Peer Mentorship and a 3D Printed Design-Build-Test Project: Enhancing the First Year Civil Engineering Experience

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Abstract

The purpose of this paper is to report the impact of a redesigned first-year civil engineering course on student confidence, sense of belonging, and retention. This paper provides an overview of the course and a peer mentored design project, the student-peer mentoring team structure, and summarizes the qualitative and quantitative feedback with statistical analysis.

Content delivery was changed (traditional to flipped classroom), and 3D CAD/simulation and 3D printing, MATLAB, and peer mentorship were also integrated. The new course was designed to introduce students to i) the various sub-disciplines within civil engineering, ii) 3D CAD, iii) basic quantitative engineering analysis and programming with EXCEL® and MATLAB®, iv) engineering design with structural modeling software, and v) 3D printing.

At mid-semester, the first-year students are placed into teams of 4 to 5 and paired with a fourth year (senior) student peer mentoring team and tasked with completing an engineering design project. The fourth-year students meet with the first-year students on a weekly basis for seven to eight weeks to i) help organize the project, ii) discuss effective time management strategies, iii) provide engineering technical expertise, and iv) provide general academic advice. Meeting notes and peer evaluations are recorded and documented as part of the project effort. Each first-year student team completes a design-build-test project centered around the design and manufacturing of a functional 3D printed structure that satisfies realistic constraints. Structural analysis and design are completed using an open-source CAD software, and a prototype of the structure is printed using a PLA plastic printer available to each team within a designated makerspace.

Quantitative methods were used to assess the student attitudes within the different cohorts using pre/post questionnaires. Four different civil engineering student cohorts were surveyed: freshman, sophomore, and juniors (completed redesigned course), and senior students (completed course prior to course redesign). The survey response data indicates that students completing the first-year course positively value the design and peer mentorship experience, and their STEM confidence, affinity towards math and science, and their sense of belonging improves. Since the redesign in 2017, the first to second-year retention rate has increased from 42% in 2016 to 57% in 2017, 70% in 2018, and 73% in 2019; and the first to third-year retention rate has increased from 38% in 2016 to 50% in 2017 and 60% in 2018. In addition, the senior mentors feel that peer mentorship experience is an excellent addition to the curriculum and gained valuable insights while mentoring first-year students.

Introduction

Freshman first-year experiences have been shown to impact student GPA [1] and retention [2]. The experiences serve as academic anchors that bolster confidence, a growth mindset, motivation, a sense of connection with faculty and peers [3], and collaborative learning [4]. First year discipline-specific experiences can better inform students of the profession, significantly improve retention, and grow strong associations of students with their respective engineering departments [5].

The use of 3D printing and CAD/simulation technology can be used in design-build-test projects within introductory courses to enrich student experiences. It can provide a realistic virtual canvas to explore, more fundamentally, the nature of the engineering design process [6]. The simulation tools provide immediate feedback on realistic engineering outputs like stress, strain, safety factors, etc., that can be used to update designs as necessary in real-time. These activities can be simplified to the extent where freshman first-year students can successfully engage with the tools and develop a working product without having any significant engineering background. This technology has been shown to improve student outcomes [7] and creative competence [8], increase student motivation, enable the creation of interdisciplinary learning communities [9], and improve metacognitive skills [10].

The implementation of peer mentoring activities into the curriculum can help to both enhance student learning by improving higher-level thinking skills, communication, and teamwork [11], and offer opportunity for mentor professional development [12]; which then positively impacts mentor self-worth [13]. Peer mentoring can make the transition to university more successful for new students, improve a students' sense of belonging, and create a social support culture where fellow students are genuinely concerned with the welfare of the first-year student [14].

In 2015, the civil engineering program at Lamar University developed a discipline-specific introduction to civil engineering course to serve as a replacement for a college-wide introductory engineering course. Since the first implementation in 2015, the course has undergone major changes, including: i) the addition of technical content (MATLAB and 3D CAD + Modelling using Fusion 360), ii) improvement in the delivery method (from traditional lecture to flipped classroom), iii) addition of guest industry lectures, iv) addition of a peer mentored experience and end-of-term engineering design project, and v) increased credit hour from one-credit to two-credits. Table 1 shows a summary of all of the major changes from 2015 to 2019.

Research Objective: To assess, across multiple cohorts, how a peer mentored engineering design experience influences students' sense of community and stem confidence and influence their overall valuation of an introductory engineering course. The cohorts include the following: current freshman completing experience, sophomores one year removed from the experience, juniors two years removed from the experience, and seniors who never engaged in the experience as freshman but served as the peer mentors in the 2019 experience.

Research Question: To what extent will a peer mentored design-build-test intervention administered during the first semester of freshman year, impact student confidence, sense of belonging within an engineering community, and student performance and retention.

Research Hypothesis: Implementation of a technical project-based peer mentorship intervention at the freshman level will positively impact student confidence, sense of belonging, and increase retention. Table 1 summarizes the major changes to the first-year program.

Table 1: Major First Year Program Changes

Year	Class	Intervention	Changes
Fall 2015	Intro to Civil Eng (Freshman)	Course was developed and implemented into the curriculum	Discipline-specific project-based learning introduction to civil engineering course was developed. Previously, students completed a one-credit general introduction to engineering course in a large seminar classroom environment.
Fall 2016	Intro to Civil Eng (Freshman)	Pre-requisite Changes:	Students must have passed or be enrolled in Calculus I to take the course.
Fall 2016	Intro to Civil Eng (Freshman)	Calculus I; Guest Lectures	Guest lectures from local industry professionals were introduced into the course: covering topics on different civil engineering sub-disciplines
Fall 2017	Intro to Civil Eng (Freshman)	MATLAB and programming content added	Lecture modules covering basic programming in MATLAB were added to course, including weekly MATLAB homework assignments.
Fall 2017	Intro to Civil Eng (Freshman)	Peer Mentoring, Fusion 360, Design Project	Freshman students were paired with the senior level students on a peer mentoring activity as a part of the course requirement.
Fall 2018	Intro to Civil Eng (Freshman)	Video modules for MATLAB, Excel, and Fusion 360	A hybrid teaching style was introduced to deliver lectures on MATLAB. Video modules were uploaded online for students to familiarize the concept before the corresponding face-to-face lecture.
Spring 2019	Surveying (Freshman)	The course was moved to 1st yr.	2nd yr. Surveying class was moved to 1st yr.
Spring 2019	CAD and Surveying (Freshman)	Credit increase	2nd yr Surveying class was renamed as CAD and Surveying and the previous 2-credit class was changed to a 3-credit class.
Fall 2019	Intro to Civil Eng (Freshman)	Credit increase	Intro to Civil Engineering class was changed to a 2-credit class from the previous 1-credit class.

Implementation

Freshman Introduction to Civil Engineering Class:

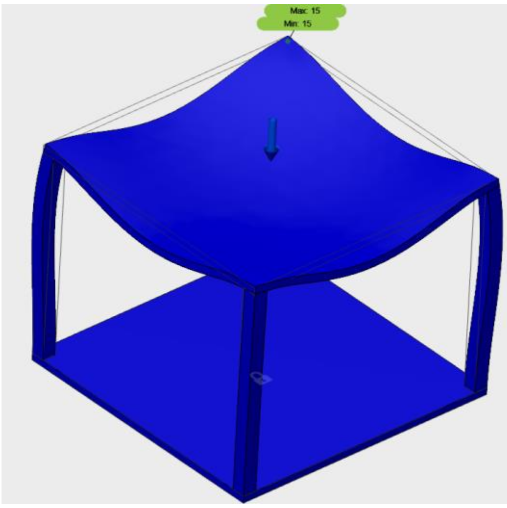
The Introduction to Civil Engineering course at Lamar University uses a flipped classroom delivery method that covers an overview of the civil engineering profession, the engineering design process, and various engineering applications of MATLAB®, EXCEL®, and FUSION 360®. Design concepts are implemented and contextualized with the use of AutoCAD/Fusion 360® and a 3D printer. The students are also introduced to technical communication including, reports, presentations, and posters. Table 2 shows the course schedule of the Introduction to Civil Engineering course.

Table 2: Course Schedule of Introduction to Civil Engineering

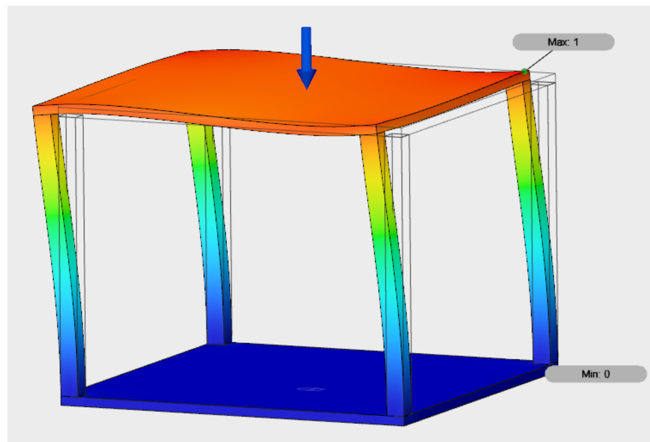
Week	Topics
1	Course syllabus, Introduction to Engineering || Introduction to Civil Engineering
2	Introduction to Civil Engineering Discipline I: Transportation Engineering || Introduction to Civil Engineering Discipline II: Structural Engineering
3	Introduction to Civil Engineering Discipline III: Environmental Engineering || Introduction to Civil Engineering Discipline IV: Geotechnical Engineering
4	Engineering Tools - Microsoft Excel I || Microsoft Excel II
5	Engineering Tools - Fusion 360 I: Modelling || Fusion 360 II: Modelling
6	Engineering Tools - Fusion 360 III: Simulation || Fusion 360 IV: Iterative Design Process
7	Engineering Tools - Fusion 360 V: 3D Printing || MATLAB I: Introduction to MATLAB
8	Engineering Tools - MATLAB II: Basics || MATLAB III: Script Files
9	Engineering Tools - MATLAB IV: Functions || MATLAB V: Vector Creation, Plotting
10	Guest Lecture: Professional Expectations, Career Outlook, Description of Local Civil Eng. Projects || Engineering Tools - MATLAB VI: Vector Operations
11	Engineering Tools - MATLAB VII: Arrays || The Engineering Method and Design
12	Peer Mentored Design Project
13	Peer Mentored Design Project
14	Peer Mentored Design Project
15	Peer Mentored Design Project

AutoCAD Fusion 360 was chosen as the engineering modeling tool for the course because it is a relatively easy software to use for both drawing and modeling, which is ideal for incoming freshman with minimal experience. Students only need a few hours to become comfortable using the software. Three weeks (Weeks 5-8) are dedicated to teaching the students how to use Fusion 360: Drawing, Modelling: Static Stress Analysis and Buckling Analysis, STL file creation and 3D Printing. The students learn how to draw, model, and print a simple three-dimensional structure (four-legged table). Basic Concepts on stress, buckling, and safety factors are covered to supplement the activity so students can interpret the computational results. The content is delivered using a hybrid approach, where students are first provided video lecture content at home (Fusion 360 tutorials created by the instructor) and tasked to complete the assignment in the class.

One of the major advantages of using Fusion 360 is the ability to output the response in terms of a scalar Safety Factor (SF) quantity for both the static stress analysis and buckling analysis (eigenvalue or load factor). Extensive training related to strength of materials concepts is thus not necessary. Students can easily grasp the concept of safety factor and failure, where failure occurs when the safety factor is less than one. In addition, the software has the capability of creating STL files and gcode to communicate with a 3D printer for printing operations. Figure 1 shows sample output from Fusion 360.



Static Stress Analysis
$SF \geq 1$, Safe



Buckling Analysis: Mode I
$SF\ (Eigenvalue) \geq 1$, Safe

Figure 1: Snapshot of Fusion 360 output (Safety Factors) for Static Stress Analysis and Buckling Analysis. Students complete this analysis in Weeks 5-8 of the course.

The objectives of the course are the following:

1. Engage and excite students on topics related to civil engineering
2. Build a sense of community within the freshman civil engineering population by encouraging interaction with upper-division students and student members of ASCE.
3. Improve retention

The student learning outcomes of the course are the following:

1. Develop an awareness and understanding of the different civil engineering sub-disciplines: Structural Engineering, Environmental Engineering, Geotechnical Engineering, Transportation Engineering, and Hydraulic Engineering.
2. Develop a basic understanding on how to function in engineering teams
3. Develop a basic understanding of engineering analysis using a various array of engineering software
4. Develop a basic understanding of the engineering design process by completing a hands-on design-build-test project.

Senior-level Professional Seminar Class:

The professional seminar course covers topics in engineering professionalism, ethics, and leadership. The mode of class delivery primarily consists of a series of seminar lectures on various topics of engineering ethics and professional developments. The course is one credit and taught by the same instructor teaching the Freshman Introduction to Engineering course. As a part of the class requirement, the senior students are expected over 7-8 weeks, to mentor, and assist freshman students in the completion of a realistic 3-D printing design project. The senior students are expected to act as project mentors and provide expert technical advice and meet with groups twice per week (one team meeting and one individual meeting with a student in the respective area of expertise), ensure the project operations are running smoothly, and tasks are completed at a reasonable time.

At the end of the semester, the senior students were asked to submit a detailed project summary report. The work is graded by the instructor. The senior student peer mentors are evaluated based on the organization and detail of the meeting minutes, project summary report, the successful performance of the freshman engineering design project, and peer evaluations, as shown in the Project Statement in the Appendix. All students in the senior-level professional seminar class participate as peer mentors. Peer mentoring teams and peer mentoring team leaders are selected by the instructor.

Description of Peer Mentored Engineering Design Project

As a part of the Introduction to Civil Engineering course, the freshman students are expected to complete a structural engineering design project. As shown in Table 2, approximately four weeks prior to the start of the project, the students were provided content related to AutoCad Fusion 360 and asked to complete several homework assignments that included content on drawing and modeling (Weeks 5-8). For the Fall 2019 project, the students were asked to design a coffee mug stand using Polylactic Acid (PLA) plastic. The students were given several design constraints and expected to use Fusion 360 to design and 3-D print the structure at the end of the semester. The freshman students were divided into 4 to 6 member groups and assigned individual tasks in the group (Project Manager, CAD draftsman and modeler, Product Manufacturer, and Communication Coordinator). Each freshman student group is paired with a mentor group comprised of Senior fourth-year students to facilitate the design project. The freshman students are expected to meet the mentors twice a week for a face-to-face meeting. At the completion of the design project, the freshman students need to submit the following: 1) Conceptual design, 2) Model simulation under given loading conditions and constraints using AutoCAD Fusion 360, 3) PowerPoint presentation summarizing the results of their design, and 4) a fully assembled structure that can support the given loading and that satisfies material and geometric constraints. The structure is then tested at the time of the presentation under the given loading.

Project Objective: Design and build the lightest possible functional coffee mug tree stand that can resist the load of one or two 12 oz coffee mugs.

The designs are subject to the following constraints (as shown in the Appendix):

- Material: ABS or PLA plastic
- Height: less than 8 inches, Base: less than 8 inches
- Support up to two 12 oz. empty coffee mugs
- Manufactured out of 3D printed ABS or PLA plastic
- Aesthetics: Letters "LU" must be tagged onto the mug stand and visible to the user
- Safety Factor must be larger than 3 but less than 10. (Static Stress and Buckling Analysis)
- Manufacturing Constraints: 3D printer that will be utilized to build the structural system has a maximum printing area of 6 in. x 4 in. x 5 in

Note, the weight of the coffee mug was not specified to inject some form of live load uncertainty into the design process. The students were compelled to research the expected range of weights and sizes associated with a 12 oz coffee mug as part of the design process. At testing, a range of 12 oz coffee mugs (with varying sizes and weights) were loaded onto the stand.

Both Freshman and Senior students were asked to submit a peer evaluation report at the end of the design project. Freshman students were asked to evaluate both the group members (freshman students) and the mentors (senior students); whereas the seniors were asked to evaluate only their own group members (senior students) in the peer evaluation reports.

Peer mentored design project organizational structure:

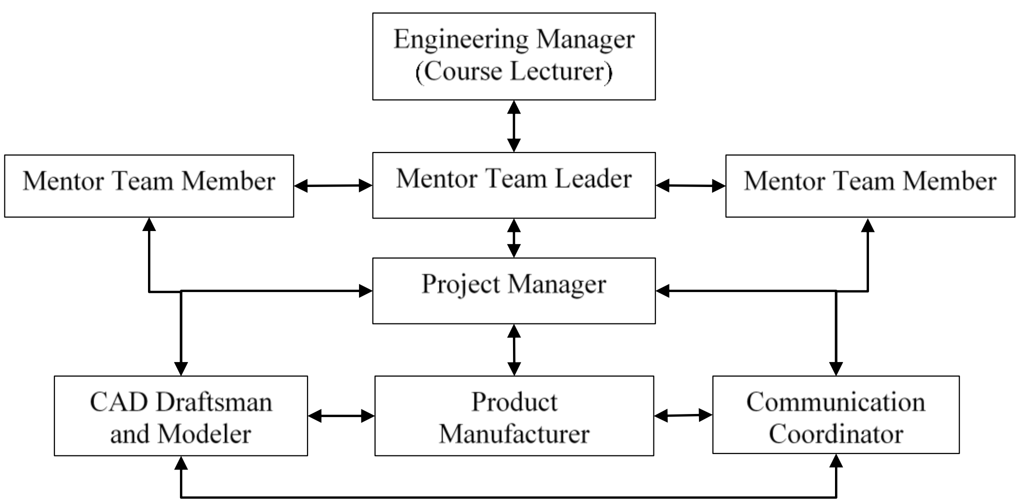


Figure 2. Team Roles and Organizational Chart

<u>Project Mentors (Senior Students):</u> Provides expert technical advice and meets with groups twice per week (one team meeting and one individual meeting with the student in their respective area of expertise). Ensures project operations are running smoothly and tasks are completed at a

reasonable time to ensure product delivery. The peer mentor team will assist only one assigned freshman team. The peer mentoring team consists of 3-5 students. The peer mentoring team meets with the assigned freshman team on the scheduled meeting dates at least twice per week.

Mentor Team Leader:

- Manages other mentor team members.
- Ensures the mentor team is meeting with the project team.
- Organizes team and individual mentor meeting schedule
- Receives email communications from project team members.
- Communicates with project team members via email or phone and deploys appropriate team mentor to address any issues.
- Meets with the project team at least twice per week to provide guidance and technical expertise.

Mentor:

- Lends specific expertise and guidance to the project team members.
- Meets with the project team at least twice per week to provide guidance and technical expertise.
- Communicates with project team members via email or phone.

Project Manager (Freshman Students): Manages each component of the project: i) Conceptual Design, ii) CAD Modelling, iii) Final Design, iv) Reporting. Ensures that each of the activities is on schedule and progress is made to ensure the product will be delivered by the due date. Develops and manages project scheduling and assists the team in completing specified project tasks.

CAD Draftsman and Modeler (Freshman Students): Manages the CAD and modeling steps and if necessary, geometrical redesign of the structural system.

Product Manufacturer (Freshman Students): Manages the 3D printing and assembly operation. This person should become familiar with 3D printing operations. This means that they should set an appointment to visit the Structure and Materials Laboratory to become familiar with the 3D printer and learn how to print simple objects. Multiple prints may be necessary to fine tune the support structure and minimize local irregularities in the printed media. The Product Manufacturer is also responsible for product assembly post-printing.

Communication Coordinator (Freshman Students): Manages the PowerPoint presentation and ensures the project is summarized in a clear and concise manner.

Each team member contributes to each phase of the project, but the responsibility of the final deliverable lies with the individual leading the specific task, e.g., CAD and Modeler, Manufacturer, etc. The leader of each task will depend on the nature of the activity. For example, during the drafting and modeling phase, the Draftsman and Modeler takes the lead and ensures each of the considered designs is adequately implemented into Fusion 360; although multiple team members can be running models on their laptops in parallel. The Draftsman and Modeler are responsible for selecting, organizing, and completing the final CAD model. The Product Manufacturer is responsible for managing the 3D printing operation, which includes tinkering with printer settings to minimize local irregularities in the printed media and final product assembly. The project workflow, scheduling, team meeting coordination, and meeting minutes are the responsibility of the Project Manager. The final presentation is the responsibility of the Communication Coordinator. As shown in Table 2, all freshman students were provided content on AutoCAD Fusion 360, 3D Printing, Excel, Powerpoint, and Matlab prior to the start of the project to ensure that each student can fulfill any team role, as needed.

Freshman and Senior students were given 4 weeks to complete the design project and present the 3-D fabricated design object at the end of the 4-week period. The freshman students met 4 times per week (twice amongst themselves and twice with the peer mentor team). During the meetings, the students work together on the team tasks. Freshman students were given 2-weeks to design the required system and perform the structural analysis using Fusion 360. Once the design of the system was approved by the lecturer, students were expected to 3-D print the individual parts and assemble the structure. At the end of the 4-week period, the students were asked to present the design in a lecture period using PowerPoint. In addition to the Freshman students, all the Senior student mentors were also asked to be present at the final presentation.

Deliverables:

<u>Project Team</u>

- **Design:** Multiple designs must be considered and compared. Each team member must complete a preliminary conceptual design.
    - Draw a conceptual structure using AutoCAD Fusion 360
    - Model the structure stand under the expected loading conditions to determine the static loading safety factors and buckling load capacity.
    - Students must track (and describe) their design process (did your initial conceptual designs meet the specifications or did you need to update the dimensions?). If updates are made to your design, make sure to keep a record of each update and describe the evolution of your design in your presentation
- **Presentation:** PowerPoint presentation summarizing the results of their design. Students are encouraged to use the template provided in Blackboard.
- **Build and Test:** Fully assemble and deliver the structure by the due date provided by your instructor. The structure will be tested on the date of the presentation.
- **Peer Evaluations:** Submit the peer evaluation form that summarizes the level of participation of each of your fellow team members and project mentor.

<u>Project Mentors</u>

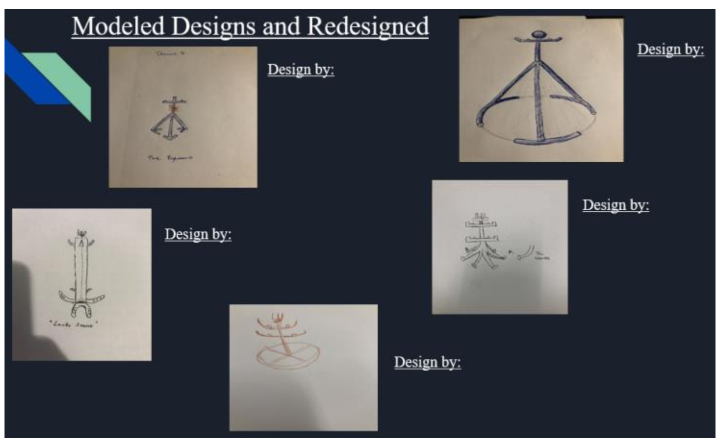
- **Meetings:** Project mentors must complete the peer evaluation to evaluate the participation of your fellow project mentors and project team members. Project mentors must meet both with their team at least **twice per week** for at least one hour per mentoring session.

- *First Meeting:* During the first meeting, the mentor and project team should discuss project management strategies, project scheduling, team vision, roles and responsibilities, and scheduling of future meeting dates for further guidance and technical assistance. Bi-weekly meeting dates should be agreed upon during the first meeting.
- *All Other Meetings:* Mentors should inquire if there have been any issues during the project experience, answer technical questions, schedule one on one individual mentoring sessions, and to also ensure project tasks are completed on schedule. Technical mentoring tasks may include assistance with Fusion 360 drawing, assembly, and modelling, and 3D printing and assembly of the structural system.

- **Report:** At the completion of the project, the project mentor must submit a project summary report that describes their interactions with their project team members that includes all correspondences between you and the team members, peer evaluations, meeting minutes, and must journal your interaction with team members at each point of interaction. The project mentor must describe the level of project success, and strategies that were used to ensure the success of the project.

Sample Work/Product from Various Teams

Phase I: Conceptual Design



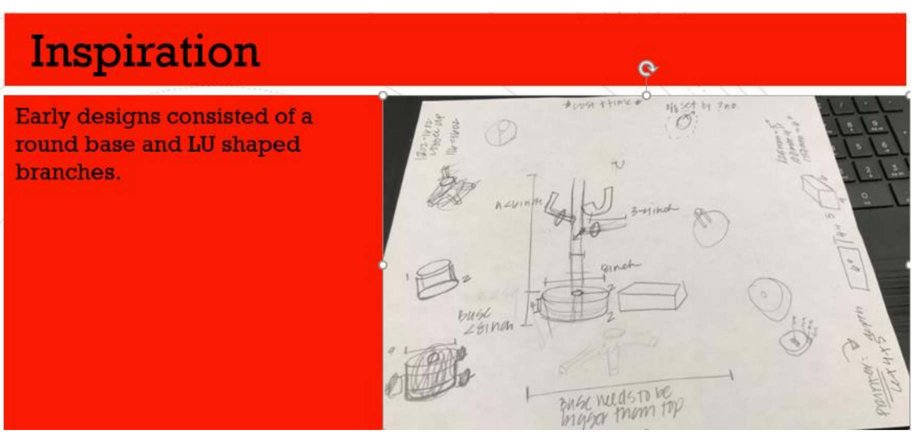
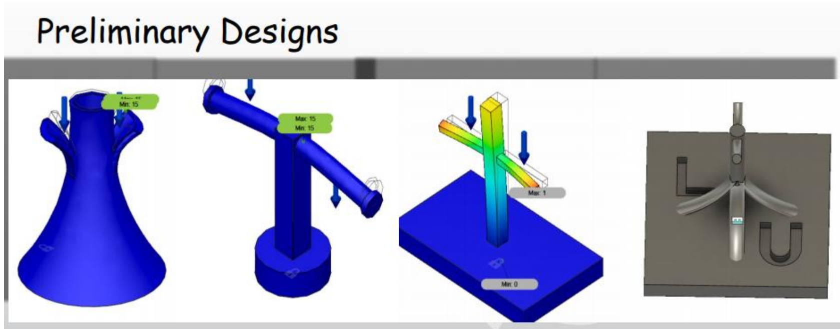
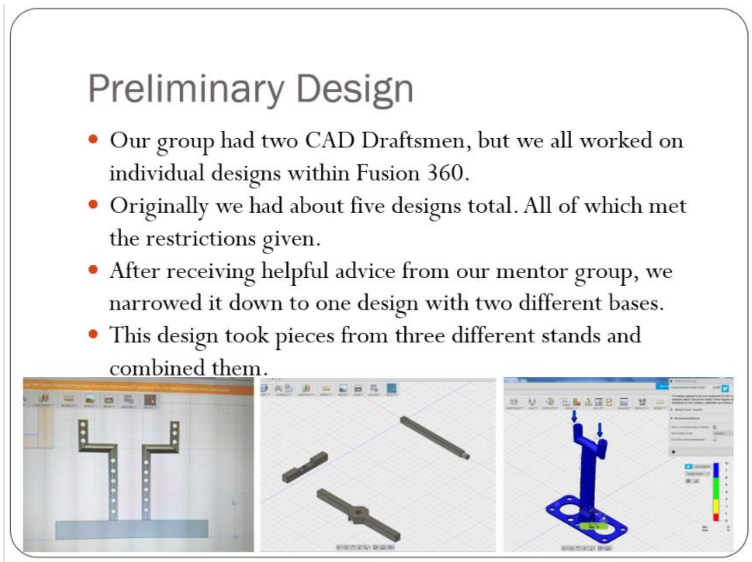


Figure 3. Snapshot of freshman student final design presentations (continued)

Phase II: Preliminary Design





Phase III: Final Analysis and Design

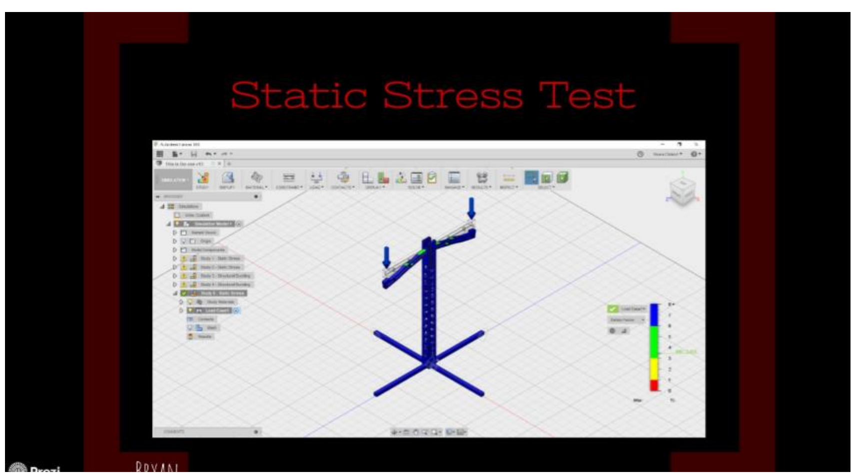
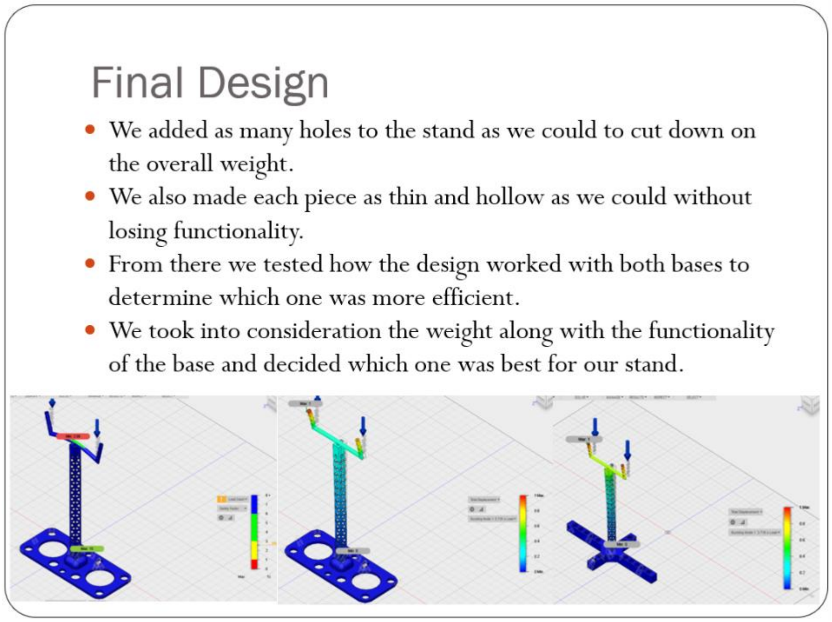
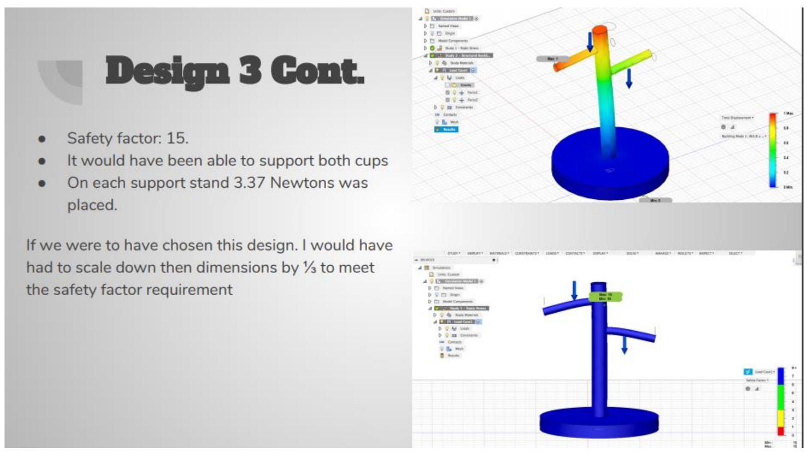


Figure 3. Snapshot of freshman student final design presentations (continued)





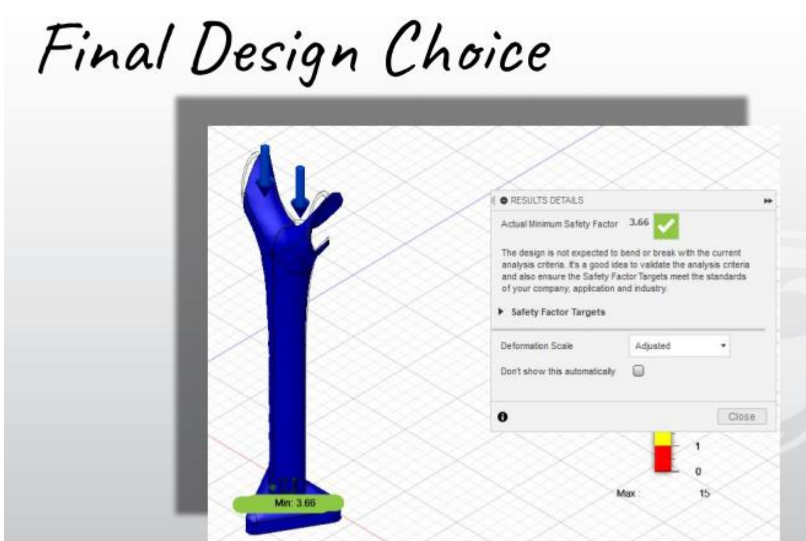
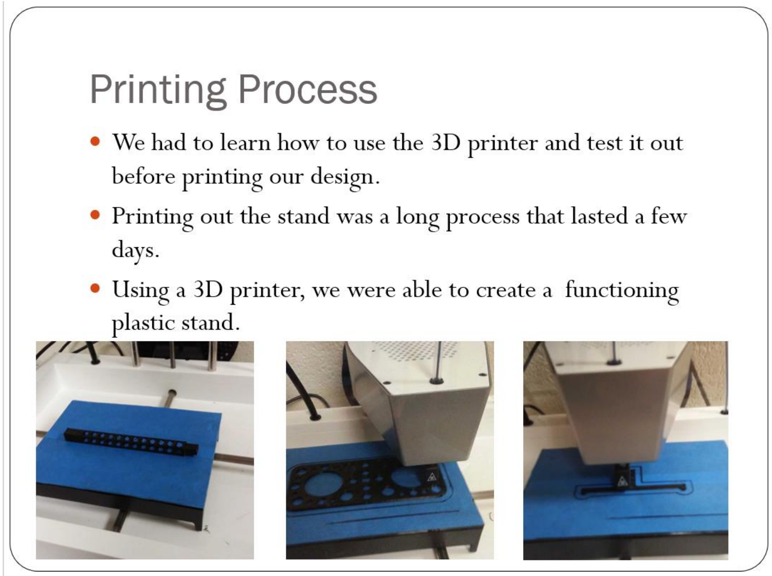


Figure 3. Snapshot of freshman student final design presentations (continued)

Phase IV: Manufacturing



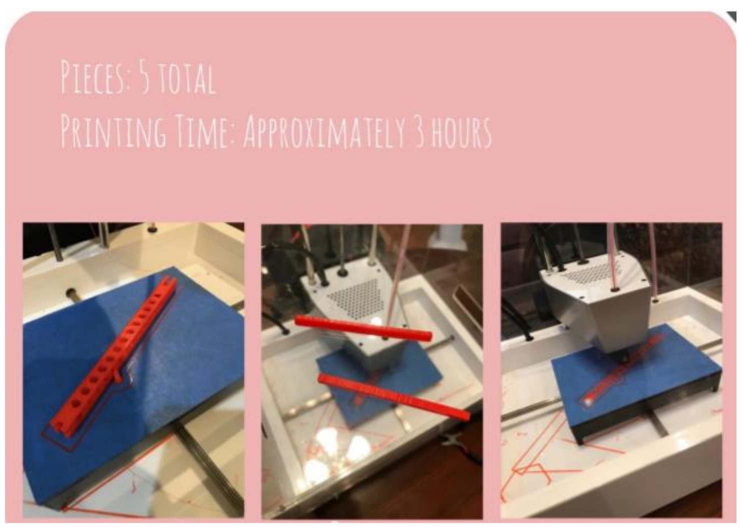


Figure 3. Snapshot of freshman student final design presentations (continued)

Phase V: Final Product/Testing

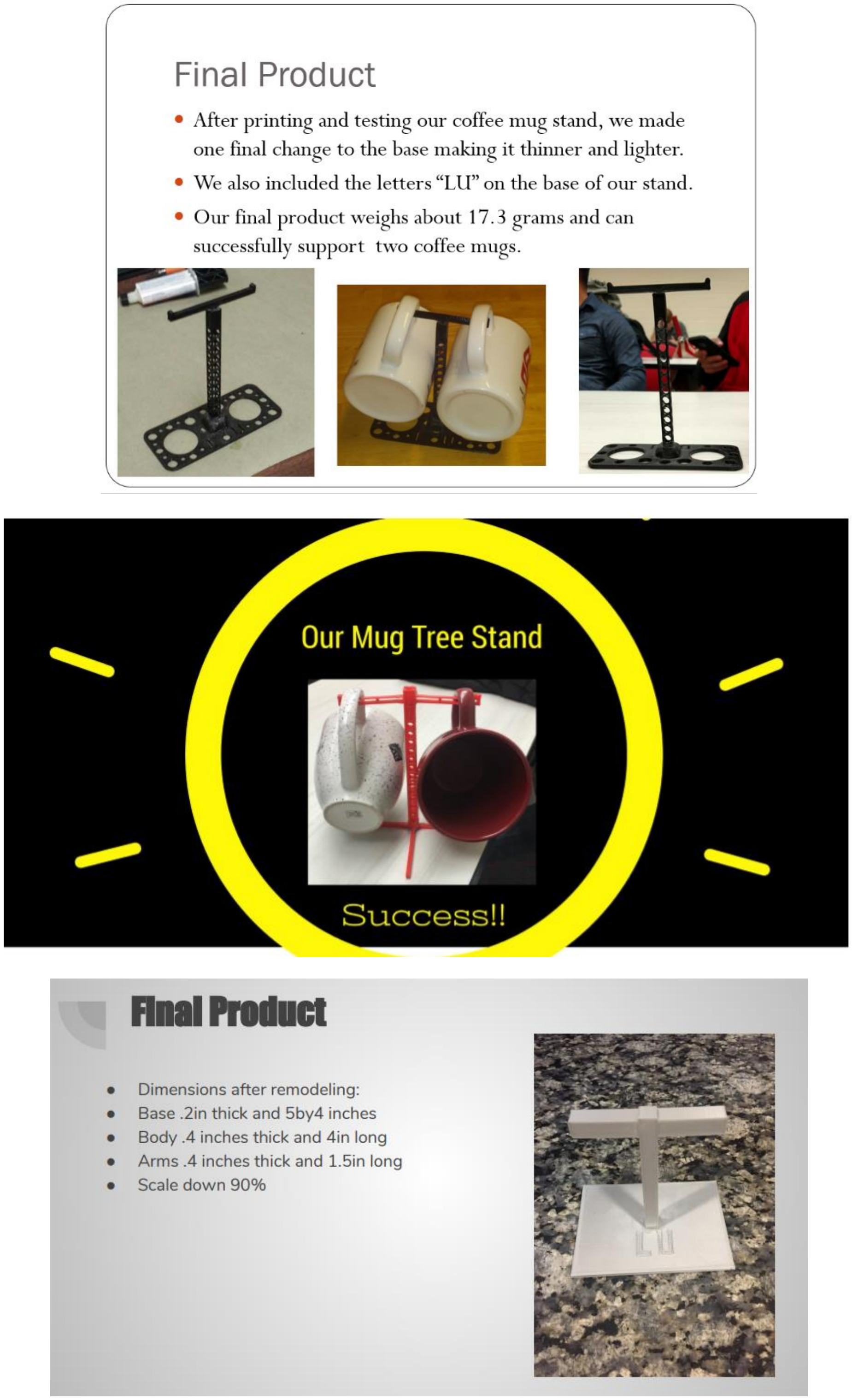


Figure 3. Snapshot of freshman student final design presentations

Methods

Survey response data was collected and analyzed to provide a quantitative link between the intervention, retention, and student attitudes. For this study, we deployed a total of five surveys. Table 3 summarizes the response rate within each cohort and Table 4 shows the items on the questionnaire.

Table 3: Survey response rates for each cohort

Survey	**Invited**	**Responses**	**Response Rate**
Pre-Survey Freshman	36	33	92%
Post-Survey Freshman	36	28	78%
Post-Survey Sophomore	38	29	76%
Post-Survey Junior	32	30	94%
Post-Survey Senior	20	18	90%

Table 4: Items from survey questionnaire

Dimension	Item
STEM Confidence	I am confident in my ability to succeed in my college engineering courses
	I am confident in my ability in my college science courses
	I am confident in my ability to succeed in my college math sources
Engineering Rewarding	Society values the work engineers do
	Engineering is boring
	Engineering is an occupation that is respected by other people
	Engineers help to make the world a better place
	I expect that engineering will be a rewarding career
	My engineering coursework will prepare me for a job in engineering
Student Community	Are group projects valuable
	Do you feel like a part of an engineering community?
	Do you like studying with other students in a group?
	Are you involved with student study groups?
	Do engineering students help each other succeed in class?
	Do other students take your comments/ suggestions in class seriously?
Major Desirability	I have no desire to declare a non-engineering major
	I can think other majors that I would like better than engineering
	It is my choice to study engineering
	I intend to complete my engineering degree
Common Perceptions	I am sure I want to be an engineer
	I like the subjects of math and science the most
	I know a lot about what engineers do
	Engineering is a respected profession
	All engineers sit behind a desk all day working with numbers

Q1	What is your opinion on whether the freshman civil engineering course better prepared students for what is to come in sophomore and junior courses?
Q2	What is your opinion on the impact of peer mentoring?
Q3	Did the interactions with the upper division students help you to get involved in student organizations?
Q4	What was your favorite part of the introduction to civil engineering course?
Q5	What was your least favorite part of the introduction to civil engineering course?

The surveys were classified into two groups, Pre-survey (freshman cohort) and Post-survey (freshman, sophomore, junior, and senior cohort). The Pre-surveys were deployed within the first two weeks of the Fall 2019 semester and Post-surveys were deployed during the last two weeks of the Fall 2019 semester. The surveys were deployed electronically through an online client, Qualtrics.

The questionnaire for both Pre and Post surveys were adopted from Litzler et.al. [15] (A total of 21 schools and 7,833 students were included in the analysis to develop the survey instrument) and Hoit and Ohland [5] (deployed to freshman-level engineering students at University of Florida); that both use a Likert response scale of 1-5, where 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5 = Strongly Agree. The pre-surveys in the freshman cohort focused on gauging students baseline perceptions on the following broader concepts: STEM confidence (α = 0.83), Engineering rewarding (α = 0.83), Student community (α = 0.78), Major Desirability (α = 0.60) [15], and Common professional perceptions [5]. The post-surveys focused on evaluating students changes in perceptions on broader concepts at the end of the semester. In addition to the above-mentioned broader concepts, the post-surveys also focused on the students' responses to other specific questions, such as: impact of peer mentoring, and favorite/least-favorite part of the course.

Student Demographics:

A summary of the student demographics of each cohort evaluated in the study is shown in Table 5.

Table 5: Student Demographics

Academic year	Race/Ethnicity (%)							Total no of students
	White	Black or African American	American Indian or Alaska Native	Asian	Native Hawaiian or Pacific Islander	Hispanic	Other	
Freshman	39%	24%	0%	9%	0%	27%	0%	33
Sophomore	45%	14%	7%	14%	0%	17%	3%	29
Junior	60%	7%	0%	3%	0%	23%	7%	30
Senior	56%	10%	6%	6%	0%	22%	0%	18

Results and Discussion

Table 6 shows the retention rates from 2015 to 2019. The 1st-2nd year retention is shown as well as the cumulative retention of the student cohort from the 1st-3rd year. In 2016-2017, a Calculus I enrollment pre- and/or co-requisite was implemented, in addition to guest industry lectures and MATLAB content. CAD and structural simulation, 3D printing, engineering design, and peer mentorship was introduced into Introduction to Civil Engineering in 2017-2018.

The enrollment pre and co-requisites in the first iteration of the course redesign appears to have led, at least in part, to an increase in the second-year retention rate by 15% and third-year retention rate by 12% which is a reasonable outcome since incoming students are presumably academically better prepared to succeed in an engineering program than those from previous years. Prior to 2016, any student could enroll into the civil engineering course; irrespective of their level expertise in math and science.

The implementation of a project-based peer mentorship intervention appears, at least in part, to have positively impacted the retention rates in the 2017-2018 and 2018-2019 cohorts; leading to further increases in second-year retention by 13-16% and by 10% in third-year retention; which could be attributable to increases in confidence, student community, and major desirability.

Table 6. BSCE Program Retention Rates: 2015-2019

Cohort	1st-2nd Year Retention	1st-3rd Year Retention
Graduates: 2015-2016	42%	38%
Seniors: 2016-2017	57%	50%
Juniors: 2017-2018	70%	60%
Sophomores: 2018-2019	73%	-
Freshman: 2019-2020	-	-

Surveys were deployed in Fall 2019 to students at every academic level in the civil engineering undergraduate program (Seniors: 2016-2017 cohort, Juniors: 2017-2018 cohort, Sophomores: 2018-2019 cohort, and Freshman: 2019-2020 cohort) to better understand their attitudes and perceptions (STEM confidence, Major Desirability and Reward, and Student Community) to see if the retention data reflects their perceptions in these dimensions.

Table 7 shows the synthesis summary of the students' favorite and least favorite parts of the course. In aggregate, the peer mentored project-based engineering design activity was rated as the students' favorite part of the course (53%). The CAD Fusion 360, EXCEL, and MATLAB modules were rated nearly equally (~15% of students). The peer mentored design project is an activity that significantly engages the freshman students in almost all three major components of the project: CAD and Simulation-Fusion 360, Group Interaction, and structural building (3D Printing). The 3D printing activity introduces the students to the Structural and Materials lab, laboratory Teaching Assistants, and provides a medium for students to gather, build, tinker, and fully assemble their structural design; providing a medium for student interaction that helps build community at the personal and professional levels. Not surprisingly, the students' least favorite part of the course is the homework assignments.

Table 7. Survey questions given to Freshman (2019-2020 cohort) course content: Favorite and Least Favorite Part of the Course

What is your favorite part of the Introduction to Engineering course?	
3-D Printing:	29%
Group Project:	24%
CAD-Fusion 360:	17%
MATLAB:	15%
Excel:	15%

What is your least favorite part of the Introduction to Engineering course?	
Homework	52%
MATLAB	17%
Other	17%
CAD-FUSION 360	14%

Table 8 shows a synthesis of student responses on their opinion of the impacts of peer mentorship and freshman course on preparedness and professional community involvement. The sophomore and junior classes believed that the freshman course positively better prepared them (more than 70% of the population in each class). In the senior class, only 53% believed that the freshman course positively better prepared them for what is to come in the curriculum and 20% believe that it negatively impacted their preparedness. This is not surprising since the senior cohort took the introduction to civil engineering course prior to the course and program redesign that now includes peer mentorship and a CAD+3D printing design-build-test project; which may be influencing their perception. Another factor could be that the seniors are three years removed from taking the course, have now completed a professional internship and may not see direct practical and professional relevance, e.g., the lack of exposure to building codes, and more scalable and realistic civil engineering design problems, etc.

Table 8. Survey questions given to Freshman-Senior Cohorts to gauge opinion on the impact of the course and peer mentorship on preparedness, professional involvement.

Q1	What is your opinion on whether the freshman civil engineering course better prepared students for what is to come in sophomore and/or junior courses?
Q2	What is your opinion on the impact of peer mentoring?
Q3	Did the interactions with the upper division students help you to get involved in student organizations

Academic Year	Response	Q1	Q2	Q3
Freshman	Positive	-	83%	50%
	Neutral	-	4%	17%
	Negative	-	13%	33%
Sophomore	Positive	74%	68%	55%
	Neutral	21%	18%	18%
	Negative	5%	14%	27%
Junior	Positive	70%	52%	46%
	Neutral	26%	20%	8%
	Negative	4%	22%	46%
Senior	Positive	53%	70%	58%
	Neutral	27%	24%	21%
	Negative	20%	6%	21%

The responses to question 2 are interesting. The freshman cohort believes that peer mentoring is important (83% view as positive). The sophomore cohort also believes the peer mentoring is important (68% view as positive). Most of the junior cohort also believes that peer mentoring is important (52% view as positive), but at a lower rate than the freshman and sophomore. The senior students view peer mentoring as positive (70% view as positive). The perceived benefits of peer mentoring thus seem to change by cohort; with a decreasing positive view from freshman to junior years and then changing significantly in the senior year; after seniors themselves serve as peer mentors; where from a different vantage point, they see value in the experience. The students currently involved in such activities have positive experiences and value the interactions. Students who have not partaken in such activities over one or more academic years tend to value these experiences at lower rates. So perhaps fully integrating peer mentorship programs from the freshman to junior years will have significant, sustained positive views of this interaction. The responses to question 3 are mostly consistent with around 50% of students viewing the interaction with upper-division students as important to getting them involved in professional student organizations.

Tables 9 and 10 show the mean survey response (standard deviation in parenthesis) for each of the four cohorts considered in the study. For the freshman cohort, the pre (week 1) and post (week 15) responses were recorded to isolate changes over their first semester of freshman year in the civil engineering program. Changes in freshman perception in all three of the four major categories are observable. The first-semester freshman engineering students indicate self-reported increases in STEM confidence ($p<0.05$) and STEM likeness ($p<0.05$), indicate a significantly higher sense of belonging within a student community ($p<0.05$), and more significantly view their engineering major as rewarding ($p<0.2$) and respected ($p<0.1$) after completion of the first semester in the BSCE program. STEM confidence amongst the senior students is greatest, which is not surprising given the experience and time within the program. STEM confidence does not significantly change within cohorts until the completion of the first semester of senior year. The different cohorts have varying perception on if they view civil engineering as rewarding. Their perceptions decrease significantly at the junior level and climb back to near 4.5/5.0 at the senior level. The freshman and sophomore cohorts have a relatively higher sense of belonging within a student community than the junior and senior cohort. The project-based peer mentored project was first implemented within the freshman year of the junior cohort. Aligned with the qualitative responses to the questions in Table 9, this may be caused due to a gap in vertically integrated group projects at the sophomore and junior levels; which may affect their perception of community. The senior students did not participate in the peer mentored project as a freshman. The senior student cohort, does believe, however, engineering to be rewarding at a level statistically equivalent to that of the freshman cohort at the completion of the first semester. Most seniors have completed their major coursework and completed internships. It is promising to see them significantly value their profession at the time of graduation. Interestingly, the perceptions of what engineers do daily vary by cohort as well; with the senior cohort best understanding what engineers do and believing the least that “all engineers sit behind a desk all day working with numbers.” This makes sense since most of the seniors have completed internships and thus have real-world practical experience, which disclaims the statement.

Table 9. Aggregate mean survey responses: STEM Confidence, Engineering Rewarding, Student Community, and Major Desirability for each cohort.

Dimension	Freshman Pre	Freshman Post	Sophomore	Junior	Senior
STEM Confidence	4.35 (0.75)	4.57 (0.52)***	4.51 (0.63)	4.45 (0.62)	4.70 (0.54)*
Engineering Rewarding	4.51 (0.68)	4.58 (0.70)*	4.61 (0.63)	4.11 (1.20)	4.58 (0.57)***
Student Community	3.87 (1.06)	4.23 (0.91)***	4.38 (0.89)	3.88 (1.00)	4.01 (0.94)***
Major Desirability	4.09 (1.09)	4.14 (1.15)	4.33 (1.10)	4.21 (1.14)	4.13 (1.16)

***$p<0.05$, **$p<0.1$, *$p<0.2$

Table 10. Mean survey responses of engineering common perceptions.

Item	Freshman Pre	Freshman Post	Sophomore	Junior	Senior
I am sure I want to be an engineer	4.41 (0.84)	4.68 (0.61) *	4.75 (0.44)	4.69 (0.54)	4.39 (0.61) *
I like the subjects of math and science the most	4.09 (1.06)	4.57 (0.74) ***	4.75 (0.59)	4.55 (0.74)	4.50 (0.71)
I know a lot about what engineers do	4.06 (0.76)	4.29 (0.66)	4.21 (0.63)	3.90 (0.90)	4.39 (0.78) *
Engineering is a respected profession	4.66 (0.48)	4.82 (0.48)**	4.68 (0.55)	4.76 (0.44)	4.72 (0.46)
All engineers sit behind a desk all day working with numbers	2.34 (1.00)	2.61 (1.31)	2.32 (1.06)	1.90 (0.77)	1.56 (0.62)***

***$p<0.05$, **$p<0.1$, *$p<0.2$

Summary of Findings

- Freshman students who recently completed the introduction to civil engineering course in 2019 reported increases in stem confidence and reported a greater sense of student community.
- Nearly 70% of the students reported that the design-build-test activities including the 3D printing and the AutCad Fusion 360 activities, were the most enjoyable parts of the course.
- More than 80% of the freshman students had positive feedback regarding the peer mentoring activities after completing the introduction to civil engineering course.
- More than 70% of the sophomores and juniors reported that the freshman civil engineering course better prepared students for what is to come in the upper-division courses.
    - Only 50% of senior students (who did not participate in the peer mentored design build test project) believed the freshman civil engineering course better prepared them for what is to come in the upper-division courses.
- More than 70% of the senior students, after serving as peer mentors in the design-build-test project, positively value the peer mentorship experience.
- Between 2015 and 2019, civil engineering 1st to 2nd-year student retention has increased from 42% to 73%.

Conclusion

The implementation of a peer mentored design-build-test project within an introduction to civil engineering course appears to have enhanced the student experience. Survey results suggest that the experience has served to build stem confidence and foster a sense of belonging within a civil engineering community. Students valued the peer mentorship experience and i) believe it has positively impacted them and helped prepare them for their upper-division classes and ii) believe it has encouraged them to participate in extracurricular civil engineering student organizations. Additionally, students' valuation on the importance of the introduction to civil engineering course seems to increase if they have completed the peer mentored design experience.

For broader implication, the survey data was complemented with student retention data. The collected survey data aligns well with the improvement in retention and can partially explain the benefits of such an experience. Student 1st to 2nd-year retention has improved over the last four years in the BSCE program (from 42% to 73%). Although many factors contribute to improved retention rates, including, but not limited to, admission requirements, bridge programs, university support services, etc., the changes occurred primarily after the implementation of the engineering design peer mentorship experience.

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Appendix – Project Statement

Plastic Coffee Mug Tree Stand Design

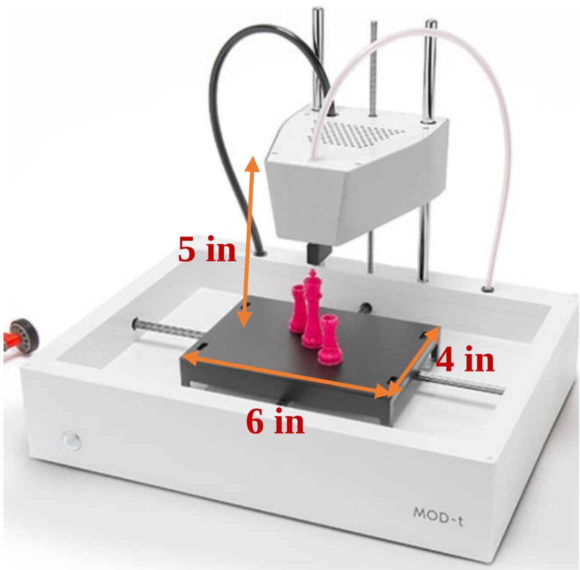


You are a structural engineer working for an international furniture company and have been asked by your supervisor to design a coffee mug tree stand made from ABS or PLA plastic that must meet the following specifications:

- Height: less than 8 inches
- Base: less than 8 inches

- Support up to two standard 12 oz. empty coffee mugs
- Manufactured out of 3D printed ABS or PLA plastic
- Aesthetics: Letters “LU” must be tagged onto the mug stand ad visible to the user
- Safety Factor must be larger than 3 but less than 10. (Static Stress and Buckling Analysis)

ADDITIONAL MANUFACTURING CONSTRAINTS: The 3D printer that will be utilized to build the structural system has a maximum printing area of 6 in. x 4 in. x 5 in. When printing out your components, make sure to consider this constraint. For example, if you design calls for a member that is 8 in., you will need to print the member in multiple parts, i.e., two 4 in. pieces. In addition, the more material your design calls for, the longer the 3D printing job will take (can take upwards of 12 hours for large prints with significant amounts of material). You should consider printing your system out in small parts using the least amount of material necessary to meet the specifications. There are some resources available online that can assist you in getting started. Please schedule an appointment with the Instructor to go to the Structure and Materials lab to begin working with the 3D printer.



To minimize the cost, you must design the tree mug stand using the least amount of material required to meet the specifications. The stand should not be manufactured in one piece. It should be manufactured in separate components to minimize the complexity of the 3D printing operation.

Project Requirements and Deliverables:

- Draw a conceptual tree mug stand using AutoCAD Fusion 360
- Model the coffee tree mug stand under the expected loading conditions to determine the static loading safety factors and buckling load capacity.

- Powerpoint presentation summarizing the results of their design. Students are encouraged to use the poster template provided in Blackboard.
- Students must track (and describe) their design process (did your initial conceptual design meet the specifications or did you need to update the dimensions?). If updates are made to your design, make sure to keep a record of each updated and describe the evolution of your design in your presentation.
- Fully assemble and deliver the coffee mug tree stand by the due date provided by your instructor.
- Submit the peer evaluation form that summarizes the level of participation of each of your fellow team members and project mentor.
- **Project Mentors Only:** Project mentors must complete the peer evaluation to evaluate the participation of your fellow project mentors and project team members. Project mentors must meet both with their team at least **twice per week** for at least one hour per mentoring session. At the completion of the project, the project mentor must submit a project summary report that describes their interactions with their project team members that includes all correspondences between you and the team members, peer evaluations, meeting minutes, and must journal your interaction with team members at each point of interaction. The project mentor must describe the level of project success, and strategies that were used to ensure the success of the project.
    - First Meeting: During the first meeting, the mentor and project team should discuss project management strategies, project scheduling, team vision, roles and responsibilities, and scheduling of future meeting dates for further guidance and technical assistance. Bi-weekly meeting dates should be agreed upon during the first meeting.
    - All Other Meetings: Mentors should inquire if there have been any issues during the project experience, answer technical questions, schedule one on one individual mentoring sessions, and to also ensure project tasks are completed on schedule. Technical mentoring tasks may include assistance with Fusion 360 drawing, assembly, and modelling, and 3D printing and assembly of the structural system.

- **DUE DATES**
    - **Project Teams**
    - Date 1: Design and Structural Analysis in Fusion 360 due. Must show the instructor the working CAD file on your computer.
    - Date 2: PowerPoint presentation due. Fully Assembled 3D printed structure due. Peer Evaluations due.
    - **Project Mentors**
    - Date 3: Report Summary and Peer Evaluations due.
- **3D PRINTING**
    - Date 4-Date 5: 3D printers will be available to use in the structural and materials laboratory and/or to “check out” to take home for an evening.

Team Roles:

- Project Mentors (Senior Students): Provides expert technical advice and meets with groups twice per week (one team meeting and one individual meeting with student in respective area of expertise). Ensures project operations are running smoothly and tasks are completed at a reasonable time to ensure product delivery on the due date.
- Project Manager: Manages each component of the project: i) Conceptual Design, ii) CAD Modelling, iii) Final Design, iv) Reporting. Ensures that each of the activities is on schedule and progress is made to ensure product will be delivered by the due date. Develops and manages project scheduling and assists team in completing specified project tasks.
- CAD Draftsman and Modeler: Manages the CAD and modelling steps and if necessary, geometrical redesign of the structural system.
- Product Manufacturer: Manages the 3D printing and assembly operation. This person should become familiar with the 3D printing operations. This means that they should set an appointment to visit the Structure and Materials Laboratory to become familiar with the 3D printer and learn how to print simple objects. *This step should be done before the team's structural system is ready for printing.*
- Communication Coordinator: Manages the PowerPoint presentation and ensures the project is summarized in a clear and concise manner.

Competition:

The team that designs the lightest functional coffee mug tree stand will be given a certificate of achievement and will be invited to submit a poster to the LU STEM Symposium.

Grading Structure:

Freshman Course:

- Powerpoint presentation (60%)
  - Clear evidence the students have considered multiple designs and redesigned their system to meet the specifications.
  - Clear evidence the students used AutoCAD Fusion 360 to assemble and model their structural system
  - Each student must be present and discuss their individual portion of the project on the date of presentation
  - Presentation is organized, concise, and professional.
- Functional Structural System (30%)
  - Fully assembled coffee mug tree stand meeting the specifications listed above

    - System is structurally stable and can withstand the loads specified within the specifications.
- Peer Evaluations (10%)
    - The results of the evaluations obtained from your peers will be used to grade your level of participation in the project.

Senior Course:

- Project Summary Report (60%)
    - Detailed Meeting Minutes (25 %)
    - Summary of the Project Outcomes (25 %)
    - Leadership and Management Reflection (10 %)
- Functional Structural System (20%)
    - Fully assembled coffee mug tree stand meeting the specifications listed above
    - System is structurally stable and can withstand the loads specified within the specifications.
- Peer Evaluations (20%)
    - Complete the evaluation form provided to you to assess your mentor team members ability to work in a team and their level of participation in the project.

Project Mentoring Structure

- Mentor Team Leader:
    - Manages other mentor team members.
    - Ensures mentor team is meeting with project team.
    - Organizes team and individual mentor meeting schedule
    - Receives email communications from project team members.
    - Will communicate with project team members via email or phone and deploy appropriate team mentor to address any issues.
    - Meets with project team at least twice per week to provide guidance and technical expertise.
- Mentor:
    - Is directed by Mentor Team Leader to lend specific expertise and guidance to the project team members.
    - Meets with project team at least twice per week to provide guidance and technical expertise.
    - Communicates with project team members via email or phone.

Project Organizational Structure

Students initially should contact the Mentor Team Leader. They will serve as the main liaison between the project and mentoring team. The instructor will communicate directly with Mentor Team Leaders and Project Managers on a weekly basis for quality control purposes.