Proceedings of the ASME 2020
International Design Engineering Technical Conferences
and Computers and Information in Engineering Conference
IDETC/CIE2020
August 17-19, 2020, Virtual, Online

DETC2020-22099

COMPARING STUDENT AND SPONSOR PERCEPTIONS OF INTERDISCIPLINARY TEAMS' CAPSTONE PERFORMANCE

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ABSTRACT
The purpose of this work is to investigate the relationship between the disciplinary diversity of capstone design teams and perceptions of success and engineering design abilities. Capstone design programs are effective environments for students to collaborate with industry sponsors on authentic design problems. They provide students with the opportunity to hone their technical and professional skills, often in teams. Previous work has demonstrated that interdisciplinary teams outperform within-discipline teams on complex open-ended tasks, but struggle to communicate across disciplinary boundaries. They also report lower levels of team cohesion and satisfaction with final outcomes. The results of the mixed-methods study conducted with 58 capstone design teams for this paper indicate that team diversity may be inversely related to students' beliefs in their abilities to construct a prototype. Preliminary qualitative analysis suggests that students tend to divide prototyping tasks based on disciplinary background and struggle to integrate design efforts for complex systems, particularly during later stage design.

Keywords: Interdisciplinary, capstone, self-efficacy

1. INTRODUCTION
Capstone courses have become a staple in engineering education [1]. Usually working in teams, senior-level students are tasked with solving authentic, real-world design problems within a set period of time. They are expected to meet certain requirements dictated by their "client", often an industry sponsor [2]. Successful capstone experiences have been associated with increased employment opportunities [3], improved teamwork and communication skills [4,5] and greater learning and understanding of design activities [6].

Real-world design problems are often ill-defined, and solving them requires a variety of technical skills from a number of engineering disciplines [7]. Engineering educators have recently emphasized the importance of interdisciplinary work [8]. Engineering programs have responded by including students from multiple departments in their capstone project teams [9]. While interdisciplinary environments provide students with the opportunity to tackle complex design problems [10], develop common knowledge [11,12] and improve collaborative design skills [13], it is possible that students will fail to bridge disciplinary differences in their short-term design course [14]. Considering the critical role that capstone courses play in engineering education, it is imperative to understand how these experiences affect learning outcomes.

Noting the increasing emphasis on interdisciplinary teams in capstone programs [9] as underscored by the Accreditation Board for Engineering and Technology [15], the goal of this work is to understand the effect of disciplinary diversity in design teams on capstone course outcomes.

1.1 Capstone Design Courses in Engineering Education
Traditionally, capstone courses are one to two semesters long, and consist of students working in teams on projects sponsored

by—or done in collaboration with—engineering industry [9]. Capstone projects require students to solve authentic, complex design problems. These design problems are intended to mirror projects that may be encountered in the "real world" [16], and require students to employ methods and practices used in engineering practice [17–19]. The use of authentic design problems in capstone courses has been linked with increased self-efficacy [20], improved group problem-solving skills [21], and more structured organization within members of a team [22].

While prior research related to capstone design has largely focused on effective instructional design and assessment techniques for capstone courses [23–25], researchers in engineering education have begun developing foundational knowledge in assessing the characteristics of capstone design teams and their related effect on course outcomes. Griffin et al. [26] found that students preferred working in smaller groups and on projects that lasted one semester. In their study of 103 senior-level engineering students, Gruenther et al. [6] found that prior to a capstone course, students with industry experience better understood the role of documentation in the design process as compared to their peers without industry experience. However, at the end of the capstone course, there was a reduction in the gaps in design knowledge between the two groups of students, further emphasizing the importance of capstone programs in engineering education. The demographics of team members have also been identified as a contributing factor to team performance. For example, Bessette et al. [27] found that international students struggle with communication anxiety and a lack of familiarity with capstone course norms.

1.2 The role of diversity in engineering design

Diversity in engineering design teams can be defined by a number of variables, including gender [28], learning styles [29], cognitive preferences [30], and functional backgrounds [31]. In general, diverse design teams have been associated with better solutions for cross-functional, complex, and open-ended design tasks [32,33]. In this work, we focus on functional or disciplinary diversity, as companies often depend on such functionally diverse teams to generate innovative product offerings [34]. However, disciplinary diversity often comes at a price: Burry [35] suggested that a lack of cohesion in interdisciplinary design teams could result in dysfunction and conflict. Milliken and Martins [36] referred to disciplinary diversity in teams as being a 'double-edged sword'. While collective knowledge aids designers in tackling complex design problems, the boundaries drawn by differences in knowledge, disciplinary language, or professional norms can lead to miscommunication [37], feelings of isolation [38], or perceptions of failure [39].

Menold and Jablokow [30] explored the effect of cognitive style diversity of student design teams on final design characteristics, demonstrating the relationship between deep-level diversity and design outcomes. Little work, however, has explored the effect of functional or disciplinary diversity on student outcomes within the context of an engineering capstone course. Yet, interdisciplinary design teams are a critical part of engineering education. Hotaling et al. [3] found that students who worked in interdisciplinary teams were more likely to be offered jobs after graduation. Gruenther et al. [6] found that within-discipline and interdisciplinary capstone teams performed similarly in their capstone projects. However, their results suggested that interdisciplinary teams performed better at early design tasks, such as needs identification.

At the same time, prior research has identified potential issues associated with interdisciplinary teams; highlighting that disciplinary diversity is a 'double-edged sword'. Kim and Nair [40] used the Team Diagnostic Survey as a metric to study team dynamics in interdisciplinary capstone teams, and highlighted challenges. Their findings suggest that interdisciplinary teams struggle to effectively manage team activities and progress. Schaffer et al. [41] studied students' self-efficacy in cross disciplinary team learning (CDTL) in interdisciplinary design teams before and at the end of a semester-long design project. CDTL broadly encompasses students' efficacies in recognizing their own and others' contributions to an interdisciplinary project, interacting effectively with team members from varied backgrounds, and valuing knowledge held by different disciplines [42,43]. While they did find a statistically significant increase in students' CDTL self-efficacy, they found that 30% of students reported a perceived decrease in CDTL self-efficacy. Interestingly, their results also suggest an inverse relationship between number of disciplines and CDTL self-efficacy. Few other studies, however, have provided evidence as to why or how disciplinary diversity in a capstone team might affect students' capstone experiences, self-efficacy, or learning outcomes.

1.3 Self-efficacy in engineering education

Self-efficacy refers to an individual's beliefs in their ability to carry out and complete certain tasks at a specific level of performance [44]. Self-efficacy has been argued to be a critical factor in engineering education; one that affects the motivation of engineering students and influences the probability of their success in future engineering activities [45]. Bandura [44] cited positive perceptions of skills in related activities, or 'mastery experiences' as being one of the key sources of self-efficacy. Positive perceptions of performances in a specific task increase an individual's confidence in carrying out similar tasks in the future. With its use of authentic, real-world design problems, capstone design courses act as these 'mastery experiences' and provide an excellent environment for students to raise their self-efficacies before transitioning out of university. This theory was put to test by Dunlap [20] in her study of 31 computer science undergraduate students enrolled in a design-focused capstone course. Results indicated that the course helped students have more positive perceptions about their performance and increase their self-efficacy.

Synthesizing the literature, we surmise that a complex relationship exists between a team's disciplinary diversity, self-efficacy, and team performance in capstone projects. While authentic design problems can act as 'mastery experiences', or key sources of increased self-efficacy among engineering students, these real-world, complex problems also require interdisciplinary knowledge. Team members may often lack the skills needed to effectively organize themselves and bridge disciplinary divides. This can be detrimental to overall team success and affect student perceptions about engineering abilities. To our knowledge, no work has examined the relationship between disciplinary diversity, perceived ability, and team performance in capstone design courses.

1.4 Research Objectives

The current work lies at the intersection of research on interdisciplinary teams, capstone education, and engineering self-efficacy. Mimicking the nature of design teams in industry, capstone courses have seen an increase in the formation of interdisciplinary design teams; hence providing students with a significant learning experience before they transition into industry. At the same time, we posit that some interdisciplinary teams may not have the skills needed to cross the divides created by disciplinary boundaries, and may fail to leverage disciplinary diversity effectively. Based on the concomitant gaps in the literature pertaining to interdisciplinary design teams in capstone courses, we seek to answer the following research questions:

1. *How does the interdisciplinary nature of a capstone design team affect students' beliefs in their engineering design skills, measured through the Engineering Design Self-Efficacy scale?*
2. *How does the interdisciplinary nature of a capstone design team affect team performance, measured through sponsor satisfaction ratings?*

2. METHODOLOGY

To answer these research questions, an Institutional Review Board-approved study was conducted at the Fall 2019 Senior Design Showcase at the Pennsylvania State University. With 250 projects sponsored annually, the capstone design program at the Pennsylvania State University is the largest multi-disciplinary client-sponsored capstone program in the world [8,46]. In 2019, 98% of the project teams consisted of students from two or more departments and 60% consisted of students from three or more. Participating departments are housed in three colleges: Engineering, Earth and Mineral Sciences, and Information Sciences and Technology.

Before the start of each semester, industry sponsors provide descriptions of their projects along with their disciplinary needs. At the start of the semester, after having reviewed the project descriptions and indicating their willingness to sign NDA and IP agreements, students indicate ten projects which they are interested in working on. Based on these preferences and sponsors' disciplinary needs, capstone teams are formed. Following this, students work with their sponsor to identify requirements, ideate design solutions, construct low and high-fidelity prototypes, and test and validate their design solutions. The semester long project culminates in the Design Showcase, where students present their projects to the public, and are judged by a panel of industry experts.

2.1 Participants

Students were recruited based on the criteria of whether a working prototype was one of the deliverables dictated by their sponsor. In this work, we identify working prototypes as including but not limited to physical prototypes, digital interfaces, CAD mockups, and simulations. 63 teams were identified and approached, out of which 58 teams consented to participating in the study. In total, 228 students were surveyed, all of whom were senior-level students enrolled at the Pennsylvania State University. Table 1 shows the representation from departments.

TABLE 1. DISTRUBUTION OF MAJORS ACROSS STUDY PARTICIPANTS

Major	# of students
Aerospace Engineering	1
Biomedical Engineering	11
Biomedical Engineering and Mechanical Engineering*	2
Computer Engineering	22
Computer Science	40
Computer Science and Mathematics*	1
Electrical Engineering	30
Energy Engineering	2
Engineering Science	5
Industrial Engineering	26
Mechanical Engineering	71
Mechanical Engineering and Nuclear Engineering*	4
Material Science	13

**indicates student(s) pursuing double majors*

2.2 Procedure

At the start of the study, the teams were approached and the purpose and procedure of the study was described in accordance with the Institutional Review Board.

Following this, participants were informed that their participation in the study would be audio and video recorded. Consent to be recorded was then obtained from the participants. The remainder of the study consisted of 3 stages, as shown in Figure 1: Pitch presentation, a semi-structured interview, and a post-survey.

At the start of the study, participants were asked to present their project and project outcomes to the research team. Following this, individual participants were asked open-ended questions pertaining to execution of the design process, beliefs about their performance, and perception of sponsor satisfaction:

1. *What was the objective of your team's project this semester?*
2. *How did you accomplish or meet this objective?*
3. *Do you feel that your project sponsor is satisfied? Why or why not?*

4. *How did your solution to the design problem evolve over the course of this project?*
5. *What factors drove this evolution?*
6. *If you had to work on the project from the start, what would you do differently?*

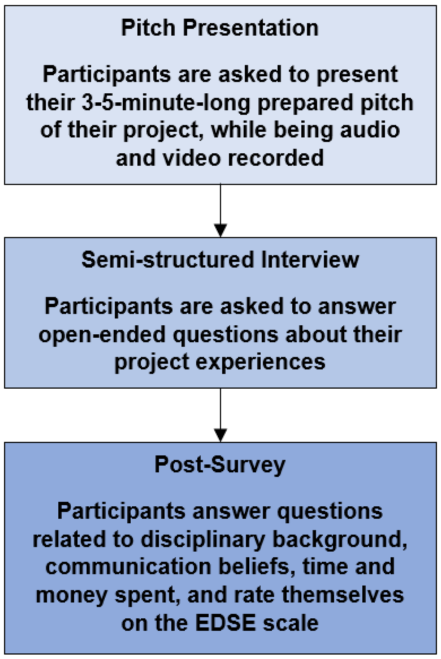

FIGURE 1. TIMELINE OF THE STUDY

Following this, participants were asked to fill out a three-part post survey. The first part of the survey asked the participants to rate the quality of their pitch on with respect to technical communication, use of prototypes, and perceived success. The second part of the survey asked participants to state how many hours per week they individually spent on the project. Previous research has found that "sunk cost" effect plays a significant role of design fixation, specifically when constructing full scale models [47]. This question was asked in order to investigate the relationship between sunk cost and students' abilities to reflect on their capstone projects and identify areas of improvement. The final part of the survey asked participants to rate their abilities on the Engineering Design Self-Efficacy scale [48].

2.3 Metrics

<u>*Engineering Design Self-Efficacy*</u>*:* Prior research in engineering education has explored the relationship between self-efficacies and students' learning experiences. Higher self-efficacy scores have been related to more involvement in makerspaces [49], and are often brought out by creating authentic learning environments [50], and conducting design challenges in engineering classrooms [51]. Carberry et al. [48] developed an instrument to measure a student's self-efficacy specifically in the context of engineering design. The 9-item instrument, based on the 8-step design process proposed by the Massachusetts Department of Education Science and Technology/Engineering Curriculum Framework [52], asks individuals to rate their ability to carry out design tasks on a scale from 0 to 100 (0 = LOW, 50 = MODERATE, 100 = HIGH). The sum total of the 8 scores yielded the individual's Engineering Design Process (EDP) score, i.e., their confidence in carrying out the steps of the engineering design process. The EDP score of each team member was then averaged across the number of people in each team to yield the Team Engineering Design Self-Efficacy (EDSE) score.

$$Team\ EDSE = \frac{Sum\ total\ of\ members'EDP\ scores}{Number\ of\ team\ members} \tag{1}$$

<u>*Disciplinary Diversity of Design Teams*</u>*:* While there exists no standard measurement for team disciplinary diversity, measurements of team diversity in prior literature [41] primarily factored in the size of a team and the number of unique disciplines team members belong to. While these are two variables that have to be considered when measuring disciplinary diversity, the number of members representing a specific discipline is a third variable that also inherently affects team diversity. For example, a team with two Mechanical Engineering students and two Computer Science students is more heterogenous than a team with three Mechanical Engineering students and one Computer Science student.

Used extensively in the biological sciences to measure ecological diversity [53], Shannon's information entropy has been shown to be a robust metric to determine the group diversity of a system [54]. In their study investigating the effect of diversity on the quality of innovation in a Fortune 500 company, Cady and Valentine [55] used this entropy-based formula to quantify team diversity. Using the negative logarithm of the probability mass function, Shannon's information entropy of a system is calculated by:

$$H = \sum_i^n p_i\, ln(p_i) \tag{2}$$

Where p_i is probability of the i^{th} outcome in a system. Hence, a diverse system with low probability values results in a higher information entropy value (i.e., the system carries more unique information). A more homogenous system would have higher probability values, resulting in a lower information entropy value (i.e., the system carries less unique information). Thus, the information entropy value of a system is a measure of the diversity of a system. The higher the information value, the greater the diversity of the system.

Applying Shannon's Information Entropy in the context of disciplinary diversity in engineering design teams, p_i is the proportion of students belonging to the i^{th} discipline to the total number of members in a team, and H is the Disciplinary Diversity Index value of the team. Table 3 shows the disciplinary diversity results for a few sample team compositions. Each shape represents a student, with each unique shape representing a unique discipline.

TABLE 3. EXAMPLE DISCIPLINARY DIVERSITY INDEX VALUES

Team	Team Composition	Disciplinary Diversity Index
1	■ ● ● ● ⬟	0.950
2	■ ■ ■ ■	0.000
3	■ ▲ ●	1.099
4	■ ▲ ▲ ▲	0.562

Team Evaluation Survey: Following the showcase each semester, sponsors of capstone projects are asked to rate the performances of their student design teams through a team evaluation survey. While the survey broadly probes sponsors' overall experience of working with their capstone team, the first half of the survey specifically asks sponsors to evaluate capstone team performance. For this data collection, sponsors were asked to rate their teams on the following criteria: professionalism, responsiveness, communication skills, technical competence, and team effectiveness. Sponsors were also asked to rate the quality of specific deliverables (reports and presentations), and indicate their overall satisfaction with the team. In this work, we specifically seek to analyze the metrics of team effectiveness, technical competence, and overall sponsor satisfaction.

3. DATA ANALYSIS AND RESULTS

Prior to the data analysis, participants who did not fill out their majors and their corresponding teams were removed from the dataset. This left us with 48 teams in the final cleaned data set. Any missing data values on the EDSE Scale were estimated using Multiple Imputation Predictive Mean Matching (PMM). Multiple Imputation PMM is an accurate and unbiased method to estimate missing data when item scores are missing in multi-item instruments [56]. Eight students each had one value on the EDSE scale missing, and Multiple Imputation PMM was used to estimate said values.

R Cran version 3.5.2 was used for all statistical analyses, and p-values < 0.05 were considered to be significant. While it is important to use p-values as metrics for significance of results, it is equally important to report the effect size of the analyses [57]. Hence, we will be reporting both the p-values and the effect sizes (Spearman's ρ for correlations and η^2 for ANOVAs) for all statistical analyses.

RQ1: How does the interdisciplinary nature of a capstone design team affect students' beliefs in their engineering design skills, measured through the Engineering Design Self-Efficacy scale?

Our first research question sought to determine the relationship between the disciplinary diversity of capstone design teams and the self-efficacy of the design team. Spearman's correlation coefficient (ρ) was calculated between teams' disciplinary diversity indices and the teams' EDSE scores. Further, while the EDSE score is a holistic measure of an individual's/team's overall design self-efficacy, it is also important to understand students' beliefs in their abilities to carry out each step of the design process. Hence, Spearman's correlation coefficient (ρ) was also calculated between team's disciplinary diversity indices and their self-efficacy scores on each subscale of the EDSE scale. The Benjamini-Hochberg method was employed to account for multiple comparisons and prevent an inflated Type I error [58].

Our analyses revealed no significant correlation between team diversity and average team EDSE score (ρ = -0.219, p = 0.135). In other words, our findings suggest that there is no relationship between a team's disciplinary diversity and average engineering design self-efficacy. Spearman's ρ was then calculated between each subscale and disciplinary diversity index values to identify the existence of relationships between a team's disciplinary diversity and their capacity to carry out specific design tasks. The results from the analyses are shown in Table 4.

TABLE 4. SPEARMAN CORRELATION COEFFICIENTS FOR DISCIPLINARY DIVERSITY AND TASK SPECIFIC EFFICACIES. ASTERISKS INDICATE SIGNIFICANT CORELATIONS (P < 0.05)

Design Task	ρ	Sig. p
Identify a need	-0.028	0.851
Research a need	0.058	0.694
Develop design solutions	0.072	0.627
Select best possible design	-0.218	0.136
Construct a prototype	**-0.293**	**0.043***
Evaluate and test a design	-0.245	0.093
Communicate a design	-0.164	0.265
Redesign	-0.201	0.170

The analyses showed that there was a moderate negative correlation (ρ = -0.293, p <0.05) between a team's beliefs in their ability to construct a prototype and a team's disciplinary diversity. This suggests that students on more disciplinary diverse teams were less confident in their abilities to build a prototype. However, it should be noted that while this result points towards the existence of a relationship between the two variables, it does not necessarily imply that disciplinary diversity in teams is the *cause* of lower efficacies in building prototypes. Future work should unravel this relationship more explicitly.

Post-hoc analysis was conducted to determine how efficacy in building prototypes varied across disciplines. Since design and building is often emphasized or taught differently in different disciplines, it is reasonable to assume that students who were not extensively exposed to design activities might have lower efficacies in constructing prototypes. For example, a Mechanical Engineering student, who may have been more frequently exposed to hands-on prototyping as compared to a computer science student, might have higher levels of self-efficacy in prototype construction. A one-way ANOVA was conducted to identify any differences in prototyping efficacies across disciplines. Interestingly, the ANOVA was not significant, with $F(6,215) = 1.575$, $p = 0.156$, $\eta^2 = 0.042$, implying that there was no significant difference in prototyping efficacy across engineering disciplines. This result will be contextualized in greater detail in the Discussion section.

A preliminary analysis of student responses to the open-ended interview questions provides further understanding into the relationship between prototyping self-efficacy and disciplinary diversity of teams. The open-ended interviews of teams with high disciplinary diversity scores and low prototyping efficacies were subsequently reviewed to identify if teams provided any insight into their prototyping behaviors. Teams' responses to our interview question about what they would have done differently provide a possible explanation of their prototyping behaviors. One team said:

"I think more in general we worked on the components of the project I feel a little too separately. There's electrical engineering, there's mechanical engineering, there's computer science parts. I think if those were, like, closer communication between those. For example, if we designed the stick with wiring implements in mind so that we were ready to just put everything together, things like that. Probably more cross discipline communication."

Another team, when asked the same question, saw members reporting design improvements based on their disciplinary backgrounds. One member explained improvements to the battery and other electrical components of the system, while another explained improvements purely from a mechanical engineering perspective. Right after this, one member gestured towards another and asked "Any improvements from the computer engineering side of things?", indicating the possibility that the team split themselves into smaller sub-teams based on their disciplinary backgrounds. A deeper, rigorous qualitative analysis of the interview data with the groups will be the topic of future publications.

RQ2: How does the interdisciplinary nature of a capstone design team affect team performance, measured through sponsor satisfaction ratings?

Our second research question aimed to investigate the relationship between team efficacy, disciplinary diversity, and sponsors' evaluation of team performance. The performance metrics analyzed were Technical Competence, Team Effectiveness, and Overall Satisfaction. Due to the limited number of responses from industry sponsors, our sample size was limited to 27 teams for this research question. A series of one-way ANOVAs were conducted to investigate the relationship of sponsor ratings on these metrics, disciplinary diversity, and team self-efficacy.

For the technical competence ratings, two teams were removed from the dataset due to the low frequency of teams that were rated 'Poor' and 'Good' (1 team per rating). Normality of data was verified using Shapiro-Wilk test ($p > 0.05$), and the Levene's test confirmed the homogeneity of variances ($p > 0.05$). A one-way ANOVA conducted between the technical competence rating of the teams and teams' disciplinary diversity was not significant, with $F(2,22) = 0.366$, $p = 0.698$, $\eta^2 = 0.032$.

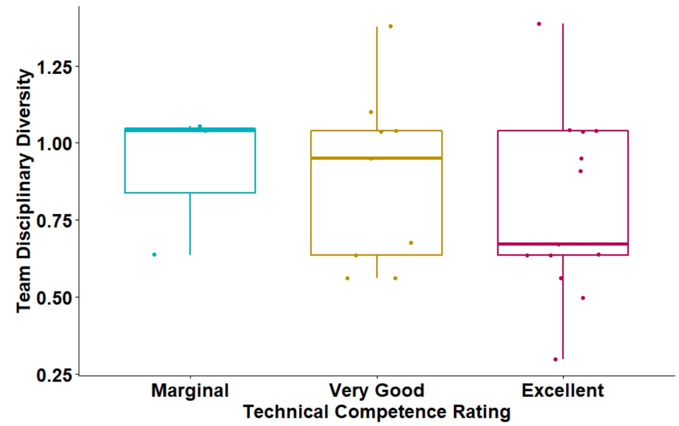

FIGURE 2. DISCIPLINARY DIVERSITY INDEX VALUES OF TEAMS COMPARED BETWEEN SPONSOR RATINGS OF TECHNICAL COMPETENCE

Next, a one-way ANOVA was conducted between the technical competence rating of the teams and teams' self-efficacies. Prior to conducting the ANOVA, normality of the data and homogeneity of variances were confirmed using the Shapiro Wilk Test and Levene's test respectively, with both yielding $p > 0.05$. The ANOVA was not significant, with $F(2,22) = 0.434$, $p = 0.653$, $\eta^2 = 0.038$. These results imply that there was no difference in team diversity or team self-efficacy between teams that were rated differently by their sponsors on the criteria of technical competence.

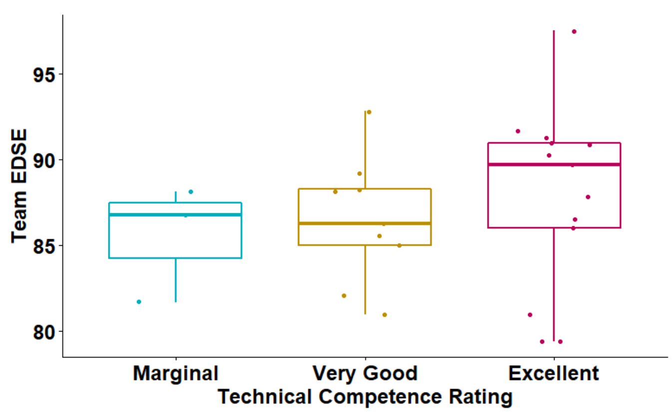

FIGURE 3. DESIGN SELF-EFFICACY OF TEAMS COMPARED BETWEEN SPONSOR RATINGS OF TECHNICAL COMPETENCE

Similarly, for the team effectiveness ratings, a one-way ANOVA was conducted between the teams' team effectiveness rating and teams' self-efficacies. One team was removed from the dataset since it was the only team rated as 'Poor'. Normality of data was verified using Shapiro-Wilk test ($p > 0.05$), and the Levene's test confirmed the homogeneity of variances ($p > 0.05$). The ANOVA was not significant, with $F(3,22) = 0.524$, $p = 0.67$, $\eta^2 = 0.066$. A one-way ANOVA was then conducted between the teams' team effectiveness ratings and teams' disciplinary diversity index. The result was not significant, with $F(3,22) = 0.874$, $p = 0.47$, $\eta^2 = 0.106$. These results imply that there was no difference in disciplinary diversity or team self-efficacy between teams that were rated differently by their sponsors on the criteria of team effectiveness.

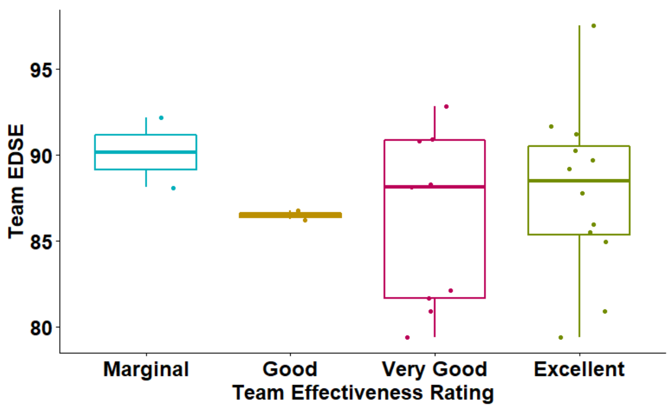

FIGURE 4. DESIGN SELF-EFFICACY OF TEAMS COMPARED BETWEEN SPONSOR RATINGS OF TEAM EFFECTIVENESS

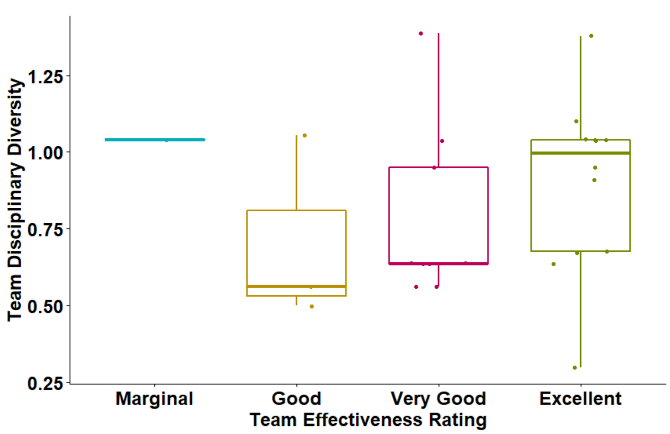

FIGURE 5. DISCIPLINARY DIVERSITY INDEX VALUES OF TEAMS COMPARED BETWEEN SPONSOR RATINGS OF TEAM EFFECTIVENESS

For overall satisfaction ratings, one team was removed from the dataset since it was the only team given the rating of 'Highly Dissatisfied'. As with previous analyses, homogeneity of variances was confirmed using Levene's test ($p > 0.05$), and normality was confirmed using the Shapiro-Wilk Test ($p > 0.05$) prior to performing the ANOVA. The one-way ANOVA conducted between the overall satisfaction rating of the teams and teams' self-efficacy was not significant, with $F(2,23) = 2.46$, $p = 0.108$, $\eta^2 = 0.176$.

Next, a one-way ANOVA was conducted between the overall satisfaction ratings and teams' disciplinary diversity index values. Prior to conducting the ANOVA, normality of the data was and homogeneity of variances were confirmed using the Shapiro-Wilk Test and Levene's test respectively While the assumption of normality was met ($p > 0.05$), the Levene's test yielded $p < 0.05$. Since the assumption of homogeneity of variances was violated, we proceeded with the Kruskal-Wallis Test. The result was not significant, with $\chi^2 = 1.240$, $p = 0.5378$.

FIGURE 6. DESIGN SELF-EFFICACY OF TEAMS COMPARED BETWEEN SPONSOR RATINGS OF OVERALL SATISFACTION

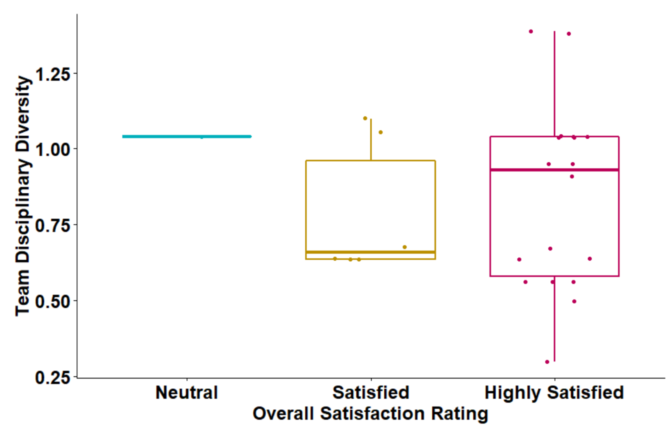

FIGURE 7. DISCIPLINARY DIVERSITY INDEX VALUES OF TEAMS COMPARED BETWEEN SPONSOR RATINGS OF OVERALL SATISFACTION

These results imply that there was no significant difference in disciplinary diversity or team self-efficacy between teams that were rated differently by their sponsors based on overall satisfaction with their teams.

4. DISCUSSION

The goal of this research was to investigate the relationship between disciplinary diversity, perceived abilities, and performance of capstone design teams. Perceived abilities were measured using the EDSE Scale, and performance ratings were obtained from sponsor evaluations of capstone teams.

While our results largely revealed no significant correlations between self-efficacy (task-specific and overall) and teams' disciplinary diversity, a moderate, negative correlation emerged between team self-efficacy in constructing a prototype and disciplinary diversity. This implies that more disciplinary diverse teams had less belief in their capacity to effectively construct prototypes. While the intuitive answer to this might be due to inherent differences in prototyping self-efficacies across disciplines, a one-way ANOVA showed no significant differences. This suggests that the negative correlation between prototyping self-efficacy and disciplinary diversity is largely independent of discipline. Additionally, it strengthens the possibility that disciplinary diversity on capstone teams is affecting students' perceptions of their abilities to construct prototypes.

A preliminary analysis of the qualitative data supports this hypothesis. It appears that in these interdisciplinary teams, students split themselves into sub-teams based on their technical backgrounds. They worked on these different technical aspects of the project separately, only to unite when the time came to build/assemble a fully functional prototype. The organic formation of sub-teams has also been observed in other problem-solving domains [59]. In prior work, such decomposition has been shown to improve outcomes for some problem types [60]. However, this is not necessarily optimal for all problems or teams. For instance, one team in this study acknowledged that since they essentially functioned as discrete sub-teams for a majority of the semester, it was challenging to combine efforts and effectively build a system solution. The lack of cohesion reported by some capstone teams may be a sign that students are not properly prepared to cross disciplinary boundaries, resulting in the emergence of problems much later on in the design process.

Our findings suggest that in some interdisciplinary design teams, a lack of cross-disciplinary collaboration and communication may be detrimental to course outcomes. This is in line with previous work, specifically Schaffer et al.'s [41] study of interdisciplinary design teams. While they did find a statistically significant increase in CDTL self-efficacy among students working on interdisciplinary projects, they also found that 30% of the teams reported decreases in CDTL self-efficacy, and suggested that CDTL self-efficacy decreased with an increase in the number of disciplines on a team. Additionally, in their study of interdisciplinary student design teams, Torrisi and Hall [37] noted that miscommunication in interdisciplinary student teams was often caused due to varied disciplinary design methods, and differences in knowledge about prototyping and manufacturing. Overall, our findings contribute to the growing knowledge surrounding the relationship between disciplinary diversity and self-efficacy. Future work should examine the nexus between team dynamics, disciplinary diversity of teams, and prototyping behaviors.

Our second research question explored how sponsor satisfaction varied with disciplinary diversity in capstone teams, and how they related to teams' perceptions of their own engineering design capabilities. Specifically, we investigated the differences in team EDSE and disciplinary diversity between the ratings of technical competence, team effectiveness, and overall satisfaction. Results reveal an absence of any kind of relationship between sponsor ratings and team EDSE. This suggests that even though sponsor's may be dissatisfied with their teams' performance, their dissatisfaction may not have an impact on students' perceptions of their engineering skills. There was no significant relationship between disciplinary diversity of teams and sponsor satisfaction. We note, that not all projects would require an interdisciplinary team; for example, a project focused on a mobile application might require a team entirely composed of Computer Science students to be successfully carried out. Future work should explore the relationship between disciplinary diversity, project prompt, and project success. Further, we note the lack of variance in sponsor satisfaction across the three metrics analyzed. As noted in the figures 2 to 7, there is a high concentration of points at the highest ratings for all metrics. While it is possible that all student teams performed exceedingly well, it is unlikely. Thus, there is a possibility that sponsors inflated their ratings, and that the survey did not accurately capture sponsors' opinions on capstone team performance. We identify this as a potential area of future work.

We see these quantitative and qualitative findings as having significance, particularly in the field of engineering education. While interdisciplinary design teams provide students with the opportunity to share technical knowledge and improve their teamworking skills, it is important that students are taught how to navigate and best make use of this opportunity.

5. CONCLUSION

This work sought to investigate the relationship between teams' disciplinary diversity, teams' perception of their abilities (measured through the engineering design self-efficacy scale), and actual performance ratings of the team (measured through sponsor satisfaction ratings). We used an entropy-based formula to determine the disciplinary diversity index for each team. Results indicate that self-efficacy in constructing a prototype decreases with an increase in disciplinary diversity. A preliminary qualitative analysis suggests that students tend to split into sub-teams based on their disciplinary backgrounds, rather than working together as a single unit. Additionally, no difference in team disciplinary diversity or team self-efficacy was observed across different sponsor ratings. This indicates that students' beliefs of their engineering skills were largely unaffected by sponsor's opinions, and disciplinary diversity was not in any way related to how satisfied the sponsor was with a team.

As with all studies, there are limitations associated with our work. First, due to the relatively short duration of the event and limited number of data collectors, we were not able to survey all capstone teams present at the showcase. This limited our sample size to 58 teams. For our second research question, our sample size was limited to 27 teams due to limited responses from industry sponsors. Further, while we did examine students' self-efficacies at the end of the capstone projects, future work should survey students' efficacies before and after capstone. This would provide insight into improvements (or declines) in students perceptions of their engineering abilities. More importantly, our interview questions did not specifically elicit information about students' prototyping behaviors within their design teams. Future work should consist of open-ended questions related specifically to team dynamics in the context of prototyping.

The aim of this study was to understand the effect of disciplinary diversity of capstone design teams on students' self-efficacies, and team performance. At the same time, we acknowledge that there are a number of variables that contribute to the overall diversity of a team, such as such as gender [28], learning styles [29], and cognitive preferences [30]. Hence, there is a possibility that these other facets of diversity may have also played a role in the performances and self-efficacies of the capstone design teams. Future work should further seek to investigate the interaction between these different aspects of diversity, and how they either promote or hinder the learning outcomes of capstone design teams.

Overall, this work seeks to build more knowledge in identifying the factors that affect students' capstone design performances, and aims to help engineering education in creating more optimal capstone design experiences.

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