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Integration of Capstone Class and Student Competition Design Teams

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Abstract

Many student competition design teams, such as SAE Collegiate Design Series teams, ASME design project teams, and others, feature interesting and challenging projects. These projects are often open-ended and require use of material from multiple engineering classes and disciplines, which suit them in many ways for capstone projects in senior design classes. In this paper, a team of faculty who have been involved with student competition design teams and have taught capstone classes analyze the student experiences with capstones and discuss the benefits of a capstone project focused on a student competition design team. Data was gathered from students by use of a survey, which was sent to students in several different classes. Analysis of the data found that students felt that they gained useful experiences from capstones focused on student competition teams.

Introduction

The values of student competition design team projects have been widely acknowledged, both by universities and by industry. Particularly, the open-ended aspect of the competition design-based projects make them an excellent platform to conduct challenge-based senior design projects. For example, the senior design students who compete as a design team in SAE/GM AutoDrive go beyond a classic design project by illuminating the values and challenges of emerging technology like automated driving from societal, economical, and environmental points of views.

In addition, many industry employers place a great deal of weight on them when deciding who to interview and hire, and universities demonstrate the value they place on them by providing space for teams to work and time for faculty to serve as advisors. Universities may also consciously and intentionally incorporate them into students' educational experiences in a variety of ways, depending on the specifics of the team and the project. Such efforts have been documented for the SAE/GM AutoDrive Challenge [1, 2] as well as for other competitions in which a larger number of universities participate. Such competitions are often sponsored by professional societies and may be integrated into the curriculum in a number of different ways [3, 4, 5]. In this paper, we focus specifically on the impact of using student design competitions in capstone classes, and conceptualize it as an example of going beyond project-based learning and into the realm of what has been called challenge-based learning.

Background and Literature Review

The capstone course, which culminates the education of many engineering undergraduates, typically addresses a specific question or problem presented by the instructor, who acts as the client or the real needs of an external client, such as an industry partner or local community [6, 7]. Tenhunen et al. [6] underlined the ACM/IEEE recommendation of using external clients in capstone courses and discussed the benefits of such a collaboration between academia and industry. These benefits include a more rewarding capstone experience for undergraduates, as well as positive implications on their skills and employment after completing the course [6]. In a separate work, Doulougeri et al. [7] suggest that the involvement of external stakeholders in a real-world challenge, such as one that may be tackled in a capstone course, can make the experience more relevant to the student. Thus, there is value in incorporating external clients into a capstone project.

Project-Based Learning (PBL) is a pedagogical approach in which students acquire knowledge and skills through an in-depth investigation of complex and authentic problems [8]. Studies have shown that this approach leads to a deeper understanding of science materials, problem solving skills, student engagement, and student motivation [8, 9, 10, 11, 12, 13]. Studies have also demonstrated that PBL fosters teamwork, communication (both oral and written), and time management [9, 11]. Most capstone projects incorporate PBL by nature, requiring students to develop real-life designs in teams, so as to tackle or solve a real-world problem [11, 12]. The PBL experience of a capstone course typically lasts for one term culminating in a student product incorporating the real-life design [14].

Challenge-Based Learning (CBL) is an emerging educational approach that, like PBL, engages students in deep investigation of real-world issues. However, CBL starts with a societal challenge that is inherently interdisciplinary, rather than a driving question or task that may be interdisciplinary or discipline-specific [7, 15, 16]. Students then develop a solution for the challenge by determining the specific problem to investigate within the challenge [15]. The challenge, itself, is often presented by an external client, thus encouraging invaluable collaboration between students, instructors, and external stakeholders to tackle sociotechnical challenges [15, 16]. A researched benefit of CBL is that it promotes the development of more transversal skills among students [15, 17, 18].

In comparison to PBL, CBL presents a heavier workload and time commitment for the instructor [6, 7, 15]. Additionally, instructors have reported difficulties in aligning industry partners' interests with a suitable learning challenge for the student [7]. Some challenges are "open-ended and ill-defined to the extent" that both instructors and students face high levels of uncertainty regarding what is to be investigated [7]. Furthermore, the time and effort to align with external clients for a capstone can be "unsustainable for some institutions" [6]. Alternatively, a capstone project focused on an established student design team (tackling a defined challenge with the coaching of available industry partners and faculty) may mitigate these issues.

Methodology

After approval by the Kettering University Institutional Review Board (IRB), a survey was distributed to students who had taken capstone classes from the researchers over a period of time, with particular attention to those who had taken capstones focused on student competition design teams. Questions were based on instructor observations, with one member of the author team drafting the survey and others reviewing it and providing feedback. The students covered several majors, including mechanical engineering, electrical engineering, and computer engineering. Survey questions are given in the Appendix.

Contacting the students who had already graduated was challenging at times, and therefore the survey had a relatively low level of responses, with 20 students providing data. Due to this low number of responses, statistical significance could not be established. However, the data is still of some value, particularly that which was compiled from free response questions.

Subjects: Demographic

Of the 20 respondents to the survey, four were currently undergraduate students, and sixteen had graduated already. Fourteen of them had taken their capstone in their final, or Senior 3, term; five took their capstone class in their Senior 2 term, which is typically the second to last term, and one had taken their capstone as a junior. The majors of the students are shown in Figure 1.

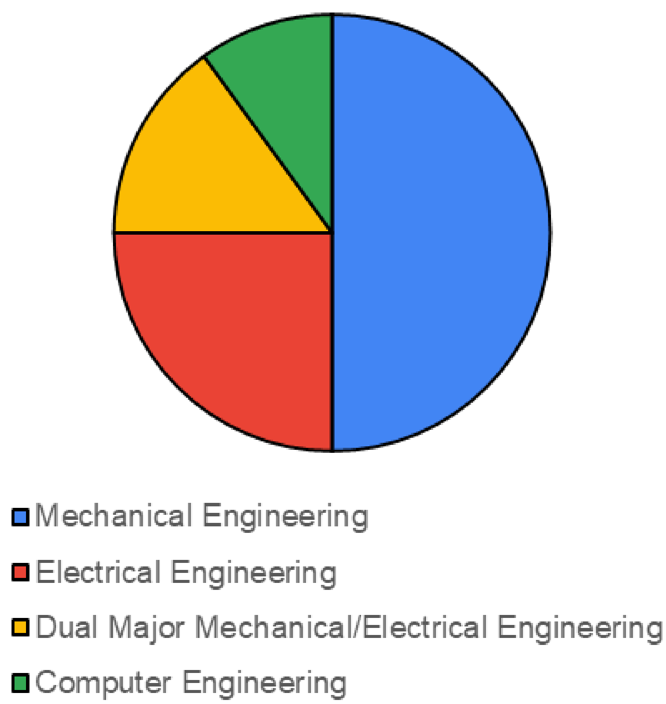

Figure 1: Student Majors

Subjects: Design Background

When asked in a free response question what classes students had taken that they considered to be "design classes", the responses naturally varied somewhat by major. There was also variation in the number of classes mentioned by the students. One student left the question blank, and two students specifically responded "none". Some of them gave a course number, while others gave a course name or general description. In the case of the thirteen students who were either purely mechanical engineering majors or dual majors in mechanical and electrical engineering, nine of them mentioned at least one of the CAD classes in the mechanical engineering curriculum; this was the most common response. A summary of the responses for these students is given in Table 1.

Table 1: Design Courses Listed by Mechanical Engineers (including dual majors)

Course Description	Occurrence
CAD course(s)	9
Machine design	6
Introductory engineering course	5
Mechatronics	4
Circuits 2	1

The electrical engineering students did not show any repetition of classes, with two of them including the responses of "none" and one stating that they did not remember due to taking a lot of classes in a short period of time. Their responses included the Circuits 2 course mentioned by one dual major, a digital controls course, a course in PCBs, an electronics course, and a CAD course. Of the two computer engineering students, one left the question blank, and the other listed a course in AI for autonomous vehicles and a computer vision course.

Out of the 20 students, six of them had participated in at least one competition team that required design activities prior to their capstone. All six of them had been involved in the AutoDrive autonomous vehicle team, with one also participating in the EV Karts team. Fourteen of the students had been involved in some form of design through their co-op work experience, with the other six specifying that their co-op did not require any design activities. All students did have co-op work experience, due to the university's requirements. Of the six students without co-op work experience, one of them obtained design experience through a student competition team; the other five did not mention any design experience aside from their coursework.

For those who stated that their co-op work assignment involved design work, the majority of them conducted some form of mechanical system design or CAD work. One mentioned designing experiments as well as small mechanisms, and four mentioned electronics, software, or code, with one specifying that they had done ladder logic design, another had worked on machine learning models, another had designed code for manufacturing machines, and the fourth had designed wiring harnesses.

Results and Discussion

Out of the 20 students, 11 of them - just over half - specifically sought out a capstone based on a student competition design team. This included all six of those with previous design team experience, as well as five students who did not report previous design team experience. Two of those 11 students also were among those who did not have design experience through their co-op, one of whom had only design experience in their coursework prior to capstone. Of those who specifically sought out a capstone based on a student design team, their motivation for doing so is shown in Figure 2, where ”interest in the topic covered” and ”more realistic design experience” were the top responses.

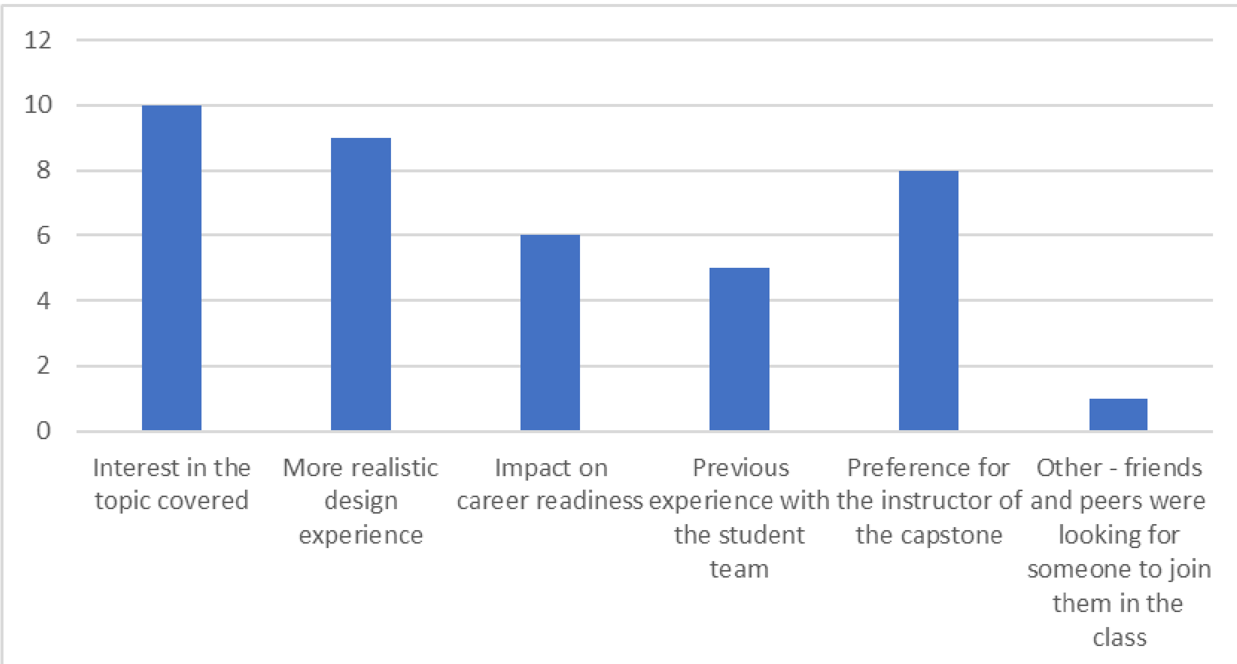

Figure 2: Motivation of Students in Competition Design Team Capstone

The concerns expressed by students, relative to a capstone based on a design team, are shown in Figure 3. In comparing their design team based capstone to previous design experiences, students were asked to rate a set of statements on a five-point Likert scale, with 5 meaning the student was completely true and 1 being completely false. Results from these questions are given in Table 2.

Table 2: Student Comparison of Capstone based on Design Team to Previous Design Experiences

Statement	Average Rating
The capstone was more difficult than previous design experiences.	3.45
The capstone was more interesting than previous design experiences.	4.36
The capstone provided more realistic design experiences.	4.09
The capstone provided better career preparation.	4.27

Out of those 11 students, eight of them added additional comments on their capstone class. Those

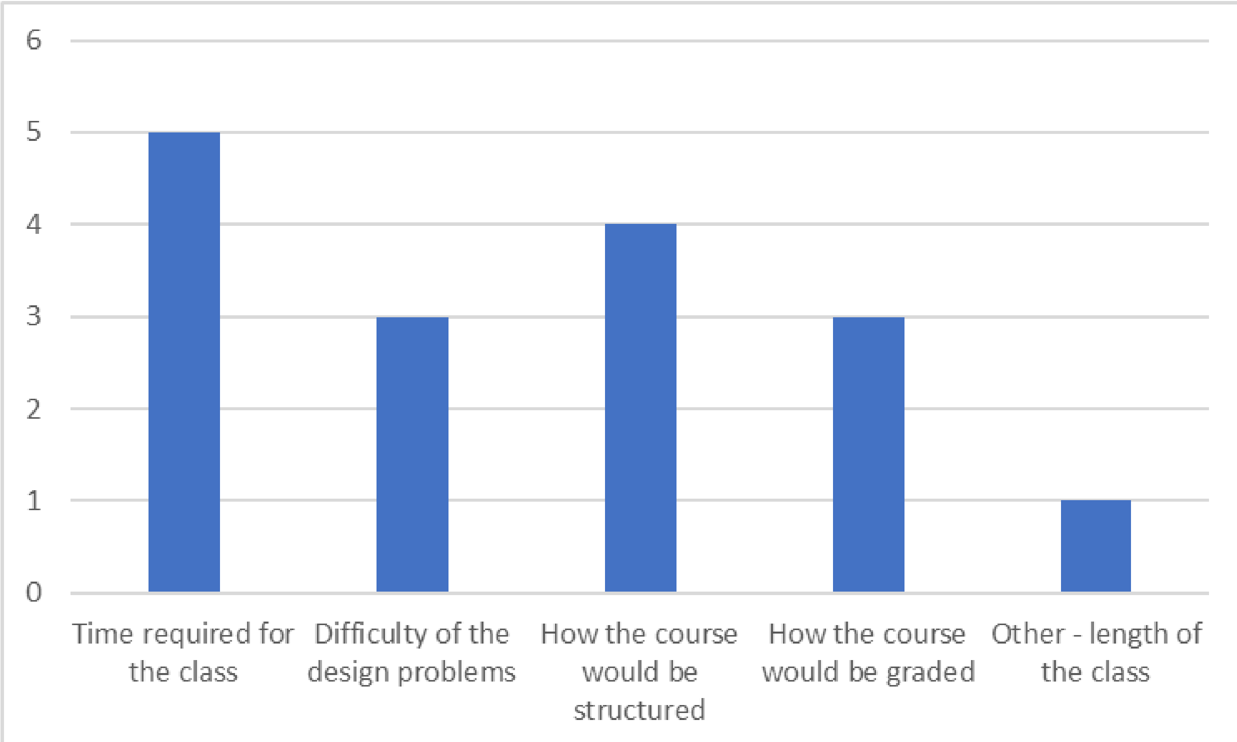

Figure 3: Concerns of Students in Design Team Capstone

comments were all positive, indicating that the students benefited from the capstones based on student design teams. One student indicated that, having taken the capstone several years in the past, they "STILL to this day talk about it in interviews. It was the only class that I've taken now having a masters and going for a PhD that truly challenged me to think On my own as an engineer for the first time. Even my masters thesis I found to be less challenging because of the preparation this class specifically provided." Another student, while they found the capstone valuable, stated that it was hard to see it as more useful than their co-op, "since my co-op experiences involve work that is exactly what engineers do in full time positions." Another student cited the involvement with multidisciplinary teams, and yet another highlighted the access to resources such as other team members who are not in the capstone class and who can assist and give advice.

Of those nine students who said they had not specifically sought out a capstone based on a student competition design team, one of them may have taken the capstone based on the student competition team, judging by one of the reasons they gave for choosing their specific capstone, which referred to a student team. This needs to be noted in any comparisons made. For those nine students, their motivations for choosing the capstone are given in Figure 4.

These students were presented with the same Likert-scale question that was answered by the students in the team-based capstone. Their responses are given in Table 3.

Fewer of these students shared anything else about their capstone, with only four giving additional comments about their capstone. One commented on the difficulties of a one-term

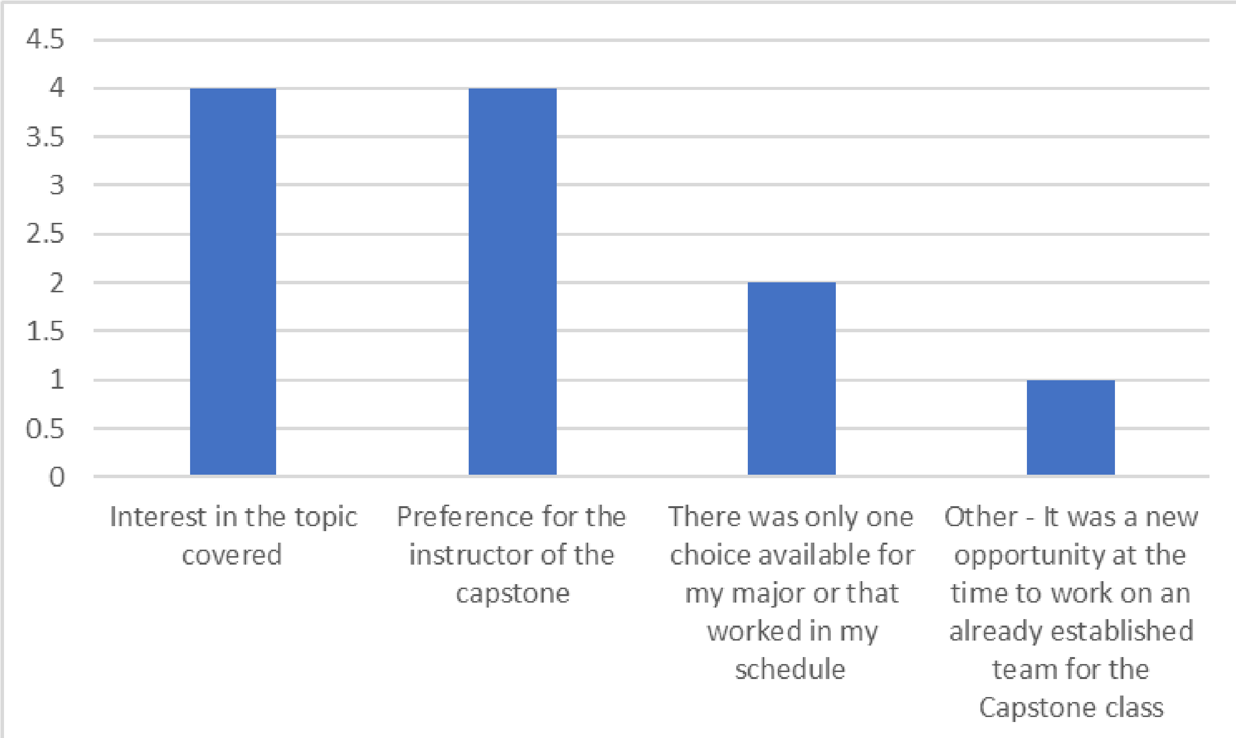

Figure 4: Motivation of Students in General Capstone

Table 3: Student Comparison of General Capstone to Previous Design Experiences

Statement	Average Rating
The capstone was more difficult than previous design experiences.	3.22
The capstone was more interesting than previous design experiences.	3.44
The capstone provided more realistic design experiences.	3.78
The capstone provided better career preparation.	3.67

capstone project, and advocated for a two-term capstone experience. Others commented on the capstone experience preparing them for the professional world, with one stating that "the capstone experience has helped me become more open to having experiences in which there is no clear cut answer and no clear cut direction in solving the design problem."

All students were presented with a final question asking if they had anything they wished to share about capstone or other design experiences. Four of the students included a response to this question. Two students specifically called out their capstone instructor for their contributions to the class, with one stating that "I appreciated the dedication of the professor that she gave to her students & willingness to go above and beyond to extend resources, introduce new concepts, and create a team environment that correlates strongly to the professional world." Another student commented on the self-motivation required for their capstone, which was based on a student competition team. The fourth response focused on design skills gained through the student's co-op job, and listed several practical skills they had learned; they also noted where those skills drew on some of their past courses.

Conclusions and Future Work

In this study, several faculty members who have taught capstone classes analyze the student experiences with capstones, and discuss the benefits of a capstone project focused on a student competition design team with respect to challenge-based learning.

Student comments suggest that a capstone focused on a student competition design team experience is beneficial to students. For instance, all the students who opted for that path spoke positively of it, and in particular one student noted it was effective preparation for graduate school and beyond. The access to additional resources, beyond those in the class, was also a feature that may not be available in a general capstone class. These and other survey responses may be useful to inform broader engineering education practices, including consideration of topic interest, a realistic design experience, and collaboration with industry partners.

There were no clear differences in previous design course experiences between the students who did and who did not seek out a student competition design team capstone, nor were there any clear correspondences with their design experiences in their co-op jobs. The only clear difference is that all the students with previous design team experience chose to seek out a capstone based on that team, while the students who had not previously been on a student design team were split. This is a logical choice, as they had already committed significant time to their team, and a capstone experience focused on it would allow them to better manage the demands of the team along with a capstone class.

While it can be seen that the students who chose the capstone focused on a student design team scored the Likert question more highly for all four items, suggesting that their capstone was a greater step above previous design experiences than a typical capstone, the results are not statistically significant due to the size of the data set. Further work would be required to establish this. The authors are planning to gather more data from upcoming capstone competition design teams and conduct both quantitative and qualitative analysis with a larger sample size.

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Appendix: Survey Questions

Demographic Questions

In this section, some basic demographic questions are asked, primarily concerned with when you took your capstone class and what your major is/was.

- Are you currently an undergraduate student at Kettering University? (yes/no)
- What is or was your major? If you had multiple majors, choose all that apply. (Computer Engineering, Electrical Engineering, Chemical Engineering, Industrial Engineering, Mechanical Engineering, Computer Science, Other)
- What was your class standing at the time you took your Capstone class? (Senior 3, Senior 2, Senior 1, Unsure, Other)

Design Background

In this section, we'd like to know about your previous design experiences aside from capstone classes. By "design experiences", we refer to any class, extracurricular experience, or work activity where you were engaged in the design process in some form.

- What courses did you take prior to your capstone class that you would consider to be "design classes"? (free response question)
- Did you participate in any competition teams at Kettering University that required design work? If yes, please indicate which team(s) in the next question. (yes/no)
- If you answered yes to the previous question, what team(s) did you participate in, and what types of design activities did you conduct? (free response question)
- Did your co-op job(s) involve any design activities? (yes/no)
- If you answered yes to the previous question, please indicate what types of design activities you carried out at your co-op. (free response question)

Capstone Experiences

Now we'd like to know about your capstone experience at Kettering University.

- Did you specifically seek out a capstone class focused on a student team? (yes/no)

If the student answered yes, skip logic took them to the following section:

Capstones focused on student team

- What were some of the reasons why you sought a capstone focused on a student team? (Interest in the topic covered, More realistic design experience, Impact on career readiness, Previous experience with the student team, Preference for the instructor for the capstone, Other)
- Did you have any of the following concerns about the capstone experience? (Time required for the class, Difficulty of the design problems, How the course would be structure, How the course would be graded, Other)
- How did your capstone compare to previous design experiences? Please rate the following statements on a five-point scale, where 5 means the statement is completely true and 1 means it is completely false.
  - The capstone was more difficult than previous design experiences.
  - The capstone was more interesting than previous design experiences.
  - The capstone provided more realistic design experiences.

    - The capstone provided better career preparation.
- Is there anything else you would like to share about your capstone experience? (free response question)

If the student answered no to the question about capstones focused on a student team, skip logic took them to the following section:

General capstone

- What were some of the reasons why you chose your specific capstone? (Interest in the topic covered, Preference for the instructor for the capstone, There was only one choice available for my major or that worked in my schedule, Other)
- How did your capstone compare to previous design experiences? Please rate the following statements on a five-point scale, where 5 means the statement is completely true and 1 means it is completely false.
    - The capstone was more difficult than previous design experiences.
    - The capstone was more interesting than previous design experiences.
    - The capstone provided more realistic design experiences.
    - The capstone provided better career preparation.
- Is there anything else you would like to share about your capstone experience? (free response question)

All students were then directed to the final section

Thank you!

We appreciate your participation in this study. If you have anything else that you'd like to share, you may do so here.

- Would you like to share anything else about your capstone and/or past design experiences? (free response question)