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Peer Mentorship Model to Enhance Design Engineering Education

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Abstract
This Work-In-Progress (WIP) paper presents the design, implementation, and preliminary impact of a simultaneous curricular intervention in first-year design and senior capstone design courses at an undergraduate Mechanical Engineering program. The two primary objectives of this intervention were to i. Enhance students' understanding of the design process, emphasizing the importance of end-users and stakeholders, and ii. To create an opportunity for students to be rewarded for learning and teaching their peers. This study lays the foundation for a long-term longitudinal study to understand further the impact of peer mentorship and socio-technical projects from freshman to senior years. The paper will present the benefits and challenges associated with engaging seniors and first-year students while solving an authentic design challenge through surveys and focus groups. These results will help develop the framework to build vertical integration within the curriculum for effectively teaching engineering design.

Introduction

Background

Peer mentorship is a learning model that allows students to learn from one another in a collaborative and supportive environment [1]. The model involves assigning more experienced students as mentors to less experienced students. The mentor serves as a guide and resource, helping the mentee to navigate the complexities of the design engineering process. There is documented literature pointing to numerous benefits of mentorship to both the mentor and the mentee. Extensive literature points to the benefits of leveraging peer mentorship as a complementary instructional method. However, some significant challenges to running a peer mentorship model are navigating through the time commitment and little motivation of undergraduate students willing to serve as mentors and mentees. Hence, the authors propose a simultaneous curricular intervention by utilizing existing required courses within the curriculum to aid in creating a peer mentoring program.

Our School's mechanical engineering undergraduate curriculum comprises a sequence of courses in which students gain hands-on skills and experiences in engineering design. Typically, this sequence begins with an introduction to computer graphics/modeling at the cornerstone level and culminates in a senior capstone design course. Both courses require students to work on a team-based project, albeit with different scopes and learning objectives. Given the similar semester timelines for the projects, the systems provide a unique opportunity to engage first-year students and seniors in a peer mentorship program without adding significant time commitment to either of the cohorts.

This Work-In-Progress (WIP) paper presents an approach that the engineering design faculty for first-year design and senior capstone design courses took to engage their respective students with each other in a structured peer-mentorship program.

Research Questions

Literature suggests numerous benefits and challenges of peer mentorship in higher education. However, barring a few exceptions, most of the published literature presents case studies of a particular mentorship program created outside the course curriculum. Given the unique characteristics of the proposed peer mentorship program, we set out to understand the efficacy of the program through the following research questions:

1. What are first-year engineering students' perceptions about peer mentorship to foster their ideation and understanding of design as a part of the conceptual design process?
2. What are senior engineering students' perceptions about peer mentorship to enhance their understanding of the design process and design leadership?
3. What benefits and challenges are associated with engaging cornerstone and capstone design teams in solving authentic design problems through peer mentorship?

Approach

In order to address the research questions, a literature review was conducted to identify the latest guidelines and framework for building a peer mentorship model. The authors engaged with faculty and staff affiliated with the cornerstone and capstone design courses within their schools to seed a pilot project and create a framework for peer mentorship. It is worth noting that the term "peer-mentorship" in this case refers to all students as peers and does not imply students enrolled in the same course at the same level. The approach taken in this work more closely builds upon the work done by Gunn [2]. He presented a course for first-year level students where a pair is partnered with a senior in a capstone design class to see the practical uses of what they will learn and are learning and get some exposure to design early in their academic career.

Literature Review

Undergrads teaching other undergrads

Undergraduates teaching other undergraduates [3] is one of the most effective methods for achieving undergraduate education's cognitive and attitudinal goals. Undergraduate student intellectual development is progressive [4]. Undergrads teaching other undergrads allows students to collaborate and learn from one another, which can help them develop critical thinking skills, deepen their understanding of the subject matter, and improve their academic performance. It also promotes active learning, as students are encouraged to participate in discussions, ask questions, and share their own knowledge and experiences. Peer teaching can positively affect both capstone student teachers and cornerstone student learners. The capstone students can improve their communication skills, gain confidence, and develop leadership skills, while the cornerstone students can benefit from receiving personalized attention and support from their peers. Peer mentorship can also promote design leadership among senior students with student-led projects, encourage collaboration and teamwork, provide mentorship and guidance, and offer opportunities for students to present their work and receive feedback. This can help senior students develop the confidence, skills, and knowledge they need to become influential design leaders. Design leadership [5] is crucial for preparing students for their future careers. In the professional world, designers are expected to take leadership roles on projects and work collaboratively with clients, stakeholders, and team members. By developing leadership skills in School, students are better equipped to succeed in their careers and make meaningful contributions to the design industry.

Freeman et al. [6] looked at the improvements made to a cornerstone class after implementing different things due to students having more design experience and hands-on experience than previous students. Whalen et al. [7] looked at how the restructuring of the cornerstone course has affected the perspectives and achievements of students taking them and ways to make the course more successful. These past publications point to several significant benefits of peer mentorship within the context of design engineering education. Students learn from their peers who have more experience and knowledge. By working with more experienced peers, students can gain exposure to different approaches, perspectives, and techniques, improving their problem-solving and critical-thinking skills. Peer mentorship provides an opportunity for students to develop leadership and communication skills. As mentors, students must communicate complex ideas clearly and concisely, and they must be able to motivate and encourage their mentees. These are essential skills for any engineer, and peer mentorship providesallowss to develop them in a supportive environment. Peer mentorship fosters a sense of community and collaboration among students. In design engineering, teamwork is critical, and peer mentorship provides an opportuniallowsw to work effectively in teams. The mentor-mentee relationship also provides a sense of accountability, encouraging students to take ownership of their learning and development.

2.2 Prior work in student peer-mentorship program

It is worth noting that numerous researchers have explored various methods to implement peer mentorship within the engineering curriculum. Corbett et al. [8] presented a WIP paper on developing a student-led peer mentorship model. Hochstein et al. [9] looked at a senior capstone course in fluid thermal systems where the seniors are awarded the project and then assigned a group of first-year students in an intro class to work with. The seniors then act as consultants to the first-year students. Harwood et al. [10] looked at how involving senior-level students in a first-year FEA class helps the first-year students learn more complex engineering concepts they have not been introduced to yet and allows the seniors to work on their leadership skills. Butterfield et al. [11] looked at a chemical engineering course where first-year students apply to different senior capstone projects. The seniors then decide which to accept and work with the teams for three weeks to develop a lab product. All these prior work points to substantial opportunities in connecting first-year students with seniors with a broad spectrum of benefits. The proposed mentorship program extends this past work with an intentional approach to reduce the amount of time commitment and additional workload necessary for participating students and the supporting instructional team.

1. Program Implementation

3.1 First-year design course

Introduction to Engineering Graphics is a freshman-engineering course in many universities. When our university converted from quarter to semester curricula in 1999, the college of engineering created a three-credit hour introductory engineering graphics course for first-year students. This core course for mechanical, civil and aerospace engineering students is offered in each Fall and Spring semesters with two to four instructors teaching nine to ten sections. All students in this course learn (i) creative design ideation (ii) formal sketching techniques and orthographic projections (iii) CAD tools and (iv) basics of design-for-manufacturing and 3D Printing. Students typically chose coffee mugs for their individual projects, airplanes and other engineering structures for their team projects in the absence of any interventions. In recent years the "socio-technical project-based learning with context" teaching-learning model [5] is implemented in the first-year course with individual projects that address human wasteful behavior of resources and environmental sustainability in product designs and team projects with contextualized design problems that address social, environmental and economic sustainability aspects in designing large engineering structures.

3.2 Capstone Design Course

Almost all ABET-accredited undergraduate engineering programs require a Senior Capstone Design course for senior undergraduates to synthesize practical solutions for real-world, open-ended design problems. All students in this course within our School can form their teams and elect to work on industry-sponsored projects, entrepreneurial projects, or projects from local communities, organizations, etc. Teamwork is critical to the success of the projects. So a dedicated custom software solution was built to allow students to optimize common project interests and complementary skills as proposed in previous literature [12], [13]. The entire course is split into three five-week sprints with an interim report and presentation requirement at the end of each sprint. Students are required to meet with their faculty instructor once weekly as a team and make interim report presentations to their faculty, and their peers enrolled in the Capstone Design class at every five weeks. The course requires students to conduct an in-depth analysis of stakeholder needs, generate detailed engineering specifications, and utilize the Quality Function Deployment tool to identify interactions between needs and engineering requirements. Since the objective of the peer mentorship program was to offer exposure to an application-based engineering project for first-year students, the authors picked an industry-sponsored socio-technical project for which the most crucial stakeholder was the end-consumer from a different socio-cultural context. The details of the specific project and the sponsor are in Appendix.

3.3 First-year design project interventions

The workflow for the first-year design course team project, as shown in Figure 1, follows ideation, sketching, CAD (parts and assembly) and functional animations of proposed engineering structure. The interaction between students and instructor in the course occurs intermittently, primarily through critical benchmarks for design review and feedback. The course structure has three built-in design review blocks, to evaluate the design progress of the engineering structure sketches, part models, and final CAD assembly with feedback. The student-instructor exchange during these review stages generally consists of a brief assessment of the project status, followed by verbal or written feedback from the instructor to guide modifications or improvements in the design. From this intervention, students are expected to revisit their design and implement changes before moving forward, as per the best practices of the engineering design process. Though the workflow structure of the project does enable some degree of intervention from the course instructors, this interaction is solely focused on providing students with guidance and direction regarding the technical aspects of the course related to graphics and visualization. As a result, instructor feedback is typically confined to the realm of CAD design principles and limited comments on engineering design process, real-world implications, or engineering feasibility of the design. As part of this research using the peer mentorship model, four mentoring interactions with capstone design teams are introduced, as shown in Figure 1.

In order to foster collaborative engagement between first-year and fourth-year students throughout an open-ended, real-world engineering project, a handful of intervention strategies and tools have been devised. The critical objectives of the intervention techniques are to provide a framework to facilitate mentor-mentee interaction and to encourage meaningful interactivity between the involved parties. Providing some structure aims to motivate active involvement, learning, and leading among students, as opposed to passive observation. To understand and appreciate the students' perceptions of peer mentorship for engineering education, survey instruments will prompt student responses and reflections. These survey tools are curated with questions and prompt to guide mentors and mentees for an effective and enriching interactive experience while drawing awareness to the nuances of the peer-assisted learning experience that may be easily overlooked. To further provide opportunities for student interactions, the respective first and fourth-year student design teams are scheduled to meet periodically, participate in faculty advisor meetings together, attend and observe presentations, and touch base ahead of major project benchmarks. During these interactions, students are also provided with prompting statements and questions to ensure their active engagement and participation.

The big-picture goal of this peer-assisted learning initiative is two-fold, 1) to provide first-year students with a sense of excitement for what their future curriculum has to offer while contextualizing the reality of an application-based engineering project, and 2) to allow senior students the opportunity to gain and refine their leadership skills and abilities while reinforcing fundamental engineering principles.

Figure 1 below maps the engagement between the first-year design and senior design teams, as assisted by the intervention framework. This figure highlights the general individual timelines of the first-year design and senior design courses, respectively, but also highlights four overlapping mentor-mentee interactions and their intended takeaways. In each of the meetings, it is expected that there will be an exchange of knowledge in which the first-year team gains exposure to higher-level technical engineering design content while the senior team develops and strengthens their leadership and mentorship capabilities through first-hand interactions. To an extent, senior students may also gain some teaching abilities as they navigate the best manner to convey complex engineering ideas to students with limited exposure to technical engineering material. Additionally, senior teams are also anticipated to be reminded of fundamental engineering design principles, such as practical techniques for creative ideation and the best practices for computer-aided design and visualization. These skills are thoroughly instilled and reinforced in first-year students, so the interaction may serve as a refresher of best modeling practices for senior students.

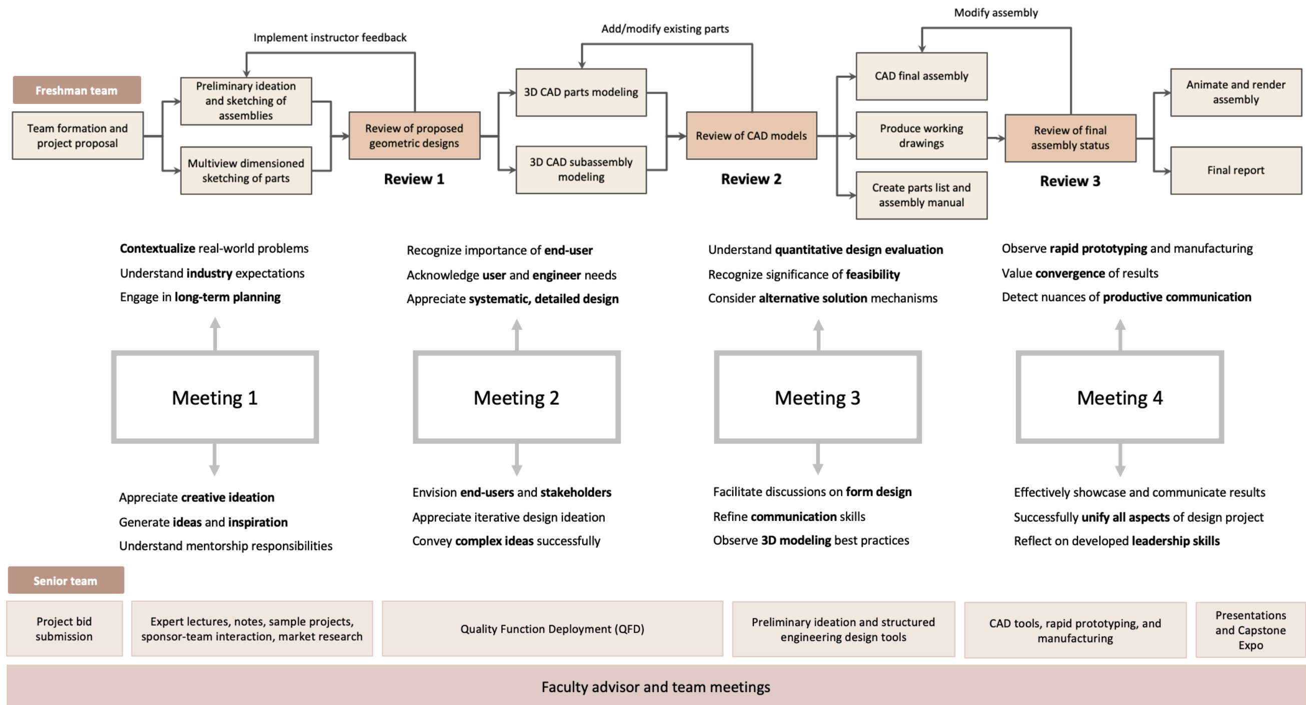

Figure 1. Mapping of first-year and senior student engagement and interaction

Structure with dos and don'ts for the peer interactions:

- Participating fully (in spirit and actuality)
- Participating professionally (i.e., civil discourse; abiding by the rules of academic honesty)
- Meeting responsibilities (i.e., completing assigned tasks on time and to the best of your ability)
- Accepting the consequences of not abiding by the team's rules
- Giving team members appropriate credit where it is due
- Not giving credit where it isn't due
- Each team member agrees to show up to all team meetings on time.
- Members agree to treat one another with respect. Respect includes no name-calling. If you don't like an idea, address the idea, not the person (for example, "I don't think that idea will work because…" not "That's stupid").
- No "cross talking" is allowed. This means not interrupting when someone else is talking.

The instructors will also provide the scope of the items and talking points for discussion in each meeting to the cornerstone and capstone teams.

2. Assessment Tools

Various assessment tools are planned to assess the research questions and to help improve the implementation of the peer mentorship model for future semesters. Specifically, a pre and post-activity survey was designed, and some of the questions are listed in the Appendix for both the first-year design and senior design cohorts. The questions (in Appendix B and C) were designed

based on a study from previous literature [2], [14]. A post-activity reflection with free text responses will also be conducted toward the end of the semester. Finally, the program staff will conduct focus group interviews after the end of the semester and grading to collect ad hoc responses, specifically to learn about any tangible and intangible benefits and challenges not documented through survey assessments.
In order to understand/assess the real-time effect of peer interactions, an anonymous guided reflection activity following each interaction is planned. Please see Appendix D for student reflection from the first reflection activity. The primary objective of this reflection activity was to understand the First-year design students' perspective on the value of these interactions on their learning and design changes. As shown in the Appendix, the first-year design students shared various responses highlighting the benefits they gained personally. For the senior capstone design students, our objective from the reflection activity was to understand their perspective on their mentees' progress since their last interaction and their benefits from the mentorship program. The benefits for senior-design students were not clearly evident from this first reflection activity, and we plan to have three more scheduled interactions between the student teams before the end of the semester.

3. Ongoing Work and Expected Results

The peer mentorship model described in the paper was started in the current Spring 2023 semester, and results from the assessment tools used will be compiled for presentation at a later stage. Ten students from the first-year design class and six from the capstone design were working on the same overall design problem – with different scopes and learning objectives. Both faculty co-authors of this paper plan to teach the courses in Summer 2023 and will continue this classroom research based on the preliminary results and feedback obtained from the current semester. One of the apparent benefits of the pilot program was that faculty from the cornerstone and capstone design got together to review the two courses, their structure, syllabus, and student learning outcomes. This experience helped faculty on two extremes of the undergraduate curriculum tenure to better understand challenges and opportunities to engage their students.

While peer mentorship is a valuable model for enhancing engineering education, implementing it across different courses within the engineering curriculum can present several challenges. Implementing a peer mentorship model in design engineering education requires careful planning and execution. Some of the challenges the team has faced so far include:

- Time constraints: Engineering courses can be demanding, with significant course loads and tight deadlines. Mentors, who were seniors in this case study, had limited time to dedicate to mentoring, especially since they were taking other demanding courses and preparing for life beyond graduation.
- Limited participation: Peer mentorship programs rely on student participation, and it was challenging to recruit enough mentors and mentees for the pilot program. Several students were not interested in participating out of fear of the additional time commitment while others were unaware of the program or its benefits. Due to this, the review-1 meeting could not be organized for the Spring 2023 semester. The program implementation team plans to rerun the model in Summer 2023 semester.

- Diverse backgrounds and skill levels: Engineering courses can have students with diverse backgrounds and skill levels, making it challenging to match mentors and mentees effectively. The approach undertaken by the authors was only to consider the common project interests of students. Students may also have different learning styles and preferences, making it challenging for mentors to tailor their approach to each mentee.
- Lack of support and resources: Peer mentorship programs require resources and support to be effective. This can include training for mentors, resources for communication and collaboration, and guidance from faculty and staff. Without these resources, peer mentorship programs may be unable to achieve their goals.

Beyond the above challenges with implementing a peer mentorship program, one of the lingering questions is about long-term sustainability. Senior students, as mentors, graduate and move on to other opportunities, leaving mentees without a support system. Additionally, without an explicit institutional support plan for sustainability, the program may not continue if the faculty and staff are assigned other duties in future semesters. However, with clearly defined interaction points and assessment, the mentorship model described would likely need minimal administrative support for long-term sustainability.

4. Acknowledgments

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6. APPENDIX

Appendix A: The design project brief for the pilot peer-mentorship program

- **Project Title**: Develop a low-cost cocoa butter press to extract cocoa butter from cocoa beans
- **Company name:** Inno Concepts Inc. dba CocoaTown.com
- **Background/Problem/Need**: At CocoaTown, we create and empower Chocopreneurs (entrepreneurs in the chocolate industry) around the world through patented equipment that we design, develop, manufacture and market, and through education. Our mission is "Pioneering Craft Chocolate Technology" Our Vision is "To create and empower chocopreneurs through technologically advanced Equipment, Education, and international Exposure". We have a complete line of machines to make bean to bar. But cocoa farmers in origin countries want to extract cocoa butter and sell the cocoa powder for drinks and cocoa powder for other preparations. For the businesses in the cocoa beans growing countries, making & selling cocoa drink mix similar to hot chocolate mixes sold in the USA will generate more sales than selling as a chocolate bar. The frequency of consumption is higher for chocolate powder. They also use it in their bread and other preparations. Currently existing commercial scale cocoa butter presses are huge, expensive and not efficient. Currently there are 3 methods are used: Screw extruder, Cylinder/Piston design, Expeller with Filter pack.
- **Concept**: The purpose of this project is to design and validate… - A low-cost cocoa butter press that is easy to operate and maintain. It should use less energy as the cost of electricity is higher in cocoa growing origin countries or they are off the power grid completely. They should also be scalable.
- **Design Constraints/Requirements/Specifications (if known):** The output for the cocoa butter should be around 5-10 lbs/hour. Should be Compact and energy efficient. If it can be used with solar power, it will be an added value to the buyers.
- **Anticipated future of the project beyond the Design Project**: To manufacture and sell these cocoa butter presses in both small size and large size.

Appendix B: Pre-survey questions

1. What are your preferred learning styles?
2. Did you participate in peer-assisted learning before? If so, what was your experience like?
3. What is your current level of understanding of collaboration in the design process?
4. What are your primary learning goals for the team project?
5. How comfortable are you with working in pairs or small groups?
6. What challenges have you faced in learning this subject matter in the past?
7. How do you feel about your ability to explain the subject matter to others?
8. Do you feel comfortable asking questions and seeking help from peers?
9. How do you think peer-assisted learning can help you achieve your learning goals?
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?

Appendix C: Post-survey questions

1. Did you find the interactions with capstone/freshman design students helpful in improving your understanding of the design process?
2. How comfortable were you working with the seniors/freshman?
3. Did you actively engage in the learning process? What questions did you ask to your mentors/mentees?
4. Was the peer-assisted learning approach effective in helping you achieve your learning goals?
5. How did peer-assisted learning compare to other learning approaches you have used?
6. Do you have any suggestions for the structure provided in the interactions with the capstone/freshman design teams?
7. For Freshman Design only
    1. Would you recommend peer-assisted learning with capstone design teams to other students?
    2. Did you feel supported by capstone teams during the sessions?
    3. Did the capstone design team provide clear explanations and feedback?
8. For Capstone Design only
    1. Would you recommend peer-mentorship experience with freshman design teams to other students?
    2. Did you feel resourceful and helpful to freshman design students?
    3. Did you feel like you improved any leadership or communication skills when engaging with freshman design students?

Appendix D: Peer-mentorship Guided Reflection Activity. Responses submitted by participating students in Spring 2023 semester to prompts

From First Year Design

1. What design changes are you considering after the meeting with capstone design students?
    - Making the parts more complex
    - Making sure they all work together well.
    - Design for machining and assembly for the future
    - Fillet parts to add safety
    - Make part interactions more realistic

2. Do you see any value in these interactions and do you expect any impact on the final quality of your end deliverable/product?
    - Yes, its always good to get input and advice from older students
    - Yes, there is a lot of value is these meetings because we learn about how our project looks like on a more advanced level and we get useful feedback to improve on our original designs.

From Senior Capstone Design

1. What did you think of the mentees' progress so far and what additional suggestions you have for them?
    - The group of 4 had made some great progress but were having some issues integrating things together. Additionally, it seemed that they had some issues with communicating dimensions, leading to ill fitment of parts. Overall, I think some more design review and communication would help, and I can't wait to see their final presentation.
    - The group we spoke to seems to have many parts designed and a solid understanding of CAD, but they seem to be lacking in an overall plan for their design. I would suggest that they spend some time making a full sketch and refine their vision for what their project looks like put together.
    - Quite a few of the parts were not feasible to manufacture. But for the purposes of ME 1670 that is ok

2. What value do you see in these interactions ror you own mentoring skills? What value do you see in these interactions ror you own mentoring skills?
    - It's always fun to speak to freshman and hear their thoughts on why they came to Tech and what they're hoping to achieve. It's a great opportunity for reflection and really makes you think about what you've learned as a student.
    - I think it's important to stay connected to the younger students and try to pass down some of the knowledge we have gained through our time at tech.