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Evaluating Self-Efficacy in Interdisciplinary Capstone Design Experiences

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EVALUATING SELF-EFFICACY IN INTERDISCIPLINARY CAPSTONE DESIGN EXPERIENCES

ABSTRACT

Engineering programs have long recognized the importance of capstone design as a culminating experience for students. This course is typically taken toward the end of students' degree plan and allows them to work on an open-ended, real-world project that primarily focuses on innovation within research or industry. While curriculum can vary based on the university, the goals remain similar: provide students with professional skills while gaining design knowledge and capabilities. Deliverables can include the development of a product prototype or proof of concept presented to their sponsor or university. The curriculum is ever evolving to match the demands of industry and improve the students' experience so they can gain skills and better prepare them for the workforce.

Literature shows that the students' motivation, including self-efficacy, has been correlated to student performance in capstone design. The goal of this study is to expand on this knowledge and examine additional facts, such as their previous experiences, on the student's engineering design self-efficacy and performance. To examine this correlation, the Engineering Design Self-Efficacy (EDSE) survey was disseminated to examine student progression through the course and to understand their thoughts about their abilities. Students also reported basic demographics (gender, degree field, etc.) and relevant previous experience. The results showed that much of the data did was not statistically significantly different between cohorts. It was found that males and engineering students felt more motivated and confident during project work, whereas females and science students felt more anxious while working on the project. Additional trends are discussed amongst fields, though statistical significance cannot be established due to sample size.

Keywords: Capstone Design, EDSE, Engineering, Science, Engineering Education

1. BACKGROUND

Capstone Design, a final requirement for graduation in many ABET-accredited engineering programs, gives students the opportunity to learn skills and experience through hands-on project-based assignments. At some universities, projects are sponsored and mentored by industry partners, also providing benefit to the local industry. This is true for Florida Polytechnic University, a Science, Technology, Engineering, and Mathematics (STEM) driven university, which offers >90% industry-sponsored capstone experiences annually. This provides a unique opportunity for the students to experience professional growth and interact with industry.

Prior work has realized the impact of industry-sponsored projects on the students' self-efficacy, in which students on industry-sponsored teams showed larger increases in self-efficacy compared to university-sponsored [1]. This work aims to closely examine students' self-efficacy by utilizing the EDSE survey to understand trends amongst cohorts, and understand influencing factors for success.

1.1. Capstone Design

Capstone Design is a course that students commonly take during their final year of undergraduate studies in engineering disciplines. This course is typically structured to bridge the world of education and real-world application [2]. Overall, this course serves as the culminating experience for students at the end of their college career, allowing them to develop and apply the knowledge they have accumulated thus far. Capstone (in engineering disciplines) is typically a team-project-based course, in which students are assigned to groups where they are tasked with an open-ended, real-world challenge. The Capstone course also encourages the use of critical thinking, creativity, and teamwork, which are essential for students to accomplish the tasks assigned throughout their coursework. Additionally, the students are able to interact with industry partners, local suppliers, and other professionals [3], providing real-world engagement. In addition to the importance of teamwork, it is also crucial for the students to exercise conflict resolution, interpersonal dynamics, and professional skills. This allows students to develop confidence in their capabilities as they prepare to enter the workforce.

1.2. Capstone Design for Industry

As stated previously, the primary objective of Capstone Design is to prepare students for industry by providing them with the opportunity to develop and mature the skills and experience necessary to succeed [4]. The projects that are assigned may be directly sponsored by companies or corporations. Engaging with these kinds of sponsors not only encourages company outreach, but also provides students with exposure to current industry trends, standards, and practices. This provides insight for the students and companies in industry looking for outside perspectives and emerging talent entering the workforce. In the course, students refine their skills in project design, analysis, management, and documentation to manage their resources efficiently, meet deadlines in a timely manner, and keep technical standards intact. These practices will help match students to the expectations of the workplace. The projects assigned to students usually reflect the sponsor's goals and intentions for research or innovative technology solutions.

1.3. Capstone Design at Florida Polytechnic University

At Florida Polytechnic University, students from all the degrees offered at the university enroll in the same, multidisciplinary capstone course. The capstone course is a two-semester sequence during the final year of academic tenure. Students are provided with a workspace to collaborate and conduct the work needed for their project, benefiting them with the resources they need to succeed [5]. This course is uniquely structured to provide hands-on experience while working on their assigned projects, encouraging the cultivation of interdisciplinary teamwork and connections to industry professionals. The Capstone Design course structure should be similar across all degree programs to make the curriculum fair to all students [6]. In addition, students must work on their team dynamic, resolve conflicts, and effectively communicate; this could be in the context of other students, their advisors from academia, or industry sponsors to meet the intended goal or solution. Throughout the course, students are required to produce regular progress reports, presentations to their peers and a panel of faculty members, and a showcase of their final product.

1.4. Self-Efficacy in Engineering Design

Self-efficacy is what a student feels towards their capabilities in completing a goal, such as the motivation to do it, the confidence they have in doing it, the success they feel in their work, and their level of anxiety whilst working toward the goal [7], [8]. Self-efficacy is a cornerstone of student performance, which plays a crucial role in Capstone Design, as the curriculum is ever-evolving to improve the student's overall experience. These continual changes strive to mimic industry changes and trends. Keeping up with these standards better prepares students to complete different tasks or projects in their future careers [9]. Because self-efficacy plays such a significant role in not only the curriculum development, but also the performance of students, self-efficacy must be determined by the personal reporting of each student. This information can be compared to different cohorts of students to determine trends within them [10].

Previous literature has shown trends of self-efficacy within certain demographic groups. STEM fields, which are typically male-dominate, studies have shown that males in STEM areas tend to have an overall higher self-efficacy in different skill areas than women [11], [12]. While other studies have examined self-efficacy across different degree programs at the university level, many do not conduct direct comparisons between them. However, there are some studies that can be inferred upon based on the trends found in singled out degree programs, such as trends that mechanical engineering students having relatively high average self-efficacy scores for their motivation and confidence, and a lower anxiety score at the senior level [13]. There are also a number of studies that have not examined science-based degrees, only the skills that those students would use, such as computer and programming skills. However, studies do not tend to corroborate findings. Therefore, it is difficult to identify conclusive trends.

2. METHODS

This study, approved by the Florida Polytechnic University's IRB committee, seeks to examine students' self-efficacy in the second semester of their multidisciplinary capstone design course, also considering previous experiences, demographics, and their perceptions of the Capstone course. The students were provided with a survey examining their background and the EDSE survey [9]. An example of the given survey questions is included in the following Survey section. Participants self-reported their motivation, confidence, success, and anxiety toward the design efforts. These components of self-efficacy are based upon what the participants define these as. The students' EDSE scores were analyzed using Kruskal-Wallis and analysis of variance (ANOVA) tests. Statistical significance is revealed at a P-value of less than 0.05, however, a P-value of less than 0.10 is also discussed. It is important to note that this study is a preliminary examination of differences in self-efficacy across cohorts, providing future research direction for the team.

2.1. Participants

The participants in the study were all second-semester senior students enrolled in the capstone design course. These students come from various backgrounds in the university's engineering and science degrees. There was a total of 125 students in the course, of which 96 students consented to the study. Of the students who consented, 85 students filled out the survey to completion. The 85 student respondents are what will be reflected in the analysis. The breakdown of student demographics is shown in Table 1, below.

Table 1: Number of Participants with Completed, Self-reported Data

Degree Program	Male	Female	Not stated	Total
Applied Mathematics	1	-	-	1
Business Analytics	9	1	-	10
Computer Engineering	3	3	-	6
Computer Science	30	6	2	38
Data Science	-	1	-	1
Electrical Engineering	1	-	-	1
Engineering Physics	4	-	1	5
Mechanical Engineering	17	5	1	23
Total	**65**	**16**	**4**	**85**

2.2. Survey

The survey used in this study was disseminated to the students enrolled in the Capstone Design course after the groups of students completed their assigned capstone projects. In the first half of the survey, they are to reflect on their personal experiences and information about themselves. This would include their personal experience of the course, such as how they thought the course/project went, how they felt their team did, etc. Students also report their demographics, such as major, ethnicity, and spoken languages. Lastly, students report any relevant previous experiences, such as courses taken at the high school level, certifications earned, or internship experiences. The second half of the survey is the Engineering Design Self-Efficacy (EDSE) survey [7]. An example of the questions from this section of the survey can be seen below.

Rate your degree of MOTIVATED to perform the following tasks.
(0 = cannot to at all; 50 = moderately can do; 100 = highly certain can do)

○	○	○	○	○
0	25	50	75	100
Not Motivated		Moderately Motivated		Highly Motivated

The EDSE measures the students' motivation in completing their work, confidence in their work, how successful they felt in their work, and how much anxiety they felt whilst working on their projects. The analysis presented here examines correlations between student demographics and their EDSE scores. Future analysis will include the examination of their previous experiences and capstone involvement with respect to their EDSE.

2.3. Analysis

Multiple tests were conducted to analyze and validate the self-reported data. First, the Shapiro-Wilk test is used to check the normality of the data [14]. If the data is normal, it is analyzed using both the Kruskal Wallis test [15], [16] and an ANOVA test [17]. Both are used to test the statistical significance of the data. However, to use the Kruskal Wallis and ANOVA tests, there must be a comparison of at least two groups, where both groups have a sample size of at least five. If they do not, they are unable to be tested for any kind of statistical significance [16].

3. RESULTS

The primary comparisons were between genders and majors at the university, as these were the most prominent groups at the time of this study. This was done to inform future research directions in the study. There are also additional cohorts that have been analyzed, including students of the less prominent degree programs offered at the university. It is important to note that throughout the results section of this study, the average scores for motivation, confidence, success, and anxiety are the reported average scores. Meaning a higher score in motivation, confidence, and success is a positive outlook, while a higher score in anxiety is negative.

3.1. Gender

The first comparison is the self-efficacy of genders. It is important to note that the analysis of the data includes Male, Female, and those that did not report. However, due to sample size, some data was not large enough to be analyzed statistically and will only be shown in the following visualizations [16]. From the survey data, the resulting average EDSE scores of the reported cohorts are shown in Figure 1 for a direct comparison of each component. It can be seen in this comparison that Males have a higher average in Motivation and Confidence to that of Females. Females showed to have a higher average in Success and Anxiety. The distribution of these scores are shown in Figure 2 with the mean shown with an 'X', the median shown with a horizontal line though the range, and outling data points past the minimum and maximum values. It can be seen that there is a higher concentration of responses throughout Male scores, while Females showed a more broad distribution of scores with fewer outliers. Table 2 states the average scores for all cohorts reported, with a respective sample size and standard deviation of the reported scores. The Male and Female cohorts have a p-value associated with each component of self-efficacy, showing that the only statistically significant data point is the success between these cohorts.

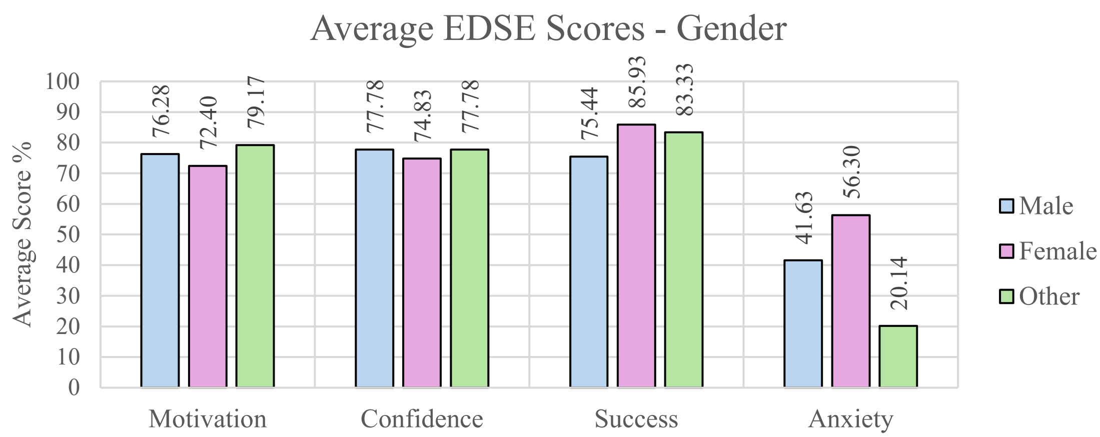

Figure 1: Average EDSE scores for Gender cohorts

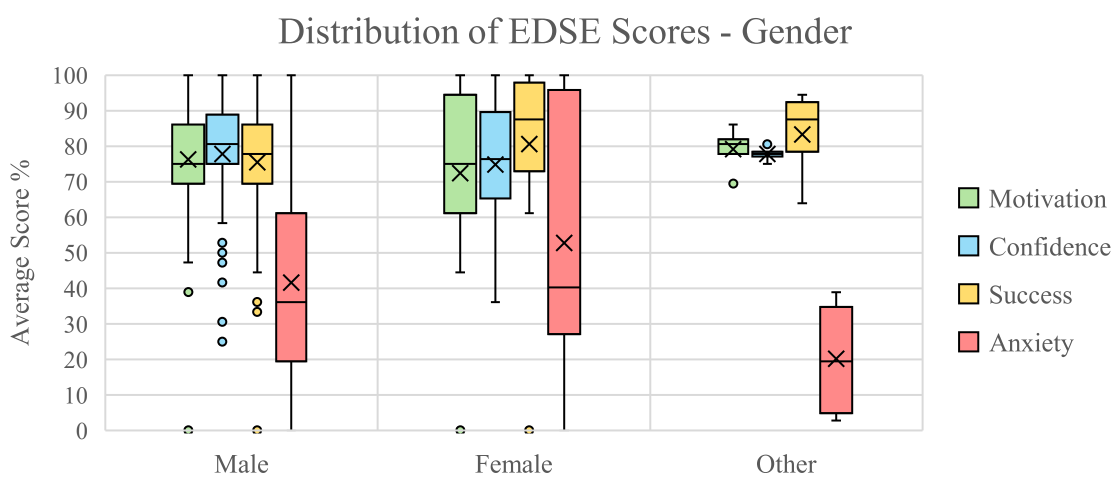

Figure 2: Box and Whisker Plot reporting the gender sample groups

Table 2: Gender Cohort Statistical Information

	Male		Female			Not Stated	
Sample Size	65		16			4	
	Average	*Std Dev*	*Average*	*Std Dev*	*p-value*	*Average*	*Std Dev*
Motivation	76.28	16.617	72.40	24.874	0.704	79.17	6.054
Confidence	77.78	17.371	74.83	18.228	0.499	77.78	1.964
Success	75.44	18.053	85.93	13.204	0.025	83.33	11.948
Anxiety	41.63	28.357	56.30	33.602	0.162	20.14	16.122

3.2. Engineering vs. Science

The second comparison was with respect to student major, in which the students were generally grouped into their respective engineering- or science-based degree programs. Engineering-based degree programs include, but it not limited to, Mechanical, Electrical, and Computer Engineering. Science-based degree programs include, also not limited to, Business Analytics and Computer Science. In Figure 3, the average EDSE scores of these degree based programs are visually compared to one another. It can be seen that students studying an engineering-based programs show a higher self-efficacy score in motivation and confidence than science-based programs. Students studying engineering- and science-based degrees show to have a similar success score, but studens studying science-based degrees had a higher anxiety. Figure 4 shows the distribution of the reported scores from this comparison, with the mean shown with an 'X', the median shown with a horizontal line though the range, and outling data points past the minimum and maximum values. Students studying engineering-based degrees show to have a smaller distribution of scores in motivation, confidence, and anxiety than that of science-based students. However, science-based students have a smaller distribution in success scores. Table 3 shows the resulting average scores from the EDSE portion of the survey with a respective sample size and standard deviation, where resulting p-values indicat that there were not any statistically significant data points.

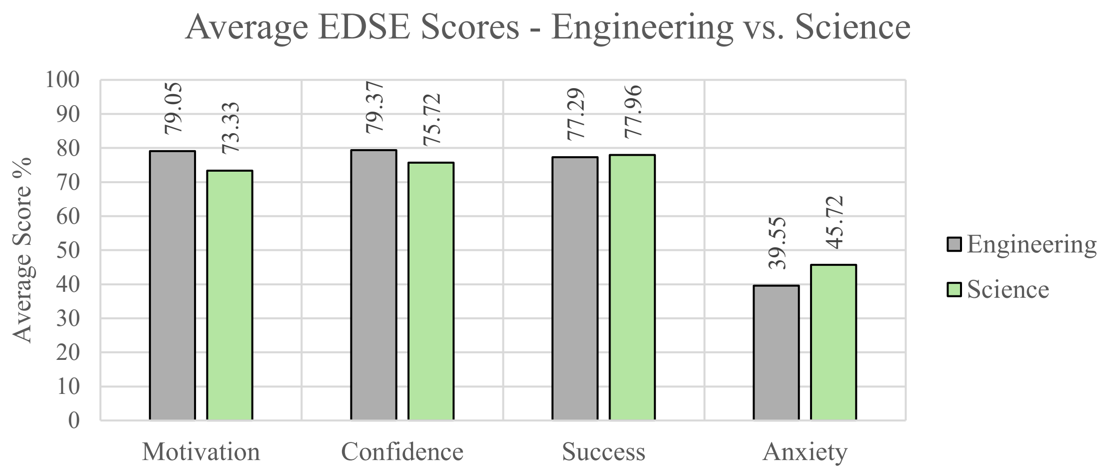

Figure 3: Average EDSE scores in Engineering- vs. Science-based degree programs

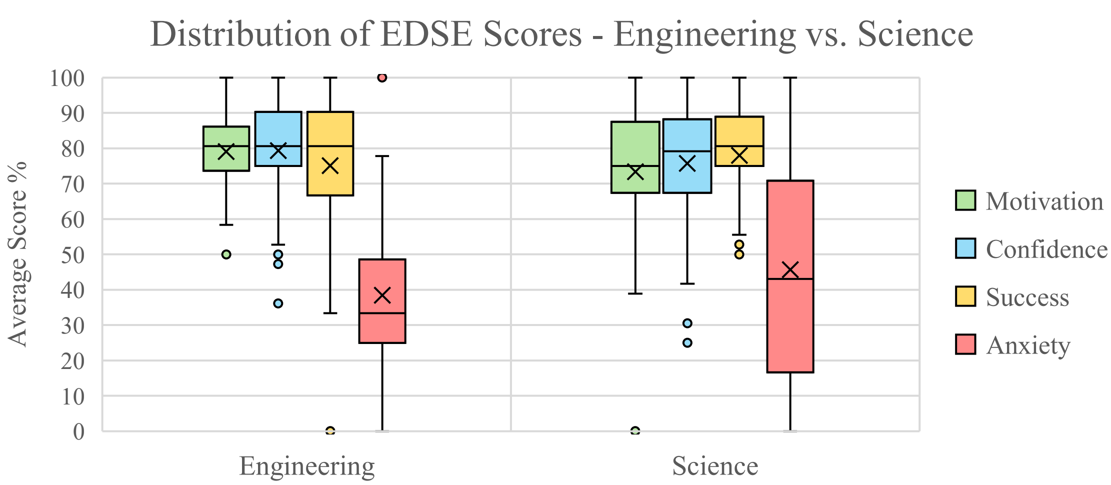

Figure 4: Box and Whisker Plot reporting Engineering- vs. Science-based degree programs

Table 3: Engineering vs Science Cohort Statistical Information

	Engineering		**Science**		
Sample Size	35		50		
	Average	*Std Dev*	*Average*	*Std Dev*	*p-value*
Motivation	79.05	12.640	73.33	20.964	0.253
Confidence	79.37	15.463	75.72	18.120	0.427
Success	77.29	18.345	77.96	16.967	0.967
Anxiety	39.55	24.768	45.72	32.703	0.506

3.3. Offered Engineering- and Science-Based Degrees

To further examine the impact of degree programs, we can expand into the individual degree programs that make up the different cohort populations for engineering- and science-based degree programs. These individual cohorts would include the students studying Mechanical Engineering (ME), Computer Science (CS), Business Analytics (BA), Computer Engineering (CE), and Engineering Physics (EP). For this section, these are the only groups analyzed. The omitted groups of students that were included in the engineering vs. science comparison are those studying Environmental Engineering, Electrical Engineering, Applied Mathematics, and Data Science. These groups were omitted for this comparison due to their sample sizes, as seen in Table 1, are too small to be used in statistical testing [16]. From the reported scores of the analyzed cohorts, we were able to find the resulting average scores from the EDSE portion of the survey, which are depicted in Figure 5 for a direct comparison across degree programs. For ME students, their scores show to be the second highest for motivation and confidence, while having the lowest success score and third highest anxiety score. CS students have a trend of their scores being in the middle across the board. BA students showed to have the lowest scores for motivation and confidence, but had a significantly higher score for anxiety than that of all other groups. CE students had the highest average scores for motivation, confidence, and success. And finally, EP students, similar to CS students, had the tendency to have scores that were in the middle, except for anxiety where they had the lowest score. Figure 6 shows the distribution of the reported scores from this comparison, with the mean shown with an 'X', the median shown with a horizontal line though the range, and outling data points past the minimum and maximum values. Across all degree programs, there seems to be a smaller distribution for motivation, confidence, and success, while anxiety had a large distribution particularly in ME and CS students. Table 4 shows the resulting average scores from the EDSE portion of the survey with a respective sample size and standard deviation. The p-values that resulted from this comparison, listed in the bottom right corner of the table, showed that there was not any statistically significant data points. However, anxiety across these degree programs did show a p-value that is extremely close to being statiscally significant.

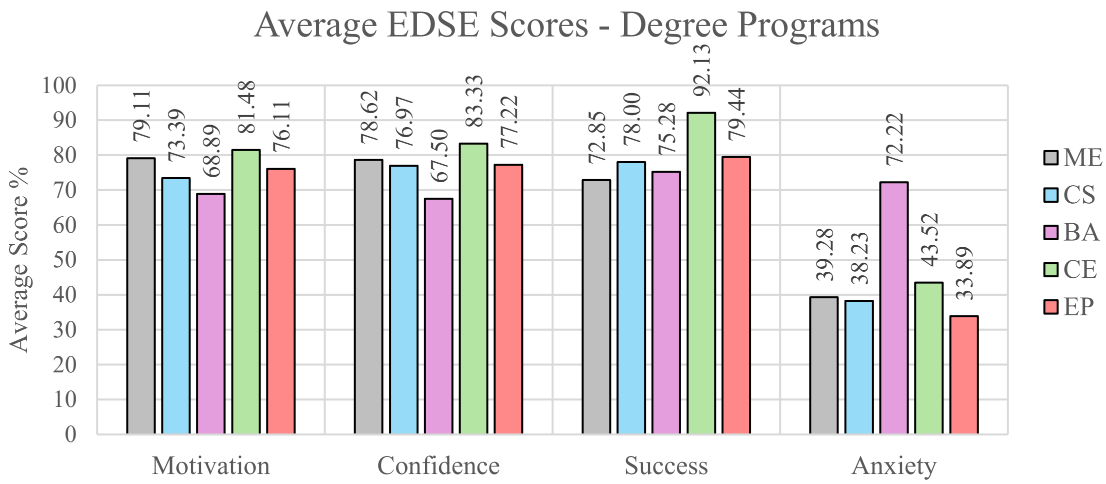

Figure 5: Average EDSE scores in individual Engineering- and Science-based Degree Programs

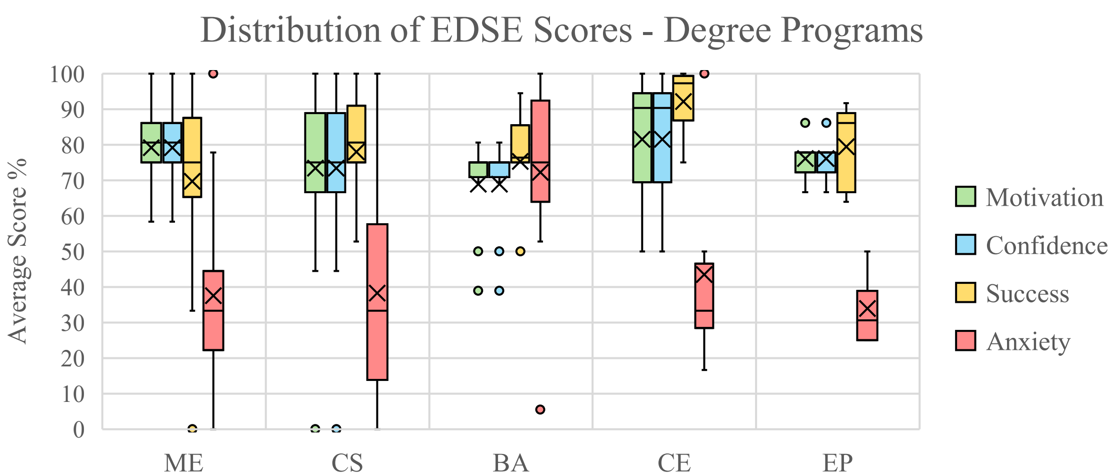

Figure 6: Box and Whisker Plot of individual Engineering- and Science-based Degree Programs

Table 4: Individual Engineering- and Science-Based Degree Programs Cohort Statistical Information

	Mechanical Engineering		**Computer Science**		**Business Analytics**	
Sample Size	23		38		10	
	Average	*Std Dev*	*Average*	*Std Dev*	*Average*	*Std Dev*
Motivation	79.11	12.248	73.39	22.784	68.89	13.405
Confidence	78.62	17.132	76.97	18.549	67.50	16.040
Success	72.85	20.030	78.00	17.914	75.28	14.725
Anxiety	39.28	27.268	38.23	31.490	72.22	28.267

	Computer Engineering		**Engineering Physics**		
Sample Size	6		5		
	Average	*Std Dev*	*Average*	*Std Dev*	*p-value*
Motivation	81.48	20.005	76.11	7.244	0.389
Confidence	83.33	18.509	77.22	3.622	0.139
Success	92.13	10.455	79.44	13.117	0.108
Anxiety	43.52	29.745	33.89	10.650	0.055

3.4. Mechanical Engineering vs. Computer Science

From the engineering- and science-based degree programs comparison, the two largest degree programs based on sample size were ME and CS. Because these students make up the majority of the population for their respective degree area, we did a direct comparison between the two programs. ME and CS students, shown in Figure 7, were relatively similar for their resulting average scores from the EDSE portion of the survey. As shown in the previous comparison, ME students have higher motivation and confidence, while CS students have a higher success score. Both groups have a similar anxiety level. Figure 8 shows the distribution of the reported scores from this comparison, with the mean shown with an 'X', the median shown with a horizontal line though the range, and outling data points past the minimum and maximum values. For ME students, there is a smaller distribution for motivation, confidence, and anxiety than that of CS students. This shows to be the opposite for success for these students. Table 5 shows the resulting average scores from the EDSE portion of the survey with a respective sample size and standard deviation, which gave the resulting p-values. These values do reveal that this comparison does not show any kind of statistically significant difference in any of the EDSE scores.

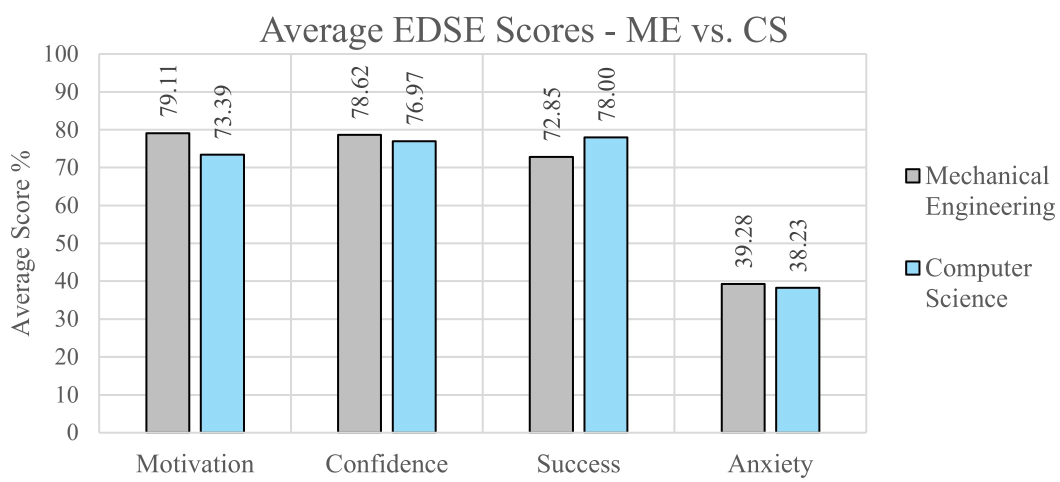

Figure 7: Average EDSE scores in Mechanical Engineering vs. Computer Science degree programs

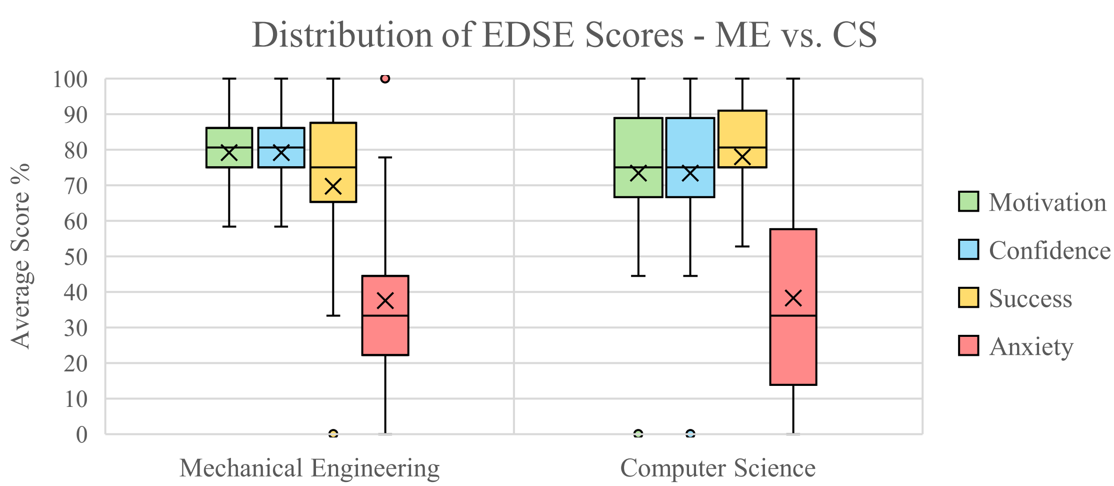

Figure 8: Box and Whisker Plot reporting Mechanical Engineering vs. Computer Science degree programs

Table 5: Mechanical Engineering vs Computer Science Cohort Statistical Information

	Mechanical Engineering		**Computer Science**		
Sample Size	23		38		
	Average	*Std Dev*	*Average*	*Std Dev*	*p-value*
Motivation	79.11	11.979	73.39	22.482	0.470
Confidence	78.62	16.756	76.97	18.303	0.858
Success	72.85	19.569	78.00	17.676	0.315
Anxiety	39.28	26.641	38.23	31.072	0.707

4. DISCUSSION AND CONCLUSION

The results indicate that much of the data was not statistically significant. Regardless of significance, this data will help inform future criteria for the study. In possible future work, there will be further investigation into other trends, such as previous experiences and demographics from the survey, in addition to a pre-survey to see students' progression through the course.

4.1. Result Discussion

This work examines the Engineering Design Self-Efficacy (EDSE) of students in a multidisciplinary Capstone Design course. From some of the resulting data, the lack of statistical significance does not deter the finding of results in this study. In fact, it still shows common trends among and between different cohorts of the surveyed population for future work. The findings of this study also might show more statistical significance between the different cohorts when testing based on other criteria, such as previous experiences or demographics.

From Figure 1, Figure 2, and Table 2, we are able to conclude that males tend to exhibit higher motivation and confidence and are less anxious in their work than females. This finding may be due to males being the more prominent gender in the STEM fields and have a higher overall self-efficacy than women, which does follow that of other studies [11], [12]. This is also more definitive as the standard deviation of data is much lower than that of females. Most of the data from this comparison is insignificant and only shows common trends. However, it was found that the success metric of self-efficacy between males and females is highly significant. This finding of significance is most likely due to the significantly higher score in success for females, which also does not match the initial trend of males having higher overall self-efficacy. The sample group comparison for unstated gender did not have a large enough sample size for comparison, warranting further investigation.

Figure 3, Figure 4, and Table 3 show that the engineering students have a higher overall self-efficacy than that of science-based. They have a better average for their motivation, confidence, and anxiety score. In addition to this, engineering- and science-based students have similar perceptions of their success. This might be caused by the students receiving similar curriculum in their Capstone Design course. It can also be seen that the distribution of the EDSE scores amongst the engineering-based degrees for motivation, confidence, and anxiety are much smaller than that of the science-based degrees, showing that there is a more common trend among them. Though, as stated before, this data does not show statistical significance, which warrants further investigation.

The individual engineering- and science-based degrees also exhibited trends found in Figure 5, Figure 6, and Table 4. This allows for the visualization of sharing similar trends to what was found in the larger grouping. ME, CE, and EP students had higher motivation and confidence in their work than that of the BA and CS students. This trend does match that of the previous comparison. It is important to note that while there is not an indication of statistically significant data points being <0.05, the anxiety of these degrees is maintained for discussion with a p-value of 0.055, which could warrant closer analysis in future studies with a new dataset. CE students also had an extremely high success score in comparison to other degrees. This finding will also warrant further investigation.

Finally, the two largest populations within the engineering- and science-based degree progams were examined, as shown in Figure 7, Figure 8, and Table 5. These cohorts follow a similar trend as the overall engineering- and science-based degree comparison, both in the average EDSE scoring and the distribution of scores. This trend was to be expected, as these two degrees are the primary source for higher populations. However, aside from the full analysis of all degrees, these were examined for any kind of statistical significance. Unfortunatley, from this comparison, it was found that this cohort's data does not show statistical significance, but it does inform future investigation. This is due to the understanding of how these cohorts effect the overall comparison of degrees. In addition, the authors now have a recorded baseline and trends for these degree programs, which can be used for future studies. The trend amongst the ME students is similar to that of other studies when looking into that degree program individually [13]. It is worth noting that most studies looking into self-efficacy do not tend to study other disciplines or degree programs. In the findings of this comparison, CS students did indicate they have a lower anxiety than that of the overall science-based degrees.

4.2. Conclusions and Future Work

Study limitations included the distribution of students amongst the cohorts and the sample sizes. Multiple cohorts did not have enough participants to examine statistical significance. In addition to the smaller sample sizes from the different degree students that consented to the study, there was also limitation to how much data could be used, as some of the students did not complete the study's survey. There was also a limitation in the data collected, as only one survey was disseminated to the students at the end of the capstone course.

Possible future work for this study would be the dissemination of additional surveys, such as a pre-survey that is taken before students begin work on their projects or at the beginning of the course, and a mid-survey that is taken either at the end of the first semester or the beginning of the second semester in the course. The addition of these surveys will allow for examination of self-efficacy change across Capstone Design. In other words, this will provide a simple way to see the progression of students' self-efficacy throughout the course instead of just at the end. The authors would also like to examine students across academic years, quantify student profiles, and examine changes in self-efficacy as the program matures.

In addition to conducting additional surveys, there can be more comprehensive correlations to other influences, such as the previous experiences students have participated in. This information can also be considered when analyzing the students' self-efficacy. This is believed to correlate with these prior experiences, which may influence the outcome of a student's capabilities and what they feel they are able to complete and, therefore, change the outcome of not only their project but also their self-efficacy.

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