WIP: Enhancing freshman students' design experience through mentorship model

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Work-in-Progress: Enhancing first-year students' design experience through mentorship model

Abstract

This paper presents the various curriculum interventions in a first-year design graphics course through a mentorship model that enhances first-year students' understanding of the design process, emphasizing the importance of end-users and stakeholders. In the ongoing initiative, both cornerstone student teams and capstone design teams work on projects with real-world clients and users to (i) Create an opportunity for other undergraduate students, senior year capstone students, and graduate students to be rewarded for mentoring first-year engineering students, (ii) Develop rubrics for student design competencies (System Design, Implementation, Project Management and Documentation competencies), and (iii) Measure student perception of design over time and design competencies from pre-engineer to professional engineer levels. In order to foster collaborative engagement between first-year and senior students, a structure consisting of open-ended, real-world engineering projects, intervention strategies, and tools are being devised. The intervention and structure are to provide a framework to facilitate purpose and meaningful mentor-mentee interaction. Preliminary results indicate a positive design experience for first-year students with enhanced understanding of the design process, curriculum, and core competencies needed, with over 80% of participants recommending that future students partake in such projects.

Introduction and Literature

The transition from high school to college can be very difficult for many first-year students. First-year engineering students' academic preparedness, their prior knowledge with respect to engineering design, and their existing practices and misconceptions can influence subsequent learning in high enrollment first-year cornerstone design courses. The student perception of design can change as a student moves through the design sequence curriculum with motivational differences between cornerstone and senior year capstone students. First-year students' intellectual development is progressive and senior year capstone students and graduate students can help them develop critical thinking skills, deepen their understanding of the design process, and improve their academic performance. Mentor-mentee interaction also promotes active learning, as first-year students are encouraged to participate in discussions, ask questions, and share their own knowledge and experiences.

Many first-year engineering programs focus on engineering design and design-oriented tasks for engineering students in the early stages of their undergraduate education. How first-year engineering undergraduates approached contextual factors during problem-scoping, a critical part of the design process, was studied by Kilgore et al [1]. Other studies have characterized engineering students' design processes with regard to the breadth of problem-scoping and consideration of the design context. Some research studies uncovered differences in the breadth of problem-scoping exhibited by "novice" student engineers and "expert" designers, who are typically advanced professionals with significant work experience. Christiaans and Dorst [2] found that novices solicited less information and exhibited less extensive problem-scoping, compared with expert designers. Additional studies include analyzing undergraduate student problem-scoping activity across academic levels and engineering disciplines [3] and [4]. These studies found that more seniors than first-year students were able to consider broad aspects of a design problem. Comparing first-year and senior designers, these studies found that seniors gathered more information than first-year students. In a follow-up study, Atman et al. confirmed most of these findings, supporting the expectation that seniors outperform first-years in design [5]. This study also concluded that first-year students' skills have improved over the course of their engineering education, and students may need additional support for progressing into the later steps of the design process.

The increasingly diverse backgrounds and skillsets of incoming students has effectively shifted their abilities to successfully solve engineering problems. In recent years, industry employers have reported a gap in academic vs industry performance standards, attributed to new graduates fulfilling technical skills, but falling short in other attributes of real-world practice. Core design competencies refer to a set of fundamental skills that, if acquired, ensure student success in both academic and industry environments, given that any deficiencies are identified and addressed with interventions early in the design curriculum [6]. Semi-experiential learning is a documented approach to strengthen competency as a practicing engineering, so an integrated program to introduce students to the nuances of design early in their academic careers would be highly beneficial to building core design skills [7].

Peer mentorship can be a very valuable augmentation in engineering education, offering several benefits to both mentors and mentees. It is considered an effective pedagogical approach to enhance student engagement, learning outcomes, and retention in engineering education. Lunsford et al. [8] highlight the benefits of peer mentoring in cultivating a sense of belonging and improving students' confidence in their abilities within STEM disciplines, including first-generation university students. Similarly, Colvin and Ashman [9] discuss the dual benefit of peer mentorship, where both mentors and mentees gain valuable learning experiences through knowledge sharing and reflective practice.

The integration of mentorship into design-based learning courses has been shown to promote deeper understanding of design processes and the role of end-users and stakeholders. Dym et al. [10] underscore the importance of design thinking in engineering curricula and how collaborative activities enhance students' ability to approach complex, open-ended problems. They also highlight the importance of embedding case studies and reverse engineering to promote integrative thinking. Peer mentorship in such courses not only facilitates this learning but also helps in the development of essential soft skills, including communication, teamwork, and leadership. Within the context of engineering education, makerspaces commonly utilize peer mentorship to provide a safe and welcoming environment for novice students, even those from outside of engineering, to develop and practice their design and manufacturing skill [11], [12], [13], [14]. Past research indicates that peer mentorship creates a supportive and inclusive atmosphere for novice learners, encouraging both skill acquisition and personal growth.

Mentorship programs could benefit by employing rubrics and structured frameworks to assess and enhance design competencies, such as system design, implementation, project management, and documentation. Sheppard et al. [15] proposes longitudinal studies as critical to understanding the progression of design skills from novice to professional levels. One of the primary goals of mentorship programs is to improve student retention in engineering tracks, particularly among underrepresented groups. Good et al. [16] and Tinto [17] argue that mentorship interventions contribute significantly to student retention by addressing both academic and social integration challenges. These programs create supportive environments that help mitigate feelings of isolation and foster a sense of purpose. Moreover, researchers like Geller et al. [18] have also documented mentoring benefits through a dual-form mentoring model, which is a blend of near-peer and reverse mentoring within engineering education. This study on curriculum interventions through a mentorship model aligns well with current research trends in peer mentorship for engineering education.

In this paper, descriptions of various interventions in the first-year design graphics course, pre- and post-activity survey results for the first-year cohorts, and post-activity reflections with free text responses toward the end of the semester are presented. This work lays the foundation for a long-term longitudinal study to understand further the impact of mentorship to increase undergrad student retention in design / manufacturing track.

Methodology

The proposed mentorship-model intervention (Figure 1) is currently implemented in a first-year design graphics core course for mechanical and aerospace engineering students offered in all three semesters with multiple sections. Project-based and learning-centered instructional approaches with creative ideation and sketching ([19] and [20]), introduction to CAD tools, basics of design-for-manufacturing and 3D Printing are part of the course content. Each week, two 50 minutes lectures are followed by a 3-hour lab session.

Figure 1. The proposed mentorship-model intervention structure

Basic concepts of the course content are introduced in the lectures with relevant tutorials followed by extended hands-on lab activities in Lab. Students also work on Team projects in the first-year design course. Three to five-member teams collaborate on the ideation, sketching, planning, designing, modeling, assembly and functional animations of proposed large engineering structures. Students divide the overall assembly into a manageable number of subassemblies, and delegate tasks so that each member contributes to parts modeling, assembly, animation, check for functionality, and documentation. As shown in Figure 1, the first-year design graphics course students choose capstone projects with different mentors that include (i) previous-year capstone projects mentored by Graduate Students, (ii) previous-year capstone projects mentored by UG students who took the course in previous semesters and (iii) new and same semester projects mentored by senior capstone teams. Appendix 1 describes mentor recruiting process in the proposed mentoring model.

As illustrated in Figure 1, several in-person meetings are arranged for information exchanges across mentor-mentee teams, aligning with key design phases to enable mentors to guide and teach mentees through their engineering decisions. These meetings, supplemented with online discussion channels, facilitate interactions between mentees and mentors who are matched based on chosen capstone-projects, while serving as a means for progress reports and prototypes from capstone projects to be shared with first-year design students. Senior capstone students submit a series of deliverables that are instrumental in both fulfilling capstone course objectives and encouraging mentorship interactions. Primarily, Capstone students are expected to produce three reports, three presentations, and a final fabrication package. Reports and presentations are opportunities for the Capstone teams to summarize their progress and future work. The reports are similar with slight variations in content to reflect the phases of the design cycles. These reports and presentations are critical in the progression of a Capstone team, but they also provide a unique opportunity for mentees to see engineering problem-solving happening in real-time. By exposing first-year students to Capstone presentations, they receive a stronger foundational knowledge of design tools and processes. Along with the reports, there are also peer evaluations submitted by sponsors and Capstone team members. Capstone team members can implement this anonymous feedback throughout the semester to improve their teamwork and cohesion. In addition, Capstone students must prepare a final fabrication package, detailing their proposed solution. The fabrication package is the official final deliverable for the course that includes all technical drawings, a bill of materials, and manufacturing instructions. It serves as a summary of all design work and details of implementation. At the end of the semester, senior students get to showcase their projects and compete for cash prizes at the Capstone Design Expo. Although participation in Expo is optional, many students enjoy the opportunity to demonstrate their prototypes and present their designs. First-year student mentees are invited to attend Expo, which serves to learn about and build anticipation for the Capstone design course. The Capstone course is designed to give students autonomy and encourage intelligent decision-making with meaningful progress monitoring throughout the semester. Mentoring first-year students provides an opportunity for senior students to be rewarded for learning and teaching their peers– developing the confidence, skills, and knowledge they need to become influential design leaders in the industry.

Assessment:

As part of assessment in Fall 2024, pre- and post-activity surveys and an end-of-semester, one-page reflection on team projects were implemented. A long-term objective of this mentorship framework would be to create a full-circle opportunity by sowing the seeds of design competencies as first-year mentees and then actively refining these competencies as senior mentors. Pre- and post-activity prompts were formulated to assess student background, draw student awareness to the progression of their capabilities, and document the impact on core competencies due to curricular intervention strategies. Appendix 2 outlines the questions presented to students via the assessment tools. For thematic analysis of open-ended questions, a best-fit coding framework was employed using a generic, a priori structure deductively, further supplemented with context-specific insights inductively.

Positionality:

Two faculty researchers in this work have several decades of experience teaching computer graphics, engineering design, manufacturing, and mechanics courses spanning across undergraduate and graduate levels. They have considerable familiarity with teaching methodology for engineering students, which informs their observations in the academic settings.

Results and Discussion

Of the first years participating in the mentorship program, 114 pre- and 108 post-activity responses were collected, indicating a survey retention rate of 85%. In general, student responses indicated considerable academic growth and professional benefits acquired through mentor-mentee interaction. The section below delves into nuances of the program's impact on student learning, based on post-activity responses.

<u>Post-survey results</u>

Perception on peer-mentorship program - The vast majority (80%) of respondents in Figure 2 recommended future students to work on capstone (senior-level) projects as first years, with 67% of students crediting program to be effective in helping achieve their personal learning goals, therefore indicating that the program was very well-received.

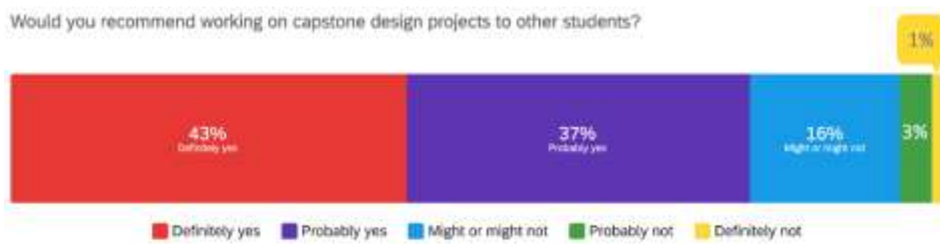

Figure 2. Reception of peer-mentorship program

Interest in pursuing design & manufacturing track - 73% of students indicated an increased interest in pursuing a design & manufacturing track as shown in Figure 3, suggesting that this program may be useful to improve retention in said track.

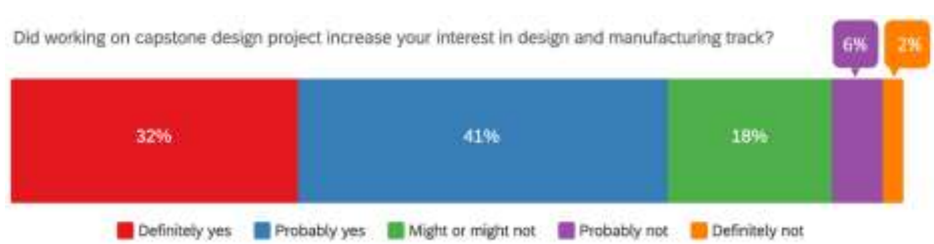

Figure 3. Impact on interest in pursuing a design and manufacture track

Understanding of engineering design process due to capstone projects and interaction - When asked about the engineering design process, over 80% of students reported changes in their perceptions of design by virtue of working on capstone projects (Figure 4), with 57% indicating a refined understanding (Figure 5).

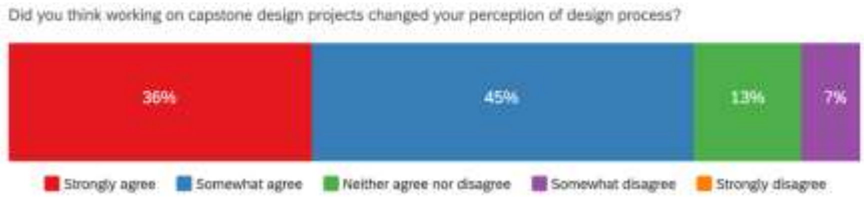

Figure 4. Impact on student perception of the engineering design process

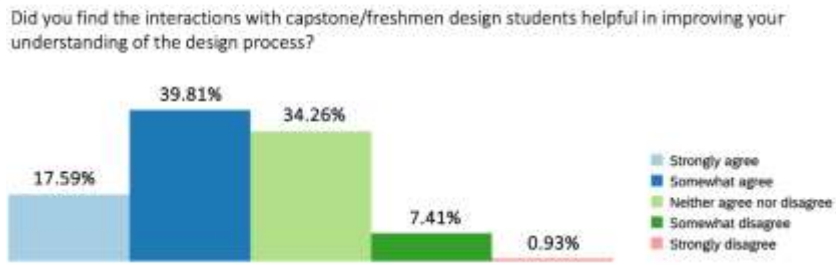

Figure 5. Degree of efficacy in understanding the engineering design process

Understanding of curriculum - Similarly, 81% of respondents gained clarity on the overarching undergraduate curriculum through exposure to semi-experiential projects with real-world applications (Figure 6). This shift and deepening of comprehension further supports the belief that exposure to the nuances of engineering early-on can strengthen core competency foundation.

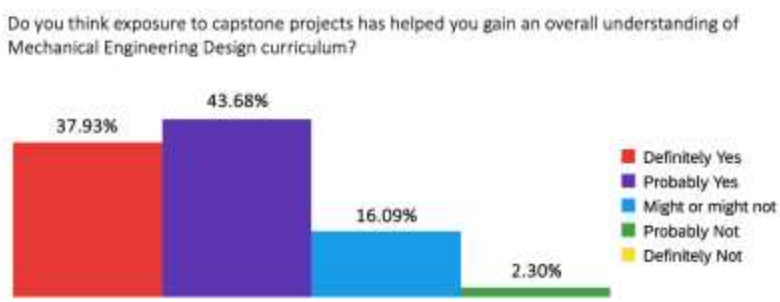

Figure 6. Ability of mentorship program to contextualize overall design curriculum

Level of comfort working with seniors - Regarding students' interaction with their mentors, the majority of students felt comfortable working with seniors, though 39% indicated feeling neutral suggesting a relatively more formal and less familiar mentor-mentee relationship (Figure 7).

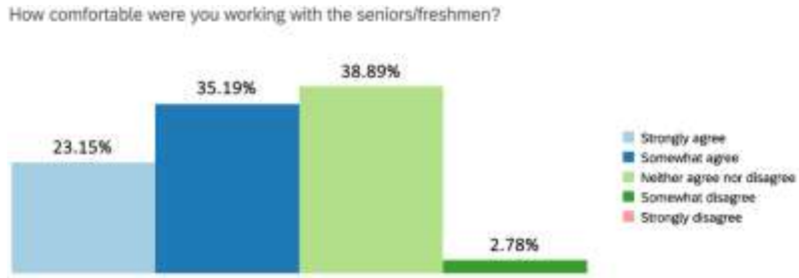

Figure 7. First years' level of comfort working with senior mentors.

Based on the pre- and post-activity responses, students demonstrated discernable progression across their experiences, perceptions, and capabilities. To gauge student background as a baseline prior to intervention, surveyors were requested to specify challenges they have faced in team-based project environments, with results illustrated in Figure 8. Responses highlighted a number of difficulties, including communication issues, working collaboratively, and disengagement, with just 2.5% of students reporting "no challenges faced." In contrast, the post-survey reflections regarding core competencies reported immense growth in both technical and professional skills such as communication, multidisciplinary teamwork, and problem-solving abilities gained after intervention, indicative of a notable evolution in student attitude and perception.

Figure 8. Word Cloud of challenges faced previously when working in a group setting.

Reflection on core competencies - As depicted in the word cloud in Figure 9, students developed a range of key design competencies, particularly to do with communication, multidisciplinary collaboration, and systematic design.

Figure 9. Core competencies acquired or refined through program participation.

<u>Students' reflections on team projects</u>

The following excerpts of student reflections convey how interaction with mentors helped better inform first-years of systematic engineering design and fortify their learning.

"The second report made available to us gave us new and valuable information about the types of scooters that would be used in this charging station… Additionally, we got to see the function tree that the team made when designing their scooters…It was clear that their thought process was a lot more focused and purposeful than ours, and the function tree proved useful when making choices between different elements we wanted to incorporate in the design as we were able to see what the Capstone team prioritized."

"The correspondence with capstone students during this project was extremely beneficial in aiding the progress and development of our project. The Cornerstone to Capstone collaboration allowed us to not only get feedback on our ideas, but also interact with other capstone students to learn about their design journey. These interactions were beneficial in not only supporting our success both in this class and as future engineers."

<u>Concluding Remarks</u>

The ongoing analysis of pre- and post-activity responses and students' reflections serve as the metrics to assess curricular intervention impact. Going forward, it is worth modifying prompts on both surveys to pair directly, for more quantifiable metrics for students understanding of design curriculum, enhancement of design experience, and understanding of engineering design competencies. Additionally, presenting surveys both to teams participating in the mentorship program and teams participating in the standard course delivery (no interventions) would provide more insight on the effect of interventions with a control group.

Appendix 1: Recruiting mentors

Recruiting senior level undergraduate and graduate students is key to the mentorship program. If no students are invested in participating in the program as a mentor, then the program cannot happen. The two main challenges to recruiting mentors for the program are

1. Students at the senior level are too busy to participate in another extra-curricular activity.

2. Students do not feel rewarded for their time.

To solve these challenges, we made sure that the program did not require a large amount of effort from the mentor's side. Keeping the program candid and casual ensures that students as both mentors and mentees feel more like they are merely having lunch and chatting with friends. This is ideal for mentorship either way, as mentees should feel able to speak truthfully and fully to their mentors.

To reward students for their time, the Certified Engineering Mentor for Cornerstone to Capstone (CEMC2) certification was created. This certification is given to students who act as mentors in the program, which they can put on their resumes to attract potential employers. This also ensures that the mentor students have a contact for potential employers to reach out to through the faculty facilitating the program. Students will also receive the most enticing reward for a college student, free lunch at each of the meetings.

Originally the CEMC2 certification was only available to undergraduate students, but the team has since decided to expand to graduate students. This increases the pool of potential mentors for the program. Graduate students also may be more likely to want the certification, as they will be more likely to be moving into management positions in the future.

Woodruff Connect is a comprehensive engagement platform recently developed in our school for student engagement with specialized tools for promoting student involvement and tracking of co-curricular activities. Co-curricular activities are any important student engagements at the Woodruff School that are outside of the formal classroom environment and promote career readiness. The proposed mentorship model also uses this platform to recruit mentors and facilitating mentor-mentee interactions.

Figure A1 above shows the user interface for the platform which allows the Woodruff School to facilitate and incentivize initiatives in the co-curricular space. Platform content is structured using an inclusive excellence framework with five key areas that lead to professional development for mechanical engineering students. These areas are:

1. Innovation: Creativity and design to help others
2. Impact: Leadership and community service
3. Interaction: Networking and communication
4. Insight: Analysis and advocacy in support of others
5. Intentionality: Personal and professional well-being

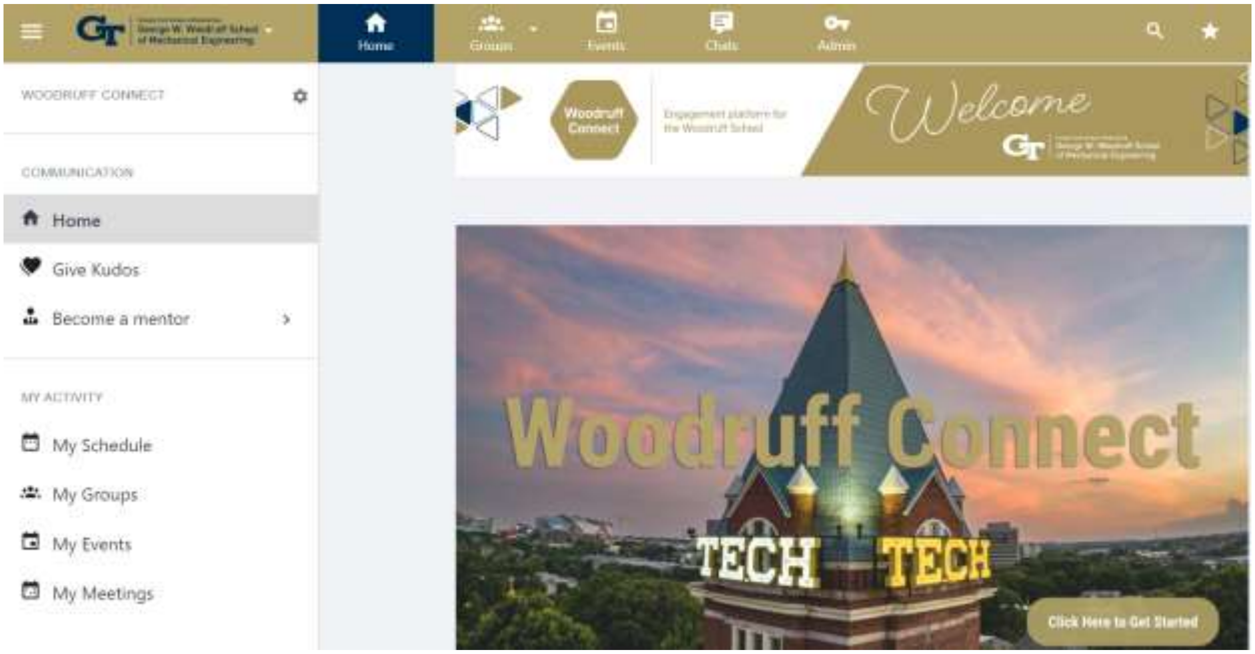

Figure A1: Woodruff Connect student engagement platform

The platform is being used for the Cornerstone to Capstone initiative in the areas to promote Interaction and Innovation. Opportunities for Cornerstone and Capstone students to connect are hosted on the platform with the ability to track student participation and promote student activity using the event hosting tool. In addition, participation in Cornerstone to Capstone events can be incentivized through the platform using its tracks and checklists feature which tracks participation using 10 criteria. Once students complete all ten criteria (see Figure A2 below) they receive an electronic badge commemorating the achievement and a certification in peer to peer mentoring.

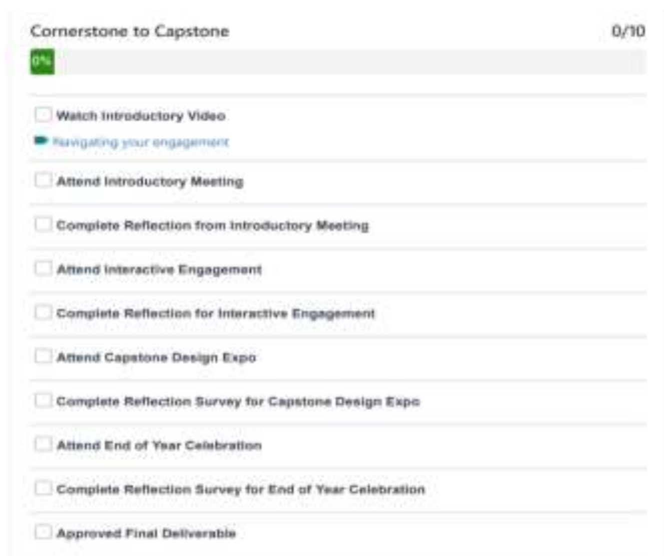

Figure A2: Cornerstone to Capstone student activity checklist

Appendix 2: Assessment Tools

To measure student progress, pre- and post-surveys were implemented, in addition to an end-of-semester reflection. Within the surveys, most questions use Likert scaling to quantify student experiences with a neutral option provided to allow students to accurately indicate an impartial view, without bias or pressure to select a side inconsistent with their feelings. The prompts presented to students in these assessment tools are outlined below.

Pre-Survey Questions

1. I am from Team…
    a. ME 1670
    b. ME 4182 / ME 4723
2. What is your project title?
3. How well do you understand the value of being a mentor to someone? (Likert)
4. How well do you understand the value of being a mentee, being mentored by someone? (Likert)
5. Rank order your primary learning goals for the team project.
    - CAD
    - Real-world design process
    - Team collaboration
    - Technical communication
    - Engineering analysis
6. How comfortable are you with working in pairs or small groups? (Likert)
7. What challenges, if any, have you faced working in a team environment in the past?
8. Rank order your preferred learning styles.
    - Visual
    - Auditory
    - Kinesthetic (manipulate or touch material to learn)
    - Reading/writing
9. Have you participated in peer-assisted learning before? If so, what was your experience like?
10. What concerns or reservations do you have about participating in a peer-assisted learning program?

11. What do you expect to gain from interacting with capstone/freshman design students?

12. (For first-years only) How well do you understand the role of collaboration in the design process? (Likert)

13. (For seniors only) How confident do you feel about your ability to explain the subject matter to others? (Likert)

Post-Survey Questions

1. I am from…

    a. ME 1670
    b. ME 4182 / ME 4723

2. Did you find the interactions with capstone/first-year design students helpful in improving your understanding of the design process? (Likert)

3. How comfortable were you working with the seniors/first-years? (Likert)

4. What questions did you ask your mentors/mentees?

5. Was the program effective in helping you achieve your learning goals? (Likert)

6. Which core design competencies have you gained or improved by participating in this program? Select all that apply.

7. Do you have any suggestions for the structure provided in the interactions with the capstone/first-year design teams?

For first-years only

8. Did working on capstone design project increase your interest in design and manufacturing track? (Likert)

9. Do you think working on capstone design projects changed your perception of design process? (Likert)

10. Do you think exposure to capstone projects has helped you gain an overall understanding of Mechanical Engineering design curriculum? (Likert)

11. Would you recommend working on capstone design projects to other students? (Likert)

12. What challenges, if any, have you faced in working with your team in 1670 team project?

13. Did working on Capstone Design Project meet your initial expectations? Please explain.

14. Did you attend Capstone Expo ?

For seniors only

15. Did you feel resourceful and helpful to first year design students? (Likert)

16. Did you feel like you improved any leadership or communication skills when engaging with first-year design students? (Likert)

17. Would you recommend peer-mentorship experience with first-year design teams to other students? (Likert)

Reflection Prompt:

A one-page reflection note on design changes your team made, based on available senior student reports (only team leader submits). Please write the project title and team member names in the one-page reflection.

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