05$.

Similarly, we hypothesized that interdisciplinary advisors generated the most successes per team. Interestingly, this was the case for the past five years of BME Capstone at the University of Virginia, according to the success metrics measured. The most prevalent combination of advisors was BME/clinician, and this combination yielded the highest average number of successes per team. Comparing teams which had industrial advisors to teams with both BME and industrial advisors, the teams with both BME and industrial advisors did significantly better, at least with the metrics considered in this study. Although there was not any additional statistical significance between a single affiliation and a combination involving that affiliation (i.e. BME and BME/Clinician), the trend existed that if there were combination advisors, more successes per team were generated (Figure 9).

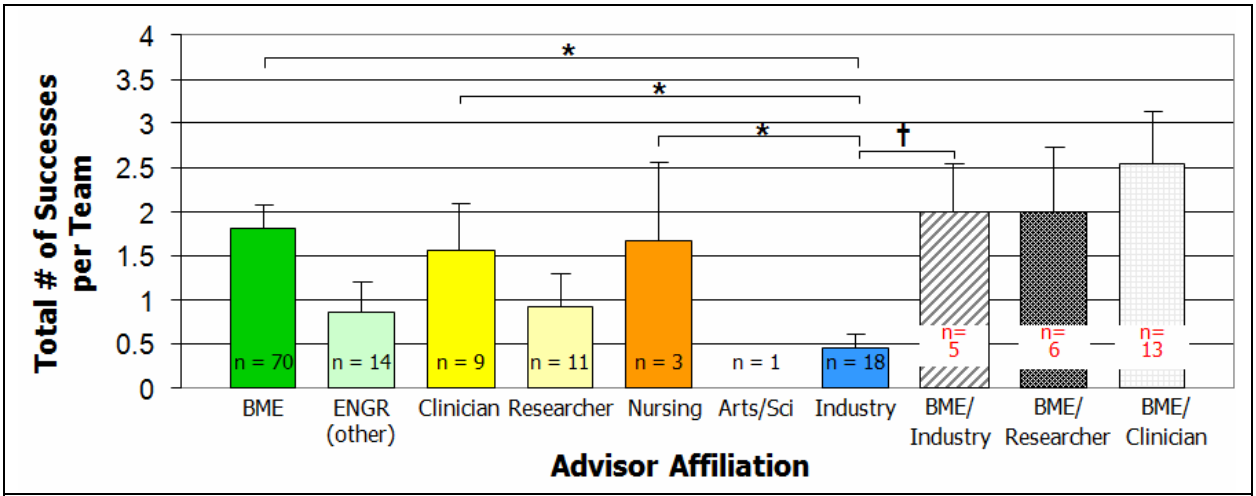

Figure 9. Impact of advisor affiliation on the generation of success outcomes. *$p < 0.03$; †$p = 0.001$. ENGR = Non-BME department in the School of Engineering and Applied Science. Researcher = Non-clinician affiliation with School of Medicine.

Although we hypothesized that years of advisor experience (in either industry or academia) would positively correlate with the generation of success outcomes per team, no trends were detected (data not shown).

Performance in Capstone as Assessed by Final Grade

The success metrics previously addressed encompass a variety of benefits a senior undergraduate student can receive as a result of their Capstone design experience. Besides benefiting the student in terms of advancing their careers, building their resumes, and preparing them for post-undergraduate endeavors such as graduate school, the success metrics examined in this study (i.e. grant applications and publications) also benefit the advisors, department, company, etc. Perhaps an outcome more immediately relevant to undergraduate students would be the end-of-year evaluation score of their design project, which is reflected by their spring semester grade. Thus, we examined the end-of-year grades to determine whether any trends in advisor demographics or team formulation were discernable.

The majority of students received final grades of an A+ to an A- (Figure 10). Of the students receiving B grades, 66% worked on teams of 2 or more and these students usually had at least one teammate who received a higher grade. This variability of grading within a team reflects the efforts of the instructors and advisors to assign grades as fairly as possible, using advisor and peer feedback to help assess individual contributions to the Capstone project. Of the students receiving C grades, 60% worked as individuals. In addition, their advisors were single-affiliation advisors, mostly from BME (60%) and some from nursing (20%). This supports the findings from the previous section in which combination advisors were found to generate the most success outcomes.

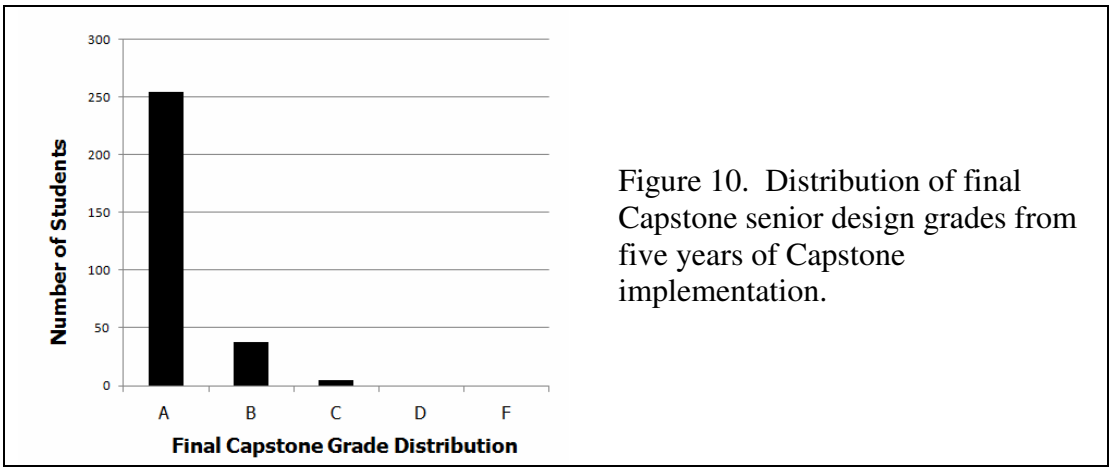

Figure 10. Distribution of final Capstone senior design grades from five years of Capstone implementation.

Conclusions

To the best of our knowledge, this is the first study to investigate the impact of team and advisor demographics and formulation on the success outcomes of Capstone senior design and to provide clear guidance on team formulation and advisor selection for BME Capstone senior design. The results of this study enable us to make possible recommendations on team formulation and advisor selection for a BME Capstone design course.

Based on the results of this study, teams tend to perform best when comprised of at least 3 undergraduate student members with mixed genders. In addition, students with below average GPAs should work as the sole undergraduate student on a project (but only if his/her 3rd year cumulative GPA is above a 2.8) or in a mixed GPA team.

Although this protocol for team formulation correlates with increased generation of success outcomes in our study, another aspect to consider when formulating teams is that larger groups have been found to have more problems with free-riding and social loafing[3, 4, 9-11]. Anecdotally, we have found that lower GPA students tend to meet the challenge of the Capstone design course and we have not encountered a problem of students making less effort to achieve their goals because they are working in a group versus individually. However, this is an important issue and we plan to implement a student preference survey to investigate task-sharing and group size issues from the student's perspective. In addition, although previous work has shown that advisors did not have a definite preference for group size[4], we plan to investigate advisor preference for group size in the future.

Regarding Capstone advisors, based on the results of this study we would recommend 3 or more advisors per team whenever possible, although faculty workload and resources must be considered as well. Future work for this study will involve an investigation of advisor workload (i.e. number of hours spent advising/week) for different team sizes and number of advisors/team.

Also, the degrees possessed by the advisors should be considered. If the advisors on a particular team possessed different types of degrees (i.e. Ph.D. and M.B.A.), this was shown to increase the number of successes generated. Advisor affiliation was also found to be an important factor in

terms of success outcome generation. Inclusion of interdisciplinary advisors on a team is recommended whenever possible, for example a BME and industry advisor versus just a BME advisor or just an industry advisor.

We recognize that this study does not encompass all the potential factors involved in a successful Capstone project, and we would like to expand this study in the future to address other factors, such as previous lab experience and the career goals of the students. With more data from future years, we also will be able to conduct an analysis of individual success metrics, instead of analyzing all the success metrics together (i.e. examine patent filings specifically). In addition, there are other less rigorous success metrics we must consider in order to assess the development of technical skills, such as problem solving and design, and non-technical skills, such as student performance at the end-of-year Capstone oral presentations. However, the results presented in this paper provide preliminary evidence of the importance of team formulation and advisor selection in the success of a Capstone senior design project, and provide guidance for other engineering undergraduate programs on the optimization of the establishment of Capstone teams.

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