2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32598

Building Self-efficacy and Interest in Engineering Through Design

Dr. Vicki V. May P.E., Dartmouth College

Vicki V. May, Ph.D., P.E. is an Instructional Professor of Engineering at the Thayer School of Engineering at Dartmouth. Her research focuses on engineering education and K-12 outreach. She teaches courses in solid mechanics, structural analysis, and design. Prior to relocating to the east coast, Professor May was an Associate Professor of Architectural Engineering at the California Polytechnic State University in San Luis Obispo.

Dr. Ryan Michael Chapman, Dartmouth College

Building Self-efficacy and Interest in Engineering through Design

Introduction

An NSF study that was completed in 2007 entitled *Investigating the Gender Component in Engineering* [1] studied factors that promote interest in engineering among undergraduate women at several institutions, including at Dartmouth. Elements of the culture and courses at Dartmouth that were identified by Craemer's study [1] to promote interest in engineering among undergraduate students who identify as women included the use of a collaborative problem-solving approach, flexibility in the curriculum, focus on real-world problems with social significance, and the interdisciplinary nature of projects. Craemer [1] identified *Introduction to Engineering* as a pivotal course in the curriculum at Dartmouth for generating interest among students, especially those who identify as women.

Building on the study by Craemer [1], faculty teaching *Introduction to Engineering* have administered pre- and post-course surveys to further assess students' interests and self-efficacy related to engineering, among all students but among those who identify as women in particular. Self-efficacy refers to an individual's belief that they can do certain things [2], in this case the belief that they can succeed in engineering. Results of these surveys as well as a description of the course and of the projects and problems addressed by student groups are presented.

Research Questions and Approach

The following research questions are explored in this paper:

- Does students' interest and self-efficacy in engineering change after taking *Introduction to Engineering*?
- Does interest and self-efficacy vary by gender?
- What types problems and projects do students identify and work on in the course?

Introduction to Engineering is a required course typically taken by students at the end of their freshman or beginning of their sophomore year. This paper focuses on students who took the course between the spring of 2019 and the fall of 2020. Table 1 gives the number of students by term, gender, the professor who taught the course, and whether the course was taught in-person or remotely. Due to the coronavirus pandemic, several offerings of the course were taught remotely (i.e., all course activities online). Course enrollment for remote sections of the courses was reduced and summer enrollment tends to be lower. A total of 172 students took the four sections of the course presented in this paper; 72 of the students identified as women (42%) and 100 identified as men (58%). Note: prior to Fall 2020, the surveys asked students to report gender as 'man' or 'woman.' The Fall 2020 Survey included 'nonbinary' as an option, however no students that term selected that option. Future surveys will be more inclusive when asking about gender.

All students were surveyed at the beginning of the course (pre-survey) and again at the end of the course (post-survey) to determine levels of interest and self-efficacy. The pre- and post-surveys were administered using Google Forms and students were given a small amount of credit for completing the surveys.

Table 1. Course Details

	Spring 2019	Spring 2020	Summer 2020	Fall 2020
Mode	In-Person	Remote	Remote	Remote
Professor	May	May	Chapman	May
Number of Students	68	44	19	41
Women	22	22	10	18
Men	46	22	9	23

Fall 2019 and Fall 2020 courses were taught by a professor who did not run the pre- and post-course surveys so those sections are not included here.

Course Overview

The *Introduction to Engineering* course at Dartmouth is a hands-on, project-based course through which small groups of students collaborate to identify real-world problems, generate solutions, and build prototypes. Problems and projects that students tackle in the course are identified by the students themselves. The primary goal of the course is to increase student interest in engineering while building self-efficacy. Through the project and course, students develop problem-solving, creativity, communication, collaboration, and design skills; all of which will help them in whatever field they choose.

The specific learning objectives of the course are as follows. Upon completing the course, students should be able to:

1. Identify a social problem or need and determine the magnitude of the problem or need.
2. Use engineering problem-solving methods to generate a set of alternative solutions, select the alternative that appears most viable, and design a component, system, or process to implement the alternative.
3. Design and conduct experiments to assess the viability of a proposed solution; analyze and interpret the resulting data.
4. Use modern engineering design and machining tools.
5. Work effectively on a multidisciplinary team and negotiate group dynamics.
6. Communicate effectively through written and oral reports.

The course is project-based rather than lecture-based with course activities focused on helping students identify and solve real-world problems. While there is typically a theme for the course such as 'improving life in the winter' or 'improving life during the pandemic,' the themes are relatively open-ended. Small student teams (3-4 students per team) are formed by the professor in the first week of the course based on interests and background, with the goal of forming diverse teams with respect to academic year, gender identity, experience, major, race/ethnicity, etc. Students then work with these teams for the entire term. A series of project presentations and written reports are required throughout the term including the project proposal (written and oral), project check-in (oral only), and final report (written and oral). In addition to in-class activities focused on design thinking and engineering problem-solving, students attend 'tools and techniques (T&T)' sessions through which they learn the skills needed to design and build prototypes. T&T sessions include: learning to use computer-aided design (CAD) software, using hand tools, building prototypes using foam-core and cardboard, using machines in the machine shop such as laser-cutters, 3D printers, mills, lathes, thermo-formers, and more.

Projects

Projects/problems that students have tackled and their team composition are listed in Table 2.

Table 2. Projects and problems tackled by student teams

Spring 2019	Team 1: Glove drying system for firefighters
	Team 2: Desktop fidget system for children
	Team 3: Sexual assault/harassment alert system for campus
	Team 4 (m): Water collection system for hikers and campers
	Team 5 (m): Anti-spill, travel coffee mug
	Team 6: Buoyancy device to help beginning swimmers with correct form
	Team 7 (m): Device to alert users to pickpocketing attempts
	Team 8: Station for children to ensure proper handwashing
	Team 13 (m): A device to lock/unlock dorm rooms using RFID rather than a key
	Team 10: Ziplock bag that is easier for seniors to open and close
	Team 11: Bed height adjustment system for use in the dorms
	Team 9: Traffic alert system for police use
	Team 12: Sustainable utensil sorter
	Team 14: Easier way to start plants at the Dartmouth greenhouse
	Team 15 (m): Floor to wheelchair transfer ramp system

Summer 2020	Team (w)1: Mobile handwashing station for locations where water is scarce
	Team 2: Assistive device for individuals with visual *and* physical disabilities
	Team 3: Portable workstation for laptops
	Team 4: Handheld climbing rope cleaner
	Team 5: Cell phone case for thermodynamic regulation
	Team 6: Automated gas station pump handle sanitizing machine

Spring 2020	Team 1: Ozone sanitation system for home
	Team 2 (w): Multi-purpose in-home workout equipment
	Team 3 (m): Social distancing sensor system for the visually impaired
	Team 4: Grocery cart distancing sensor system
	Team 5 (w): UV light sanitation wand for cleaning public transportation
	Team 6: Handwashing system for people with disabilities
	Team 7 (m): UV sterilization system for personal items
	Team 8 (m): Entry/exit tracking system for the Dartmouth dining hall
	Team 9: Sanitation system for styluses
	Team 10: Compression slippers for the elderly with circulation issues
	Team 11: Standing workspace system to improve posture
	Team 12 (w): Medication sanitation system

Fall 2020	Team 1 (w): Transparent mask with a fan for teachers
	Team 2 (m): Open-source, social distanced Halloween candy dispenser
	Team 3: Plant self-watering system
	Team 4: Face mask for athletes
	Team 5: Seat availability app
	Team 6: System to foster social connection
	Team 7: Mask disinfecting system
	Team 8 (m): Electric rollerblades for commuting
	Team 9 (m): Dorm lighting that mimics natural light
	Team 10: Reusable food containers for dining hall

mixed gender teams unless noted: (m) = all men; (w) = all women

Teams are of mixed genders unless noted '(m)' indicating a team with all members identifying as men or a '(w)' indicating a team with all members identifying as women. While we try to achieve gender balance in groups, it is not always possible given the students' interests, skills, and backgrounds. Although not significantly different, teams in which all members identified as men were more likely to tackle electronics-based projects, whereas teams in which all members identified as women tended to have fewer group dynamics issues.

A primary criterion for the project is that it solves a social need, either one on campus or in the broader population. A second criterion is each project is that the students build a physical prototype. In a minority of cases, the project is app- or computer-driven but still must include a physical device (e.g., a button or wristband). Short videos showcasing projects from the Spring, Summer, and Fall of 2020 are available here: https://sites.google.com/dartmouth.edu/engs21-final-projects/home. Figure 1 highlights prototypes constructed in the course. Prototypes range from fabric to wood or metal devices; some incorporate electronics while others use 3D printing, laser-cutting, or other machines in our machine shop. Even for those sections conducted remotely, students were able to send files to machine shop instructors who then manufactured and mailed the resultant part/prototype back to the student.

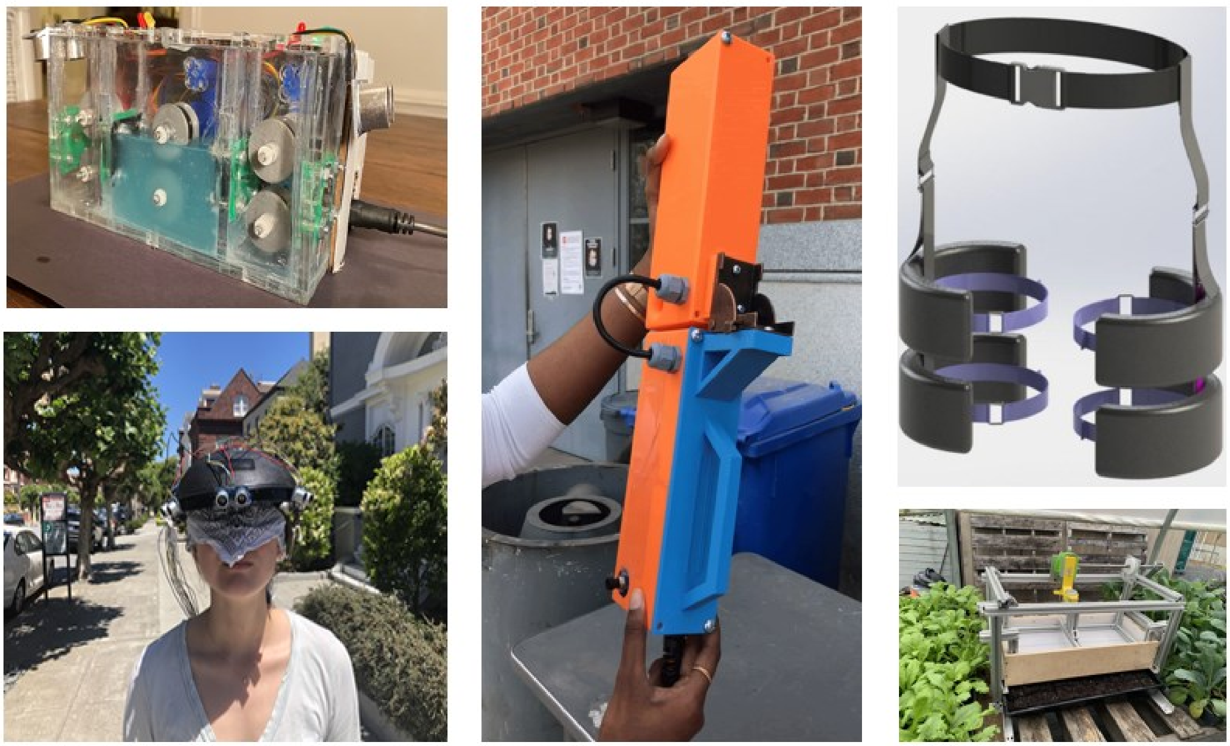


Figure 1. Example prototypes

Interest

One course goal is to increase interest in engineering and shift perceptions of what engineers do (not just math, science, and problems with one right answer but design, create, and solve problems with multiple solutions) [2]. To measure interest in engineering, pre- and post-course surveys were completed with a range of questions including asking students to list 3 words to describe engineering. Word clouds (Figures 2 & 3) visually show the words selected by students before and after the course. A breakdown of the main themes of the words listed are given in Figure 4. The themes were generated by combining similar words. For example, 'creative' was used as a theme for words such as 'create', 'innovative', 'entrepreneurial', etc. Surprisingly, 'creative' as a theme was listed fewer times on the post-course survey than on the pre-course survey. Because the course is highly subscribed and discussed amongst the undergraduate population, discerning between students' unbiased perspective of engineering from what students have 'heard' about the course is difficult.

Figure 2. List three words to describe engineering (pre-course survey)

A broader range of words was used in the post-course survey. Three words that increased in frequency included 'interesting,' 'collaborative,' and 'challenging,' while 'analytical' decreased in frequency. Thus, the hope is that students are gaining a fuller picture of engineering through the course.

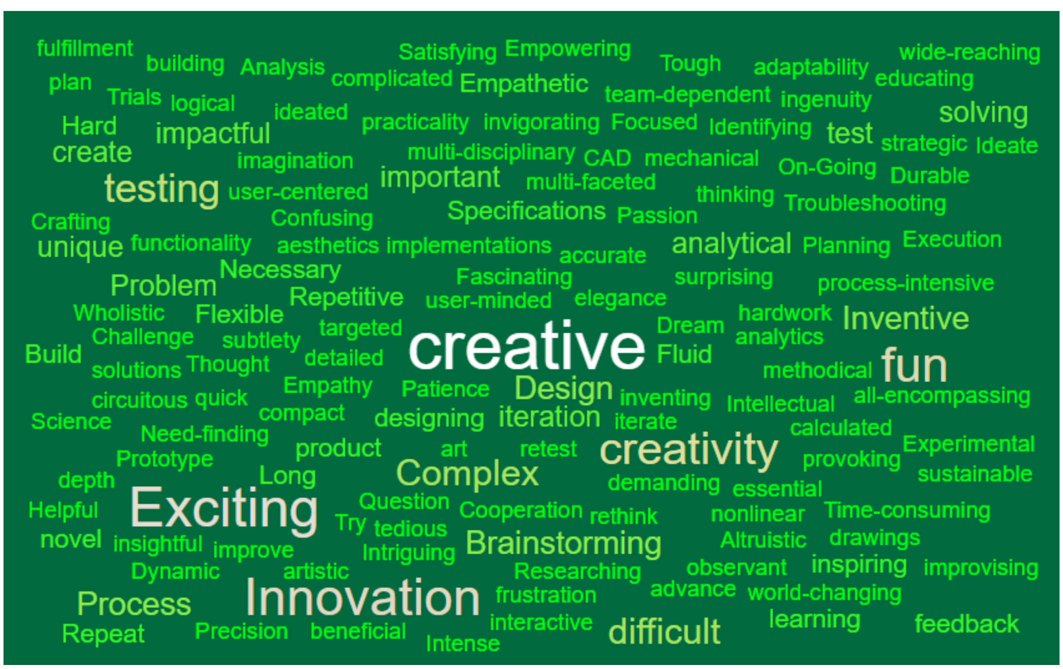


Figure 3. List three words to describe engineering (post-course survey)

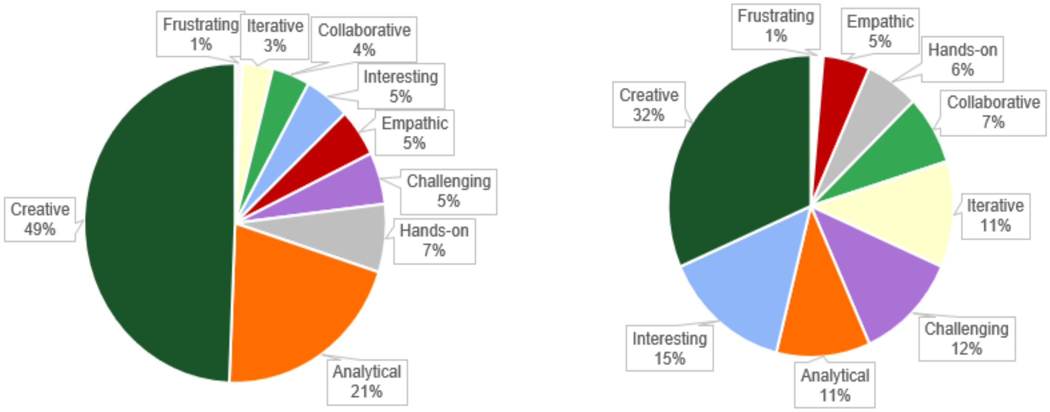
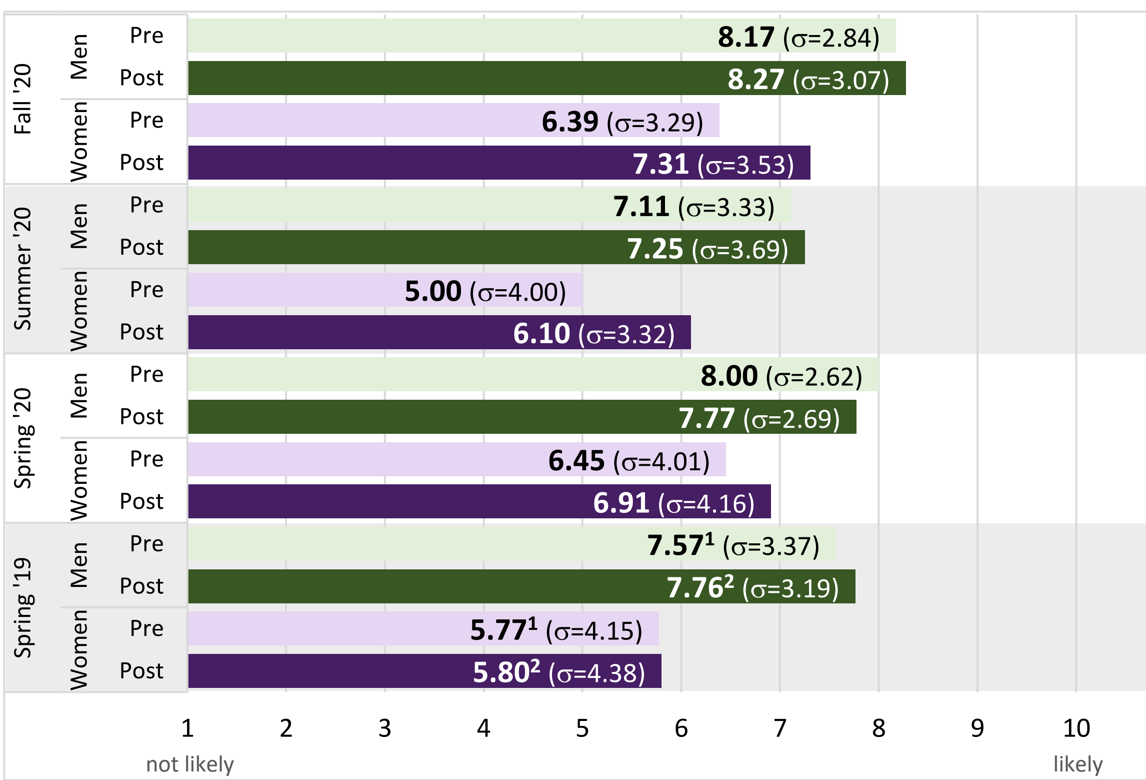


Figure 4. Themes in word list on the pre-course survey (left) and post-course survey (right)

We also asked students 'how likely are you to major in engineering?' on the pre- and post-course surveys using a 10-point scale from 1 (not likely) to 10 (very likely). The average responses to that question are given in Figure 5 by section and gender, with the average responses for those identifying as women shown by purple bars and the average for those identifying as men shown with green bars; lighter colored bars indicate pre-survey responses and darker colored bars indicate post-survey responses. Standard deviations (σ) are indicated in parentheses. With the exception of those identifying as men in the spring of 2020, the likelihood of majoring in engineering increased for both genders during each term. In all cases those identifying as men in the course were more likely to major in engineering than those identifying as women. This is



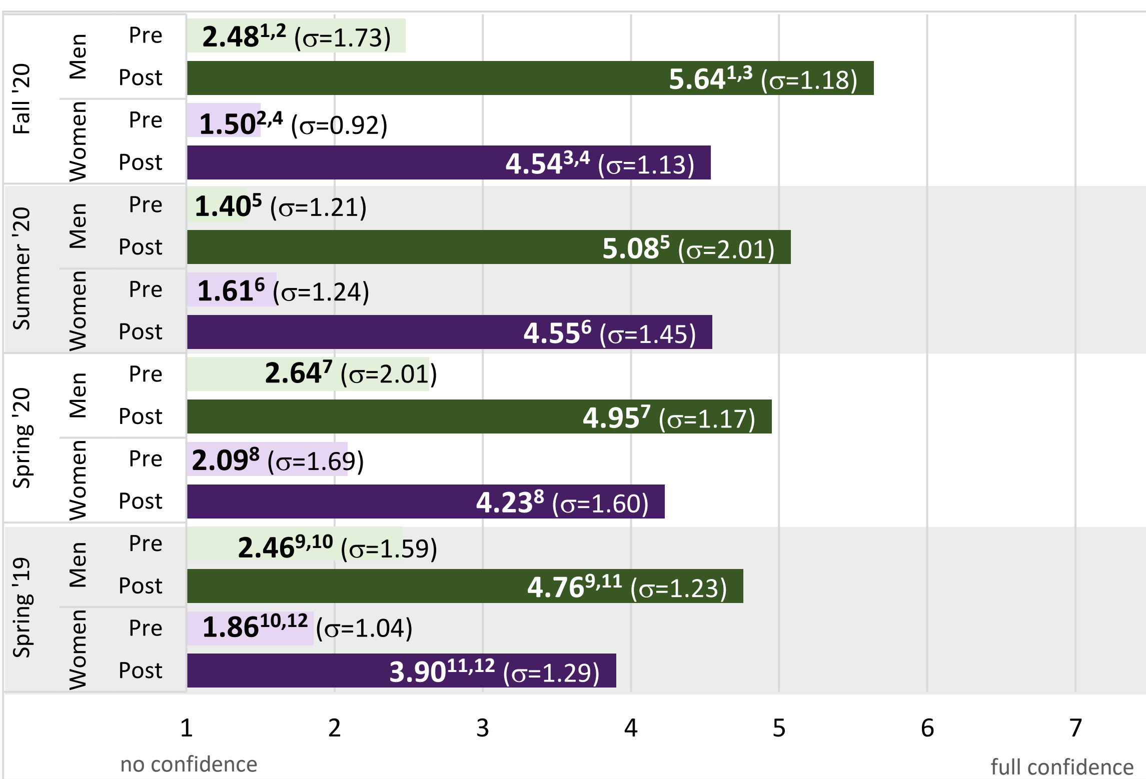
= statistically significant difference

Figure 5. How likely are you to major in engineering?

likely due in part to greater numbers of those identifying as women taking the course to fulfill a human-centered design minor, with no intention of ever majoring in engineering.

A t-test was run on all of the results to identify statistically significant differences. The difference between the likelihood of majoring in engineering by those identifying as men and those identifying as women in the spring of 2020, both on the pre-course and post-course surveys, was the only statistically significant result ($p<0.05$) related to this question. Means that are statistically significant are indicated by a superscript number, with pairs of numbers indicating the means that are statistically significant. In Figure 5, the superscript 1 indicates that the difference between the post-course survey means for those identifying as men and those identifying as women are statistically significant and the superscript 2 indicates that the difference between the pre-course survey means for those identifying as men and those identifying as women are statistically significant.

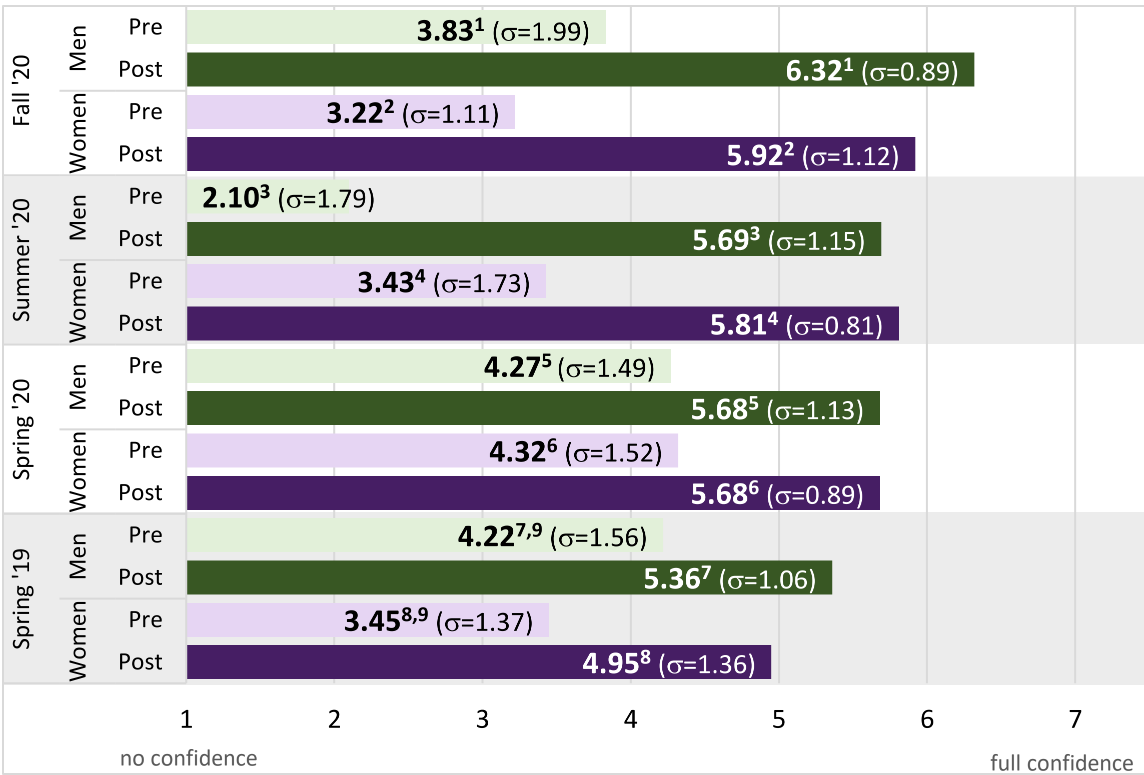
A series of questions was also asked related to students' confidence doing specific engineering tasks. Students were asked to rate their confidence on a scale from 1=no confidence to 10=full confidence. Those questions with significant increases in confidence are included here. Students' confidence ratings using SolidWorks (computer-aided design or CAD software) by gender and term on the pre- and post-course surveys are given in Figure 6. Confidence using SolidWorks increased significantly between the pre-course and post-course survey, with all changes by gender being statistically significant and differences between genders being statistically significant in the Spring of 2019 and the Fall of 2020. In all cases, the confidence of students identifying as women was lower than that of those identifying as men.



= statistically significant difference

Figure 6. Rate your level of confidence using SolidWorks (computer-aided design software)

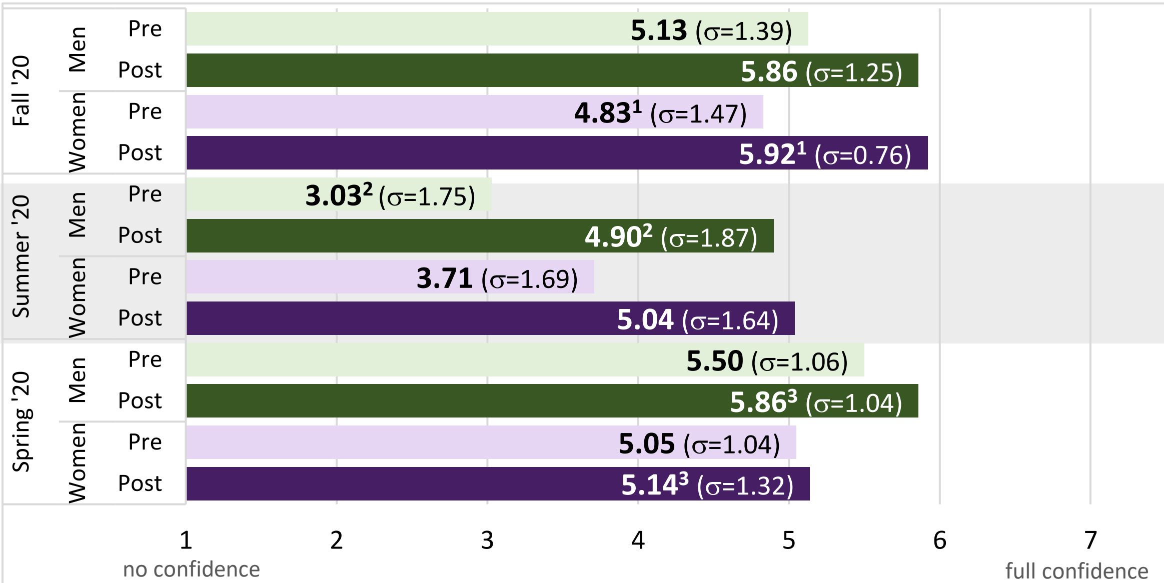
Student ratings of confidence building prototypes are shown in Figure 7. In all cases student confidence increased during the course, with confidence of those students identifying as women exceeding the confidence of those identifying as men in a few cases. Interestingly, students in the sections that were taught remotely (all but Spring 2019) reported greater increases in confidence than those in the in-person section (Spring 2019). All students in the remote sections were required to build and share individual prototypes using a kit of supplies that they received, whereas in the in-person section students built prototypes as a team. We plan to continue to require every student to build at least one prototype on their own in future in-person sections of the course.



= statistically significant difference

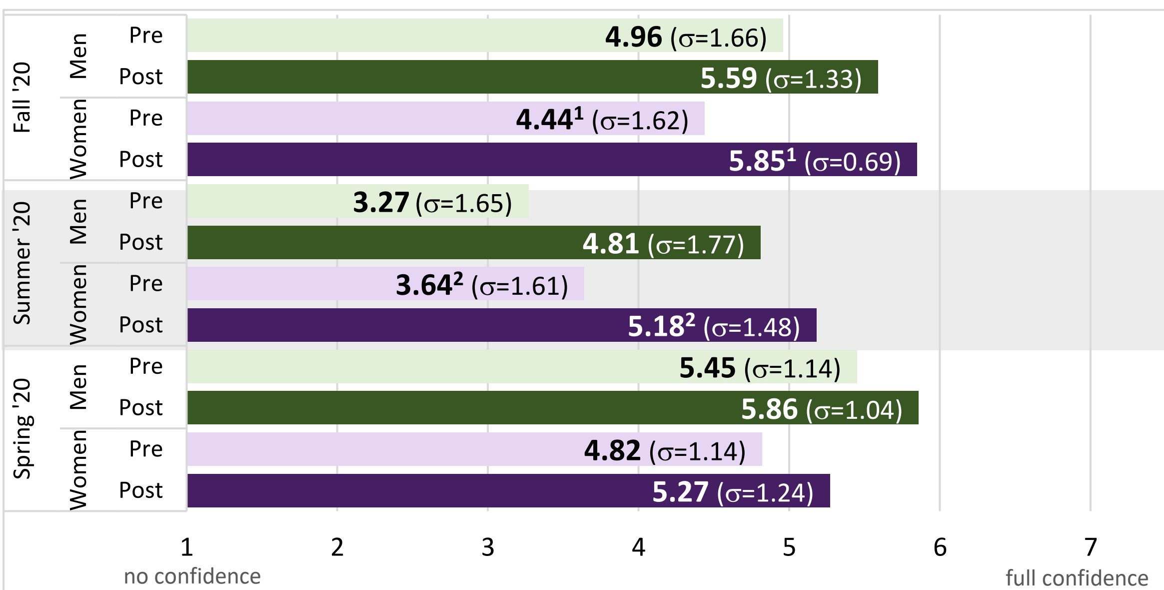
Figure 7. Rate your level of confidence building prototypes

In the spring of 2020, questions taken from the *General Engineering Self-Efficacy Scale* [4] were added to the pre- and post-course surveys to assess student self-efficacy. Self-efficacy refers to an individual's belief that they can do certain things [2], in this case the belief that they can succeed in engineering. Studies have found that self-efficacy correlates with both academic performance [5] and persistence [6]; research has found that while some aspects of women's self-efficacy in engineering have increased over the years, their self-efficacy tends to decrease over the course of their academic career [7]. Two questions from the survey are included here in Figures 8 and 9. The first question relates to students' confidence mastering engineering content and the second relates to students' confidence earning good grades in engineering. In all cases students' confidence increased during the term. While confidence of students identifying as women was lower than that of students identifying as men on the pre-course surveys, in a few cases confidence of students identifying as women exceeded that of the men on the post-course survey.



= statistically significant difference

Figure 8. Rate your level of confidence mastering engineering content



= statistically significant difference

Figure 9. Rate your level of confidence earning good grades in engineering

Conclusions and Future Work

Through this project we set out to answer the following research questions:

- Does students' interest and self-efficacy in engineering increase after taking *Introduction to Engineering*?

- Does interest and self-efficacy vary based on gender?
- What types problems and projects do students identify and work on in the course?

We found that while students' interest and self-efficacy did increase after taking *Introduction to Engineering*, interest and self-efficacy among those students who identify as women still lags that of those who identify as men. For this study we only looked at women and men but future work will look at nonbinary students as well as minoritized students. 'Minoritized' students include: Black, African American, Hispanic, Latinx, Native Hawaiian or other Pacific Islanders, and multi-racial students; the term 'minoritized' is used rather than 'minority' to recognize that these populations are often 'pushed to the margins' and have less power than those in the majority [8]. Further, we plan to try to determine through focus groups and interviews, which aspects of the course have the biggest impact on students' interest and self-efficacy. In particular, we plan to look at how role models (faculty and teaching assistants) impacts self-efficacy.

References

[1] Craemer, Elizabeth (2007). Report to xxx. *Investigating the Gender Component in Engineering*. NSF Grant GSE 0522767.

[2] Bandura, A. (1997). Self-Efficacy: *The exercise of control*. New York, NY: W. H. Freeman.

[3] May, Vicki (2014). "Broadening the Path to Engineering," Huffington Post. http://www.huffingtonpost.com/vicki-may/broadening-the-path-to-engineering_b_4941739.html. March 2014.

[4] Mamaril, Natasha A., Usher, Ellen L., Li, Caihong R., Economy, D. Ross, and Kennedy, Marian, S. (2016). "Measuring Undergraduate Students' Engineering Self-Efficacy: A Validation Study.' Journal of Engineering Education. Vol. 105, No. 2, pp. 366-395.

[5] Hsieh, P., Sullivan, J. R., Sass, D. A., & Guerra, N. S. (2012). Undergraduate engineering students' beliefs, coping strategies, and academic performance: An evaluation of theoretical models. *Journal of Experimental Education*, 80, 196–218. http://dx.doi.org/10.1080/ 00220973.2011.596853

[6] Concannon, J. P., & Barrow, L. H. (2010). Men's and women's intentions to persist in undergraduate engineering degree programs. *Journal of Science Education and Technology*, 19(2), 133–145. http://dx.doi.org/10.1007/s10956-009-9187-x

[7] Marra, Rose M., Rodgers, Kelly A., Shen, Demei, and Bogue, Barbara, (2009). "Women Engineering Students and Self-Efficacy: A Multi-Year, Multi-Institution Study of Women Engineering Student Self-Efficacy." Journal of Engineering Education. Vol. 98, No. 2, pp. 27-38.

[8] Paniagua, Amanda Anastasia (2015. "Opinion: Minoritized, not a Minority." *Kentwired.com.* http://www.kentwired.com/latest_updates/article_dc83f7e0-5fe9-11e5-b6c0-2b8c8a9b5266.html

Appendix: Fall 2020 Pre-Course Survey

ENGS21 Pre-Course Survey

The purpose of this survey is to better understand your background and interests in order to improve and tailor the course. Your responses will remain anonymous; no identifying information will be shared.

Your email address will be recorded when you submit this form.

Not **vicki.v.may@dartmouth.edu**? Switch account

What is your name (as you prefer to be called)?

Your answer

Do you have any accessibility or other requests for me in general or specifically regarding remote teaching and learning?

Your answer

List 3 words that you would use to describe engineering:

Your answer

How likely are you to major in engineering?

	1	2	3	4	5	6	7	8	9	10	
I am NOT planning to major in engineering	○	○	○	○	○	○	○	○	○	○	I AM definitely planning to major in engineering

Rate your level of confidence performing each of the following on a scale from 1 to 7, with 1 indicating NO confidence and 7 indicating full confidence.

	1 NO confidence	2	3	4	5	6	7 FULL Confidence
Using SolidWorks	○	○	○	○	○	○	○
Building prototypes	○	○	○	○	○	○	○
Identifying machines in the machine shop	○	○	○	○	○	○	○
Using hand tools to build things	○	○	○	○	○	○	○
Working with a group	○	○	○	○	○	○	○
Designing new things	○	○	○	○	○	○	○
Identifying a design need	○	○	○	○	○	○	○
Developing design solutions	○	○	○	○	○	○	○
Evaluating a design	○	○	○	○	○	○	○
Mastering the content in an engineering course	○	○	○	○	○	○	○
Earning good grades in engineering	○	○	○	○	○	○	○

Any other comments or concerns related to course?

Your answer